The influence of mood during incubation on subsequent design ideation

by

Gerard Campbell

A thesis submitted to the University of Strathclyde

for the degree of

Doctor of Philosophy

Department of Design, Manufacture and Engineering Management

University of Strathclyde

Glasgow, UK

December 2021

Signed:

Date: 02/12/2021

Acknowledgment

I have greatly enjoyed my PhD journey and would like to warmly thank everyone who has helped me along the way.

In particular, I would like to thank my supervisor Madeleine Grealy for her continued support throughout my PhD and for being an all-round excellent mentor. I would also like to thank Laura Hay, who came on board as a supervisor in the final year and provided invaluable guidance.

My gratitude goes to all other members of the Imagine-D team, past and present, who have in some way helped out. I must especially thank my fellow PhD student, Chris McTeague, who had a versatile role as a product design consultant, Adobe Illustrator wizard, and a general 'go-er to' for a second opinion.

Thank you to everyone else who participated in or assisted with the project. I am particularly grateful to the post-graduate students who assisted with the novelty assessment procedure.

I must also thank my parents for putting me up (and putting up with me) during the final year, and more generally for your unwavering love and support. Significant recognition is also given to the efforts of my brother John, Percy the Pug and all my wonderful friends - for bringing much needed laughter, joy and entertainment.

Finally, I express dearest thanks to the love of my life, Lisa. It has been exactly 500 days since we last saw each other, and who knows how many more before we meet again. Yet even in your absence, my world is filled with your beauty, inspiration, and sunlight, which keeps me going through the toughest chapters.

Abstract

Incubation, which involves putting the problem aside temporarily and performing an unrelated activity, has been widely shown to enhance creativity. It has also been proposed that incubation may facilitate design ideation, though relatively few studies have empirically examined this. As such, there is a lack of knowledge regarding the role of incubation in a design context, including the key psychological factors that may determine the effectiveness of incubation. One possible influencing factor is the mood of the designer during incubation. It is well known that creative cognition is influenced by mood, with positive moods in particular being linked with increased cognitive flexibility and novel thinking. Previous research has also indicated that positive mood during incubation can improve subsequent divergent thinking, although it is not clear whether similar effects occur in a design context. Against this background, this thesis aimed to assess whether incubation, in general, would facilitate subsequent design ideation. In addition, it aimed to examine whether positive moods during incubation would be particularly effective in enhancing ideation.

A preliminary study was firstly conducted to establish the cognitive processes associated with the generation of novel design concepts and identify which, if any, of these processes were known to be influenced by mood. To this end, 101 product design engineering students performed a series of open-ended ideation tasks as well as a range of psychological tests that assess different cognitive processes, including measures of associative processing, executive function, mental imagery, and intelligence. Correlation analyses indicated significant positive relationships between idea novelty (assessed by 3 independent raters) and scores on associative flexibility, verbal fluency and fluid intelligence. In addition, a significant negative correlation was

observed between inhibition and novelty. Finally, a regression model with the cognitive test scores showing significant correlation as predictors was found to be explain 26% variance in ideation novelty in the sample.

Importantly, several of the cognitive processes highlighted as key to the generation of novel concepts (associative flexibility, verbal fluency and disinhibition) have been shown by previous research to be enhanced by positive mood. This suggested that positive moods during incubation, through stimulating these processes, may facilitate subsequent design ideation. This was formally tested in study 2, in which a group of product design engineering students (n=72) were randomly assigned to one of four conditions. Each participant performed the same ideation task but with: an incubation period with a happy mood induction, or incubation with sad mood induction, or incubation where no mood was induced or no incubation period and no induced mood. The happy and sad mood induction used in the experiment involved exposure to mood appropriate music and text. The neutral group were also exposed to music and text during the incubation period but this was not designed to induce any specific mood. The results suggested that firstly, there was no evidence of a general (i.e. non-mood related) incubation effect in that the control group and the neutral group showed no significant differences in terms of fluency or novelty of ideas generated. Secondly, there were no significant differences in ideation performance between the three incubation groups (i.e., happy, sad, neutral incubation), showing no support for the hypothesis that positive moods during incubation period would have a particularly beneficial impact on performance. Finally, while there was no evidence of an incubation effect, the results did suggest that in general, participants generated more novel ideas in the second half of the ideation task. This is consistent with a substantial body of evidence to suggest that people become more creative with increasing time on task.

The findings of study 2 were inconsistent the wider creativity literature, where mood and incubation have been widely demonstrated to be key factors of influence on creative performance. However, much of the evidence for this is based on studies using standardised creativity tasks such as divergent thinking and insight tasks. Thus, a possible explanation of the findings was that incubation and mood simply have reduced influence in more domain-specific, applied creativity settings. In general, incubation may interfere with some designers' established routines and preferences regarding if and when to take a break. In terms of mood during incubation, previous work has indicated that mood may exert counter-active effects on more applied creativity tasks, because while it enhances novel thinking and cognitive flexibility, it impairs the more constrained and analytical processes that are required for generating practical solutions – the result being no overall impact on ideation performance. The above arguments could be explored further by examining the effects of the mood-based incubation paradigm in a more domain-general creativity context. If incubation effects (either general or in relation to mood) were observed under such circumstances, this would give support to the notion that incubation and mood have more facilitative effects in general-creativity settings, with reduced influence in more applied, domain-specific contexts. Alternatively, if similar results to study 2 were observed, this would suggest that the findings were due to methodological factors associated with the experimental paradigm.

To explore this, a final study was conducted (n=80) which examined the effects of the mood-incubation procedure in a more domain-general creativity setting. The same incubation paradigm was employed as in study 2 with the exception that participants were from a non-design background (mainly psychology students) and the creativity task was Finke's (1996) mental synthesis task. The results suggested that fluency was marginally affected by incubation, in that while both the control group and the neutral incubation group showed a decline in the number of ideas generated in the second phase of the synthesis task, this decline was less pronounced for the incubation group. However, in most key respects the results were similar to study 2: there was no evidence that incubation facilitated novelty, nor was there any evidence to suggest that positive moods were particularly effective during incubation. Finally, as in study 2, a serial order effect was observed with all groups showing higher novelty in the latter half of the task.

Overall, the thesis found no evidence to suggest that incubation facilitates subsequent ideation, nor was there any evidence for the notion that positive moods are particularly effective in enhancing ideation. The fact that this was the case for design ideation and domain-general creativity suggests that the findings may be due to specific methodological factors, rather than an incompatibility between incubation and design ideation, as was initially proposed. Regarding the absence of general incubation effects, this could be due to the nature of the incubation task, as well as participants' lack of awareness of a task return following incubation. The lack of positive mood-related effects could be attributable to limitations with the mood induction procedure, or the influence of sketching during ideation. The potential involvement of these factors and how they may have influenced the results is discussed in the relevant chapters. Suggestions are also made for how future research can further explore their role in incubation. Overall, the research highlights that incubation effects can be elusive, and that taking a break is by no means guaranteed to facilitate performance. Finally, the results do provide clear support for the notion that creativity improves with time (serial order effect). Future research should explore the cognitive mechanisms that underlie the serial order effect in a design context, and whether certain factors (e.g. expertise, fluid intelligence) moderate it.

Contents

List of Figures

List of Tables

Chapter 1. Introduction and Thesis Overview

1.1 Introduction

It is difficult to imagine a creative professional whose works are more fundamental, influential, and readily accessible than that of the product designer. The artefacts, services and systems that they create shape our everyday actions and interactions and have become an essential part of human existence. In order to enjoy the great masterpieces of Da Vinci and Van Gogh, one would have to go to the Louvre Museum in Paris, or the Museum of Modern Art in New York. The creations of the Product Designer, however, are enjoyed virtually every minute of every day, whether in wake or in sleep. And while some maintain that they cannot live without the majestic symphonies of Beethoven, or the hypnotic Goldberg Variations of Bach, it is in fact only the works of the product designer that our lives are truly dependent upon.

Indeed, one would not have to think too hard or look too far to find an example of a lifesaving product. From backpacks that convert to lifejackets during tsunamis (Akuzawa, 2021), to drones that assist with mountain rescue operations (Jackson, 2020); from a device that stops internal bleeding immediately following a stab wound (Cobham, 2021), to facemasks that prevent the transmission of respiratory viruses during global pandemics (Pepples, 2020) - our world is filled with an ever-expanding array of products that can provide vital support in the most critical and threatening of situations.

Of course, it would be wrong to suggest that all products are literally lifesaving – most simply make life more worth living. It is hard to imagine where we would be, both individually and societally, without the artefacts that we use and interact with on a daily basis: coffee makers, thermal flasks, fitbits, nutribullets, air fryers, soundbars, iPads and electro-scooters - to mention only a few. These products - whether we truly need them or not - have come to colour our everyday existence, and they epitomise the technological advancement of modern civilisation.

Given the importance of products, it is unsurprising that there is a significant level of interest in the creative minds responsible for bringing them into being. In fact, for some 60 years now there has been an entire field – known as design cognition – devoted to better understanding how designers think when designing (Dinar et al., 2015). A significant amount of this work has focused on the early and ill-structured conceptual design phase, often regarded as the most creative stage of design (Ma et al., 2011). It is during this time that design ideation is conducted, whereby a designer (or team of designers) generate ideas in response to a design brief. Ideation is the key means by which solutions are discovered (Helm et al., 2016) and plays a key role in determining the cost and quality of the final product (Helm et al., 2016; Jin & Benami, 2010; Pahl et al., 2006). On a broader scale, the ability to generate novel and feasible concepts during the ideation phase is thought to be a necessary condition for a company's commercial success, as well as for societal and technological progress more generally (Chakrabarti & Khadilkar, 2003; Li et al., 2007; Ma et al., 2011).

Ideation is thus a critical phase of the design process, and there is widespread acknowledgement that we need to better understand the cognitive processes that underlie it. Knowledge in this area is essential for devising methods that can enhance ideation (Nguyen & Zeng, 2010), for developing computational tools to support it (Duffy et al., 2019; Gero & Tang, 2001; Kim et al., 2010), as well as for the general improvement of design education (Liu et al., 2018a; Park & Kim, 2007). In short, design cognition research is not merely about satiating the appetite of curious researchers: it is essential for the development of the tools, systems and organisations that will cultivate and support the next generation of designers.

"Imagine-D", the wider research project with which this thesis is associated, has taken a multidisciplinary approach to design cognition research, combining expertise in design engineering, psychology, and neuroscience in order to explore the neurocognitive underpinnings of design ideation. A prominent contribution of the project has been the use of fMRI to uncover the neural regions and networks that support ideation in professional product design engineers (Hay et al., 2019a; Campbell et al., In preparation). This research has highlighted the involvement of prefrontal-based executive control regions during ideation, as well as contributions from regions involved in long-term semantic and episodic memory (Campbell et al., In preparation; Hay et al., 2019a). Functional connectivity analysis has also shed light on the interaction of large-scale brain networks during ideation, such as the Default Mode network and Executive Control network (Campbell et al., In preparation).

In addition, the project has also utilised behavioural methods to explore various design cognition-related phenomena such as the cognitive basis of design synthesis (McTeague et al., 2017; 2018), as well as how designers intuitively use gestures to interact with CAD-like 3D environments (Vuletic et al., 2019; 2021). In light of significant developments in Human-Computer Interaction (HCI) systems within the last decade, there is a long-term possibility that insights from the above neuroimaging and behavioural research could contribute to the development of a CAD system that responds directly to the designer's neural/cognitive activity and intuitive gestures (Duffy et al., 2019).

Naturally, much of the focus of the research stemming from the project has been on designers as they are engaged in the act of designing – whether this be capturing brain activity during ideation, or gestures elicited when manipulating 3D objects in virtual environments. Yet there is good reason to suppose that we also need to consider the processes occurring when the designer temporarily steps away from a design task, putting the problem out of conscious awareness and attending to other matters. This period, commonly known as the ‘incubation period’, forms the focus of this thesis.

1.2 The role of incubation in design ideation

It is an interesting paradox that creativity, a highly valued attribute that is thought to be essential for the production of novel and unique work, can often be facilitated by engaging in the most routine (even mundane) of human activities. An international consumer survey of 4000 people conducted by creativity expert Scott Barry Kaufman reported that 72% of people get their most creative ideas in the shower (Smith, 2016). Empirical evidence also suggests that creative cognition can be facilitated by the simple act of taking a walk (Oppezzo & Schwartz, 2014). In fact, some of the most fundamental scientific discoveries and breath-taking artistic creations were made under circumstances that might be considered procrastination (Ghiselin, 1952). One of the most influential anecdotal cases of this is Poincaré, who reported discovering solutions to complex mathematical problems while relaxing on holiday.

While it may be unintuitive, it seems to be the case that sometimes the most productive thing we can do on a task is to step away from it temporarily. In the psychology literature on creativity, the official term for this phenomenon is incubation. Incubation was first introduced in Wallas’ (1926) four-stage model of creativity, which theorised creative discovery as a linear process of 1) preparation (initial work on the problem), 2) incubation (conscious work on the problem is suspended, but processing may continue unconsciously), 3) illumination (the solution to the problem is realised), and 4) verification (a final period of conscious work on the problem during which the veracity/suitability of the solution is thoroughly examined). While Wallas’ (1926) model was largely based on anecdotal cases, there is now a substantial body of empirical evidence to show that creativity can be facilitated by having an incubation period (see Sio & Ormerod, 2009; for a meta-analysis).

While there is much support for the incubation effect, it does have to be noted that the majority of this is based on relatively simplistic creativity and problem-solving tasks, such as the Alternative Uses Task and the Remote Associates Task. There is less knowledge regarding the influence of incubation in more practical problem-solving contexts, including creative ideation as carried out by professional designers in industry.

Although design ideation and generic creativity tasks have some commonalities, there are also a number of key factors that distinguish the two. Firstly, while both design ideation problems and generic creativity tasks generally require novel solutions, in the former a range of additional requirements and considerations exist, including technical/functional constraints (Hay et al., 2019; Shah et al., 2003;2012), client/stakeholder demands, budget limitations and wider social/environmental pressures (e.g., global warming). Secondly, in design ideation much greater emphasis is placed on the externalisation of ideas generated e.g., by producing sketches. Sketches are widely utilised in industrial practice, and have a diverse range of functions such as offloading memory constraints (Bilda and Gero, 2007), as well as in stimulating creative mental imagery processes (Goldschmidt, 1991). In addition to sketches, Ball and Christensen (2019) discuss the important role of 'post-it notes' in design industry, which provide "simple, yet powerful and flexible, representational medium for capturing ideas and imposing a degree of organisation on a complex situation." (p.9). Finally, owing to the higher level of complexity of design problems and the difficulty associated with generating solutions that are both novel and feasible, it is common for professional designers to use various techniques, methods or support tools during ideation. For example, a number of techniques have been developed to facilitate the use of analogical reasoning during design ideation (e.g. Design-by-Analogy; McAdams & Wood, 2002).

Despite these key differences between design ideation tasks and more simplistic creativity tasks, there are nonetheless a number of ways in which incubation could also be highly effective in a design context. Firstly, it has been suggested that incubation may provide a means for overcoming design fixation, in which prior knowledge and experience lead to a 'restricted exploration of the design space' (Crilly and Cardoso, 2017, p.6) and constrain creativity. Design fixation is a widely observed phenomenon both in laboratory experiments (Chan et al., 2011; Jansson and Smith, 1991) and in design practice (Crilly, 2019). Incubation may help relieve design fixation by providing the designer time to shake off the influence of counterproductive knowledge (e.g. regarding existing designs) that has led to initial fixation (Smith & Linsey, 2011).

Secondly, temporarily suspending the problem could provide designers an opportunity to discover inspirational stimuli in the environment which may aid in the discovery of a novel solution (Kolodner & Wills, 1996). This may principally involve encounters with visual stimuli, given that this form of stimuli has been widely shown to influence design creativity (Cardoso & Badke-Schaub, 2011; Casakin & Goldschmidt, 2000). However, there is also evidence for the role of verbal stimuli (Goldschmidt & Sever, 2011), thus activities such as reading during the incubation period could also influence subsequent ideation. Finally, it is possible that task-related unconscious processing during incubation could facilitate ideation. Such processes could contribute to the experience of "sudden moments of inspiration" that have been reported by designers (Chandrasekera et al., 2013). Alternatively, the benefits of unconscious work during incubation may reveal themselves more gradually when the designer returns to a suspended task.

Despite the proposed benefits of incubation on design ideation, only a handful of studies have empirically examined this issue. Moreover, results from these initial studies have been somewhat mixed, with some suggesting incubation benefits ideation (e.g. Al-Shorachi et al., 2015; Vargas-Hernandez et al., 2010) but others finding limited or no incubation effects (e.g. Cardoso & Badke-Schaub, 2009; Tsenn et al., 2014). As such, the question of whether incubation actually facilitates design ideation is still open to investigation.

A related issue concerns the factors that might influence incubation in design ideation. Existing research within the general creativity literature suggests that incubation is influenced by a number of variables including the type of incubation task (Gilhooly et al., 2012; Sio & Ormerod, 2009), the duration of the incubation period (Kaplan & Davidson, 1989) and the level of fixation before the incubation period (Vul & Pashler, 2007; but see Morrison et al., 2017). In a design context, however, little work of this nature has been conducted, and there is a poor understanding of the factors that may influence incubation for designers and lead to enhanced incubation effects.

One factor that could be crucial is the designer's mood during incubation. In general, the relationship between mood and design ideation is a relatively under explored topic. However, the broader psychological literature has shown that mood and creative cognition are closely related, with positive moods in particular being linked with enhanced creativity. Importantly, there is also increasing anecdotal, theoretical and empirical work to suggest that positive mood during incubation has a facilitative effect on subsequent creativity. In the face of this growing body of work, this thesis explored the possibility that the mood state experienced by a designer during incubation has a critical influence on the novelty of ideas subsequently generated. The potential role of mood during incubation in design ideation will be discussed in more detail below (section 1.4). Before doing so, some clarification of key mood-related terminology is provided.

1.3 Clarification of key terminology

It is important to firstly distinguish *mood* from *affect* and *emotion* because these terms are often used interchangeably which can lead to confusion. Affect is a general term encompassing mood and emotions, which are held to be two distinct but related forms of affective state. One of the key characteristics that distinguish emotions and moods is object-directedness. Emotions are held to be directed towards a specific target or stimulus (Baas et al., 2008; Davis, 2009; Frijda, 1993; Parkinson et al., 1996), such that one might be sad about a film, or angry about being caught in a traffic jam (Baas et al., 2008). Moods, by contrast, are held to be more generalised in nature, and are not necessarily caused by, or directed towards, a specific event (Davis, 2009). In addition, emotions are argued to be more intense than moods (Frijda, 1993) and may also be experienced or felt with greater clarity (Beedie et al., 2003). While moods may be less intense than emotions, they are of longer duration (Baas et al., 2008; Davis, 2009). It has also been suggested that the onset and decay of emotions occur instantaneously, as opposed to moods which emerge, change and dissipate more slowly over time (Beedie et al., 2003; Parkinson et al., 1996).

Secondly, it is important to clarify the distinction between the concepts of tone and arousal. Most theorists maintain that affective states can differ in terms of levels of tone and arousal (Baas et al., 2008; Jallais & Gilet, 2010; Russell, 1980; Serino & Repetto, 2018). Tone refers to whether the affective state is positive or negative, whereas arousal refers to “the degree of physical and psychological activation” that is experienced during the affective state (Schellenberg et al., 2007, p. 5). Affective states can thus be distinguished according to their different patterns of tone and arousal. For instance, a calm mood involves positive tone with low arousal, whereas states such as anger and fear involve negative tone with high arousal (Baas et al., 2008).

1.4 The role of mood during the incubation period in design ideation

The notion that positive mood plays an important role during the incubation period is firstly premised on the fact that there is a well-established link between positive moods and creativity (see Ashby et al., 1999; Baas et al., 2008; for reviews). This is thought to stem from the fact that positive mood stimulates exploration, cognitive flexibility, and the adoption of novel perspectives (Carver, 2003; Friedman & Förster, 2010; Schwarz, 1990, 1994). Positive moods have also been shown to stimulate semantic association (Corson, 2002; Topolinski & Deutsch, 2013), a process widely held to be fundamental during divergent thinking (Benedek et al., 2012b; Runco, 2004).

Importantly, there is a growing body of work to suggest that positive moods may play a particularly important role during incubation. Anecdotally, a number of reports from creative geniuses such as Poincaré and Mozart suggest that they generated some of their most creative ideas and works under relaxed and pleasurable circumstances, such as while travelling or during an evening walk (Amabile et al., 2005; see also Vernon, 1970). Such cases indicate the possibility that an incubation period in which positive affect is experienced may be highly conducive to subsequent creativity.

In terms of more modern accounts, a number of theorists have suggested that positive moods during incubation are particularly effective in reducing cognitive fixation because they induce a broader attentional state and enhance cognitive flexibility (Haager et al., 2014; Morrison et al., 2017). Thus, the solver may be more likely to move away from ineffective strategies applied before the incubation period. The potential fixation-reducing effects of positive mood during incubation are particularly important within a design context since fixation has been widely documented as a significant hinderance to creativity. For instance, it is well-known that designers have difficulty overcoming the influence of existing products (Jansson & Smith, 1991), as well as their own previously generated ideas (Neroni & Crilly, 2019). An incubation period with positive mood may be particularly effective in allowing the designer to adopt a more flexible approach which can aid in the generation of novel ideas.

With regards to empirical evidence, only one study to date has directly investigated the role of affect during the incubation period (Hao et al., 2015). This study found that positive emotions (induced over a 30-second incubation period) were most effective in enhancing subsequent divergent thinking, as compared with a negative and neutral emotion condition. The authors interpreted this within the Unconscious Work Theory of incubation (e.g. Gilhooly, 2016; Ritter & Dijksterhuis, 2014; Wallas, 1926), arguing that positive moods stimulate unconscious remote associative processes during incubation.

The above gives some indication that positive mood may also be an important factor during incubation in a design context. However, it is important to emphasise that these insights are largely based on the psychology literature on creativity, where there has been a tendency to rely on divergent thinking tasks. Design ideation and divergent thinking share a number of key similarities in that they are both thought to involve creativity i.e. the production of ideas that are both novel and in some way useful (Runco & Jaeger, 2012). However, it is important to acknowledge that they are not the same thing, and likely differ in key ways in terms of their respective cognitive underpinnings (see section 3.2 for further discussion). As such, it cannot be assumed that mood will have the same effect in both cases. The influence of mood during incubation on subsequent design ideation may depend to a large extent on what cognitive processes are involved in design ideation and whether they are influenced by mood. This issue formed the focus of study 1 (chapter 3) of the thesis, which directly examined the cognitive processes associated with the generation of novel design concepts. From this, more precise predictions could be made regarding the interaction of mood and cognition during incubation in design ideation.

Note finally that the above factors are largely concerned with the theoretical justification for examining mood during incubation in design ideation. However, there is also a more practical dimension to this issue that is worth highlighting. Given the complex nature of design ideation problems and the requirement that designers be able to think innovatively (Daly, 2012), there is significant interest in developing methods and interventions that can be utilised by professional designers in order to facilitate ideation. Importantly, the types of activities that are typically used to induce mood (or affect more generally) are highly accessible, including listening to music (Rowe et al., 2007; Yamada & Nagai, 2015), watching videos (Hao et al., 2015; Rottenberg et al., 2018) and reading texts (Watts et al., 2019; Willner & Healy, 1994). If an incubation period which included one or more of these activities was found to be particularly effective in enhancing subsequent design ideation, then it is possible that a mood-based incubation procedure could be applied more formally as a short-term intervention for improving design ideation. At the very least, the results could give designers an idea of the types of activities they ought to engage in during incubation as a means of boosting ideation performance.

In sum, the above theoretical and practical considerations suggest that mood during incubation could be a key factor in influencing subsequent design ideation, and also has the potential to be utilised as a means of improving ideation. In this thesis, the role of mood during incubation was explored over the course of three empirical studies. In addition, the thesis more generally explored the impact of incubation on subsequent ideation. Before an overview of the studies is provided, it is useful to clarify the overall methodological approach adopted in the reported research.

1.5 Methodological approach

The three empirical studies reported in this thesis were conducted using the *controlled experiment* approach, which typically involves controlled hypothesis testing and examination of relationships between variables. However, this is only one of many methods available to design researchers, and so it is useful to consider the merits and limitations of the current approach in relation to other methods, as well as the reasons for adopting it in the present research. It is also useful to discuss the current approach in the context of broader changes that are underway within design cognition research, particularly in terms of efforts to increase theoretical cohesion and introduce new methodological perspectives (Cash, 2018; Hay et al., 2020). A final issue that warrants discussion concerns the measures of ideation performance assessed in the current research studies - i.e. novelty and fluency. These are commonly used metrics of creativity performance – especially in incubation research – though several other measures exist (e.g. usefulness, feasibility). It is therefore important to clarify the rationale for focusing only on novelty and fluency in the present research.

1.5.1 Controlled experiment approach

The research reported in this thesis used the *controlled experiment* approach, which is characterised by use of controlled tests of ideation/cognitive performance, the specification of pre-defined outcome measures as well as the application of quantitative data analysis methods (e.g. ANOVA, multiple regression). It is regarded as particularly suitable for hypothesis testing as well as controlled isolation of variables and examination of their relationships (Cash et al., 2013; Dinar et al., 2015). In the design cognition literature, this approach has commonly been applied when examining the utility of a particular method/tool/intervention on subsequent design outcomes (e.g. Al-Shorachi et al., 2015; Lindsay et al., 2012; Vargas-Hernandez et al., 2010). It was thus deemed to be appropriate in the current research in terms of assessing the effects of incubation on ideation performance. More generally, the approach can be used to examine the cognitive processes involved in ideation, for instance by examining statistical relationships between cognitive tests (assessing a particular cognitive process) and metrics of ideation performance. This approach has been widely applied in the general creativity literature (e.g. Beaty et al., 2014b; Benedek et al., 2012b; 2014b), and a handful of studies within the design cognition literature have also taken this approach (e.g. Dumas et al., 2016; Kim et al., 2005). In the current research, this approach was highly useful for investigating the cognitive processes associated with ideation novelty (study 1), allowing for examination of a) the strength and direction of the relationship between cognitive processes and novelty, b) whether different cognitive processes interact to influence novelty and c) the total variance in novelty that can be accounted for by the cognitive processes assessed.

In a number of respects, the controlled experimental approach addresses many of the shortcomings of the more widely applied protocol analysis method, which requires the designer to verbally report their mental activity relating to the design task either concurrently (i.e. while performing the design task) or retrospectively (i.e. while watching a video recording of themselves performing the design task; Gero & Tang, 2001). Within the controlled experimental approach, there is no need for concurrent verbalisation, which circumvents two key issues associated with protocol analysis. The first is that concurrent verbalisation during ideation may influence the very cognitive processes under investigation (Chiu & Shu, 2010; Lloyd et al., 1995; Suwa & Tversky, 1997). Note that the protocol method can also avoid this by using retrospective reporting although this approach has its own limitations (e.g. selective recall, see Suwa & Tversky, 1997). The second is that not all cognitive processes are capable of being verbalised. It is well-known, for instance, that cognitive processes such as inhibition and semantic association can occur automatically and unconsciously (Dijksterhuis & Meurs, 2006; Howard et al., 2014), and so they may be difficult to detect using protocol analysis. In the context of this thesis, this is a particularly salient limitation, since many of the cognitive processes that are influenced by factors such as incubation and mood could be implicit and automatic.

Another notable advantage of the controlled experimental approach is that it is conducive to large sample sizes. Larger sample sizes generally give greater assurance that the observed effect is meaningful and generalisable to the wider population (Button et al., 2013; Dinar et al., 2015). This contrasts with the protocol method which, due to its time and resource intensive nature, often necessitates the use of small sample sizes. As such, a significant portion of protocol study findings may be subject to a high margin of uncertainty (Hay et al., 2017a).

It is, however, important to highlight that the controlled experimental approach is not without limitations. In general, controlled experiments yield data that are less rich than studies using qualitative methods such as protocol analysis and case studies, and they are less well suited to exploratory investigations in new research areas. While experimental approaches can achieve richer data by conducting post-experiment interviews and questionnaires (Dinar et al., 2015), this is often unfeasible because it substantially increases time costs, both in terms of running the actual experiment as well as conducting subsequent data analysis. Thus, the incorporation of quantitative and qualitative methods in a single study, while likely fruitful, remains a considerable challenge to design researchers (Hay et al., 2017a).

A further criticism of the current methodological approach is that it lacks ecological validity and findings can be difficult to relate to design as it occurs in practice (Ball & Christensen, 2018; Cash et al., 2013; Crilly & Cardoso, 2017; Shah et al., 2003b). This criticism can be levelled at any research method (e.g. protocol, conversation analysis) conducted under laboratory conditions, although it may be particularly applicable to the controlled experimental approach given the tendency for this method to isolate particular variables of interest whilst controlling for others. In general, Ball and Christensen (2018) argue that laboratory studies often overlook the multitude of factors that influence the design process, such as interaction with team members, other key departments and stakeholders, as well as the impact of technology and external support tools. They therefore advocate for more studies to adopt an ethnographic approach to design which integrates theoretical approaches from a number of levels including cognitive, social, and cultural perspectives. A final consideration relating to ecological validity is that experimental studies tend to use student designers (Cash et al., 2013) and it is not necessarily the case that findings from this population generalise to experts, owing to differences between the two groups such as age and experience.

While the experimental approach undoubtedly has its limitations, this does not undermine the fact that it can make a valuable contribution to our understanding of design cognition. Indeed, Cash et al. (2013) carried out an observational study of design practitioners working on a project under natural conditions and compared this with design students working on a similar task during more contrived laboratory settings. While Cash et al. (2013) did observe some differences between the two (e.g. in terms of sketching behaviour and rate of idea generation), they also found that there were many similarities in terms of ideation activity across these settings. The authors therefore concluded that lab studies are a useful research tool, and that findings from such studies can meaningfully relate to design practice.

1.5.2 Current approach in the context of broader developments in the field

It is also worth considering the current approach in the context of the broader discussion about the maturation and advancement of design cognition as a field (Cash, 2018; Duffy et al., 2019; Hay et al., 2020). A salient criticism of design cognition research is that there is a lack of diversity in terms of methodological approaches (Cash, 2018; Crilly, 2019), with a tendency to rely on small-scale protocol studies (Hay et al., 2020). While protocol studies can undoubtedly be useful and have enhanced knowledge in the field, reliance on this approach may be problematic in light of its aforementioned limitations. In this sense, the current research (and the Imagine-D project as a whole) may be considered part of a broader trend towards the diversification of methods applied to design cognition research, which includes protocol studies but also involves larger-scale quantitative studies as well as use of neuroimaging methods. Such efforts do not seek to assert the superiority of any one method in particular, but rather to embrace the notion that a diversity of methods is most conducive to the development of scientific knowledge in the field (Cash, 2018).

A further criticism of the existing literature is that there is a lack of terminological consistency across studies (Hay et al., 2017a), which has made it difficult to identify commonalities in the literature and develop scientifically robust theories of ideation (Cash, 2018). As such, there is still a lack of clarity regarding the nature of the cognitive processes involved in ideation (Duffy et al., 2019; Hay et al., 2017a). In accordance with previous publications from the Imagine-D project, this thesis has described specific cognitive processes as they are defined within the cognitive psychology literature, given that in this field there is generally a greater level of terminological consistency in this regard, as well as a shared understanding regarding what cognitive processes exist and their biological basis. For instance, there is general consensus regarding the existence of a number of separate, higher-order cognitive processes involved the monitoring and regulation of thought (broadly known as executive functions), including inhibition, shifting and updating (Diamond, 2013). Early evidence for the independent existence of such processes was based on factor-analytical modelling (Miyake et al., 2000), and this has been further supported by neuropsychological evidence showing that they have distinct neural underpinnings (Cristofori et al., 2019). Likewise, there is a unified theoretical understanding of the existence of a number of distinct memory systems including semantic memory (stored knowledge of facts/concepts), episodic memory (stored knowledge of personal experiences) and working memory (short-term storage and manipulation of information) as well as evidence for their corresponding neural substrates (Binder & Desai, 2011; Chai et al., 2018; Dickerson & Eichenbaum, 2010). In this thesis, use of terminology from cognitive psychology thus aimed to aid clarity regarding the specific cognitive processes under discussion. In addition, this facilitated the mapping of well-established theories of creative cognition (developed within cognitive psychology) onto the domain of design ideation, including theories specific to incubation and mood as well as more general models of the creative process.

1.5.3 Outcome measures examined: novelty and fluency

It is finally important to discuss the measures of ideation performance assessed in the current research. The key outcome measure of interest across the three studies was *novelty*. In design research, novelty is regarded as one of the most important measures on which to evaluate early-stage design concepts (Brown, 2014; Chakrabarti &

Khadilkar, 2003; Hay et al., 2019b). This likely relates to the fact that novelty is fundamental to most existing conceptualisations of creativity (e.g. Amabile & Pratt, 2016; Mumford, 2003; Runco & Jaeger, 2012) as well as the fact that the generation of novel design concepts (and subsequently novel products) is thought to be fundamental to a company's commercial success (Chakrabarti & Khadilkar, 2003).

In addition, novelty is widely regarded to be one of the key measures enhanced by incubation. For instance, several Unconscious Work-related theories of incubation emphasise the importance of diffuse, associative cognition during incubation and how this facilitates the generation of more novel and unique associations that would be relatively inaccessible on the basis of conscious work alone (Dijksterhuis & Meurs, 2006; Gilhooly, 2016; Hélie & Sun, 2010). Thus, an increase in novelty following incubation is expected, and indeed, novelty - or similar (e.g. originality, uniqueness) - is one of the most common performance metrics used in incubation studies on divergent thinking (Baird et al., 2012; Chiang & Chen, 2017; Gilhooly et al., 2012; Hao et al., 2014; 2015). This includes the only existing mood-incubation study by Hao et al. (2015), which suggested that positive moods during incubation stimulated unconscious associative processes, thereby enhancing subsequent novelty (Hao et al., 2015). In light of the above factors, novelty was adopted as the key measure of ideation performance in the present research.

Another aspect of ideation performance examined was *fluency* i.e. amount of ideas produced. In general, fluency continues to be a widely adopted measure of ideation performance in both the creativity (Chen et al., 2019; Gilhooly et al., 2015; Hendrik et al., 2019) and design literature (Al-Shorachi et al., 2015; Cao et al., 2021; Vasconcelos et al., 2017). In a design context, it is argued to be a useful indicator of creativity on the premise that the more ideas generated, the greater likelihood that a solution will emerge that is novel and meets the requirements of the problem (Tversky & Chou, 2010). Among the existing design incubation studies, a number have suggested that incubation improves fluency (Al-Shorachi et al., 2015; Tsenn et al., 2014; Vargas-Hernandez et al., 2010), but it is not known whether there is any additional influence of positive mood on this measure. Given the above, as well as the ease with which fluency can be assessed, it was deemed useful to include fluency as an outcome measure in the present incubation studies.

It is finally important to highlight that there are other measures of creative performance that were not assessed in the present research. In a design context, a particularly important measure is *feasibility* i.e. the extent to which a concept can be manufactured and implemented (Al-Shorachi et al., 2015). Closely related to this is the measure of *quality* i.e. extent to which solution is feasible and meets the design specifications (Shah et al., 2003a). Such factors are critical in distinguishing design ideation tasks from divergent thinking tasks - only in the former is it important that ideas meet a set of specifications and have the potential to be realised as functional products (Hay et al., 2019a; Shah et al., 2003a; 2012).

Whether and how these measures are influenced by incubation (both in general and in relation to mood) is a highly interesting question, though it is beyond the scope of this the present research. This is partially due to the motivation to focus mainly on novelty, given the theoretical prominence of this measure in the existing incubation literature. However, it is also due to more practical issues surrounding the method of creativity assessment employed in this thesis, which was based on the Consensual Assessment Technique (Amabile, 1982; see section 3.3.3 for overview). While this is widely regarded as a valid and reliable method for assessing creative performance, it is a highly lengthy procedure which also relies on the availability of domain-experts in the field. As such, the inclusion of additional creativity measures here would have led to a considerable increase in time and resource costs. This practical consideration also influenced the decision to focus on novelty in the present research.

1.6 Overview of thesis

Incubation is a well-studied phenomenon in the psychology literature, and its beneficial effects on subsequent creativity have been widely demonstrated. However, there is a lack of understanding on the role of incubation specifically in a design context, including its general impact on design ideation and the factors that may influence its effects. In this thesis, a key aim was to establish whether incubation would facilitate subsequent design ideation. In addition, drawing on a wide body of anecdotal, theoretical, and empirical literature, the thesis also aimed to explore the notion that positive moods during incubation may be particularly effective in enhancing subsequent design ideation.

The thesis is composed of a main literature review chapter, followed by three empirical study chapters, and finally, a general discussion. Note that each empirical study chapter also commences with a review of research literature specifically relating to the focus of that study.

In the main literature review (chapter 2), a general introduction to incubation research is provided, including common experimental paradigms and tasks used for exploring incubation effects. The main theories of incubation, and their empirical support in the psychology and design literature, are also discussed in depth in this chapter.

Chapter 3 reports a preliminary study (study 1) which aimed to gain clarity regarding the cognitive processes associated with novel idea generation in design. The influence of positive mood during incubation on subsequent design ideation likely depends to a large extent on what cognitive processes contribute to the generation of novel ideas and whether they can be enhanced by positive mood. It is difficult to make predictions in this regard due to existing shortcomings in our knowledge of the cognitive processes involved in ideation (as discussed in section 1.5.2 above). As such, study 1 (n=101) used a relatively novel approach in the literature in which product design engineering students performed a series of ideation tasks as well as range of cognitive tests, each assessing different cognitive processes (e.g. semantic association, executive functions). Statistical relationships were then examined between the cognitive tests scores and novelty scores on the ideation tasks. After identifying the cognitive processes associated with novelty, the existing mood-cognition literature was consulted in order to establish how such processes were known to be influenced by positive mood.

In study 2 (chapter 4) the influence of mood during incubation on subsequent design ideation was directly investigated. Product design engineering students (n=73) performed an ideation task under one of four conditions (positive, negative, neutral incubation and control). In the incubation conditions, participants performed the ideation task for 8 minutes, and were then given an incubation period during which they performed a mood induction for 8 minutes (involving exposure to mood-relevant music and text). They then returned to the ideation task for a final 8 minutes. In the control condition, participants simply performed the ideation task continuously for 16 minutes. Ideation performance was then compared across the four groups in terms of novelty and fluency of ideas produced.

In Study 3 (chapter 5), the influence of mood during incubation was examined within a more domain-general creativity setting. This study was conducted because the findings of study 2 indicated that the effects of incubation and mood on ideation performance may differ in design ideation as compared to domain-general creativity. In this study, the incubation procedure employed was highly similar to that used in study 2, with the key difference that the creativity task was Finke and Slayton's (1988) mental synthesis task, and participants were from a non-design background.

Finally, in the general discussion chapter (chapter 6), the main findings across the three empirical studies are discussed. Reflection is given on the implications of the findings both regarding the role of mood during incubation, as well as the effects of incubation on the ideation process more generally. Some key findings observed across the studies that were not necessarily directly related to the issue of incubation are also discussed. Finally, limitations of the reported research are outlined in this section, as well as suggestions for future research on incubation and mood in a design setting.

Chapter 2. Literature Review of Incubation Research

2.1 Introduction

It is a well-documented phenomenon that creativity can be facilitated by a period of incubation, whereby the problem is temporarily put aside and unrelated activities are performed. The concept of incubation was developed in the psychological literature on creativity following anecdotal accounts of creative geniuses such as Einstein, Poincaré and Newton who reported that many of their most novel and influential ideas came to them while they were not currently working on the problem (Ghiselin, 1952; Poincaré; 1910; Wallas, 1926). Since then, empirical evidence for the 'incubation effect' has accumulated, with Sio and Ormerod's (2009) meta-analysis of 117 studies finding an overall positive influence of incubation across divergent and convergent thinking tasks.

Despite receiving wide empirical support, it is important to highlight that incubation is by no means a straight-forward phenomenon. While in the minority, a considerable number of studies have found no evidence for the incubation effect (e.g. Carruthers, 2016; Cardoso & Badke-Schaub, 2009; Dorfman, 1990; Lapteva et al., 2020; Olton, 1979; Torrance-Perks, 1997). Conversely, others have observed a positive impact of incubation, but only under specific circumstances (Beck, 1979; Hao et al., 2014; Vul & Pashler, 2007). For instance, Vul and Pashler (2007) found that incubation was only beneficial if participants were initially fixated on the problem before taking a break. Accordingly, a number of reviews of the incubation literature have emphasised that specific methodological factors can influence the incubation effect, and simply giving participants a break is by no means guaranteed to enhance subsequent performance (Kaplan & Davidson, 1989; Sio & Ormerod, 2009). It is also important to highlight that most of the evidence for incubation comes from generic creativity and problem-solving tasks, and less is known about how effective it is in facilitating creativity in more applied, domain-specific contexts.

With regards to design ideation, which may be regarded as a form of domain-specific creativity, a number of perspectives have been put forth as to how incubation could facilitate this process. As discussed in section 1.2, incubation may provide a means of overcoming design fixation (Smith & Linsey, 2011), as well as an opportunity to encounter inspirational stimuli in the environment (Kolodner & Wills, 1996). tationsUnconscious task-related thought processes occurring during incubation may also contribute to the discovery of a solution (Chandrasekera et al., 2013).

There is also a practical dimension to incubation research in a design context. In the psychology literature, many studies have observed incubation effects across short time periods (e.g. 30 seconds to 5 minutes; Gilhooly et al., 2012; Hao et al., 2014). The types of tasks and activities that have been shown to bring about incubation effects are also often highly accessible (e.g. watching videos, reading texts, problem solving exercises). This suggests that incubation has the potential to be implemented more formally as an efficient and convenient method for improving design ideation performance. Despite these considerations, the number of incubation studies conducted in a design setting is still relatively small, and there is a lack of knowledge regarding whether incubation impacts design ideation, as well as potential factors that might influence this process.

2.2 Examining and measuring incubation effects

In order to examine incubation in experimental settings, studies typically use a delayed-incubation paradigm which involves three phases: a) *preparation phase* during which participants carry out initial work on the problem, b) *incubation phase*: participants stop work on the main task and perform an unrelated task; and c) *post-incubation phase*: participants return to the main task again. Performance can then be compared with a control group who perform the main task continuously, i.e. with no incubation period in between. However, some variants to the standard paradigm have also been used. For example, some studies have used an immediate incubation paradigm, in which the experimental group receive the incubation period immediately after being presented with the problem, rather than after a period of preliminary work (Dijksterhuis & Meurs, 2006; Gilhooly et al., 2012). In addition, some studies have utilised a within-groups rather than between-groups paradigm, such that participants perform both incubation and control trials (Hao et al., 2015; Lapteva et al., 2020).

In terms of measuring the incubation effect, there are a number of different dependent variables that may be used. For studies using convergent insight problems for which there is only one correct answer, incubation can be measured simply by analysing whether the number of problems correctly solved (and rate of problem solving) is improved in the incubation versus control condition (Kohn & Smith, 2009; Smith & Blankenship, 1991). By far the most common insight problem used is the Remote Associates Test (RAT; Mednick, 1962) in which participants are shown 3 cue words (e.g. cottage, swiss, cake) and asked to find a fourth word associated with each cue (i.e. cheese; Bowden and Jung-Beeman, 2003). In divergent thinking tasks, such as the Alternative Uses Task (AUT) which requires participants to generate unusual uses for everyday objects, incubation studies have typically measured incubation effects using fluency (number of ideas generated) and novelty (or originality) as the independent variables.

In order to measure novelty, a common method involves having judges subjectively score each participants responses and then calculating an average score (e.g. Hao et al., 2014; 2015). Alternative methods have also been used including calculating the average statistical frequency of participants responses (less frequent = more novel; Baird et al., 2012; Chiang & Chen, 2017) and having participants self-rate the novelty of their own concepts (e.g. Gilhooly et al., 2012). Finally, in design studies on incubation, fluency and novelty are also used to measure incubation effects although some other measures may also be used such as usefulness (Al-Shorachi et al., 2015), feasibility (Al-Shorachi et al., 2015; Tsenn et al., 2014), variety (Starkey et al., 2020; Vargas-Hernandez et al., 2010) as well as levels of fixation before and after incubation (Cardoso & Badke-Schaub, 2009).

2.3 Theories of incubation

There is currently no consensus on what precisely causes an incubation effect, and as argued by Smith (2011), the phenomenon is likely caused by multiple factors. Many theories have been proposed to account for incubation and these can broadly be categorised into four different types. These will be discussed in more detail below but briefly they are: a) the Conscious Work Theory, which suggests that incubation results from intermittent conscious work occurring during the incubation period; b) Forgetting Fixation Theory, which argues that incubation serves to relieve fixation on the problem; c) Unconscious Work Theory, which proposes that the individual continues to solve the problem unconsciously during incubation and d) Opportunistic Assimilation, which holds that the individual encounters inspirational stimuli in the environment during incubation which aids subsequent problem solving. In the following literature review, each theory will be reviewed in more detail followed by a discussion of the evidence relevant to each theory. Studies will be reviewed from both the psychological literature on creativity as well as studies in the design cognition literature. It should be noted that the number of studies conducted on incubation in design is substantially less than in the psychological literature and this is reflected in the review.

2.4 Literature review of incubation

2.4.1 Conscious Work Theory of incubation

This is arguably the simplest explanation of the incubation effect and therefore merits little theoretical discussion. It makes the straightforward proposition that during incubation, participants continue to work on the main task rather than the incubation task (Weisberg, 2006) and as such, the incubation period merely affords the individual more time to generate solutions via conscious processing of the task. In daily life, Smith (2011) also suggests that people may engage in short bursts of conscious work on an unsolved problem during incubation. Though such episodes may be easily forgotten, they can accumulate over time and incrementally lead the individual to the discovery of a solution.

2.4.1.1 Evidence for the Conscious Work theory of incubation

Evidence for the Conscious Work theory of incubation is mixed. An early study by Browne and Cruse (1988) found support for the theory, showing that individuals performing a relaxing, low demand incubation task were more likely to successfully solve an insight task than those engaging in a high demand task during the incubation period. Importantly, the former group reported thinking about the insight task during incubation, which may have been responsible for their higher success.

In another relevant study, Gallate et al. (2012) found that participants who were aware that they would return to the main task after an incubation period outperformed individuals who were not informed of this. On the surface, this would appear to support the Conscious Work theory in that participants in the aware condition may have been motivated to continue working on the task during incubation. On the other hand, both groups engaged in a cognitively demanding maths task during the incubation period which would make conscious work on the main task difficult. In addition, both groups performed equally well on the maths task, further arguing against the Conscious Work theory. An alternative explanation offered by the authors was that participants' awareness that they would return to the task meant that they continued to work on the problem unconsciously (see section 2.4.3).

As noted by Gilhooly (2016), a methodological check can help confirm whether or not conscious work has taken place during experimental studies on incubation. This involves comparing cognitive performance of the incubation task with a control group performing the same task independent of the incubation paradigm. For example, the main experiment may involve participants performing a divergent thinking task, followed by an incubation period with an unrelated memory task, before returning to the divergent thinking task again. In order to confirm whether or not conscious work had taken place, the experiment should have an additional group of participants perform the memory task independently to allow for comparison with the incubation group. If the Conscious Work theory is correct, then the incubation group should show impaired performance relative to the independent group, since some if not all of their attention is assumed to be on the main task. Importantly, studies including this methodological check have not found evidence for the intermittent conscious work during incubation (Gilhooly et al., 2012; 2013; Hao et al., 2015).

Overall, while the Conscious Work theory offers a straight-forward and logical explanation for incubation effects, there has been no consistent evidence in favour of this account. Nonetheless, studies should continue to include methodological checks where possible to confirm that conscious work has taken place. This may be particularly important for paradigms in which participants are aware they will return to the task following incubation.

2.4.2 Forgetting Fixation theory of incubation

The Forgetting Fixation theory emphasises incubation as a process of forgetting, breaking down, or disengaging from contents that contribute to fixation during problem solving (Dodds et al., 2004; Smith & Blankenship, 1991). Fixation refers to a situation in which prior knowledge or existing ideas inhibit one's ability to think creatively about a problem (Smith, 2003). The pervasive effects of prior knowledge have been demonstrated across a wide range of tasks and problem-solving contexts (Haager et al., 2014; Schultz & Searleman, 2002; Smith & Blankenship, 1991). A classic example of this is the mental set effect, i.e. the tendency to rigidly apply previously learned strategies to new problems even in situations where more simple and efficient strategies could be adopted (Luchins, 1942).

In the design literature, the notion of 'design fixation' has received considerable attention and is often noted as a significant barrier to the generation of novel concepts. The term was first introduced by Jansson and Smith who defined it as "a blind, and sometimes counterproductive, adherence to a limited set of ideas in the design process" (Jansson & Smith, 1991, p.4). More recently, Crilly and Cardoso (2017) defined it as a "restricted exploration of the design space due to an unconscious bias resulting from prior experiences, knowledge or assumptions" (p.6).

In the first experimental demonstration of design fixation, Jansson and Smith (1991) had design students carry out a range of ideation tasks and also presented some participants with examples of existing solutions designed to induce fixation. It was found that participants provided with example solutions repeatedly incorporated features from these examples in their own designs, often in ways that were inappropriate and that contradicted the design brief. Since this seminal study, a substantial number of experiments using similar paradigms have delineated a number of factors influencing fixation levels, including the modality of provided examples (Chan et al., 2011), richness of examples (Cardoso & Badke-Schaub, 2011) as well as participants' specific field of design (Purcell & Gero, 1996).

In the design field, and in psychology more generally, incubation is often held to provide relief from fixation on a problem (Smith & Linsey, 2011; Tsenn et al., 2014), and there have even been some suggestions that incubation is only useful after a state of fixation has been reached (e.g. Vul & Pashler, 2007). With regards to *how* incubation relieves fixation, several explanations have been put forth. Smith (2011) argues that in the pre-incubation phase individuals may become fixated after ineffectively applying a learned mental set (i.e. sequence of cognitive operations), either because this set was used recently or in a similar context. He proposes that an incubation period may help the individual to break away from the fixating mental set, either by providing a new context which distracts the individual from that particular sequence of operations, or simply by allowing sufficient time to induce forgetting of the mental set.

Another explanation holds that incubation may facilitate the forgetting of salient but misleading memory contents (Smith & Blankenship, 1991). It is a well-documented phenomenon in psychology that the retrieval of information in memory causes the forgetting of other memory contents (retrieval induced forgetting, Anderson et al., 1994). Thus, information that is currently highly accessible in memory but that does not help solve the problem will consequentially block the retrieval of other information (including that which is relevant to the solution). Proponents of the inhibitory account of retrieval induced forgetting have argued that fixation can be overcome through the direct inhibition of misleading memory contents (Anderson et al., 1994; Storm & Angello, 2010; Storm & Levy, 2012) which allows previously blocked information to be accessed. However, it has also been proposed that fixation can be relieved simply by taking an incubation period, which provides sufficient time for highly activated but misleading memory contents to be forgotten (Koppel & Storm, 2014; Smith & Blankenship, 1991). Upon returning to the task, the individual can then more easily access previously blocked information that is relevant to the solution.

This explanation can be easily applied to standardised tests of creativity. For instance, in the RAT task time away from a given problem (e.g. Coin, Quick, Spoon) may weaken the accessibility of strongly activated close associates (e.g. Money, Fast, Fork), facilitating the retrieval of the less strongly activated target word (i.e. Silver). In design ideation, an incubation period may allow for the forgetting of structures and mechanisms relating to existing designs, enabling the generation of more novel solutions to the problem (Smith & Linsey, 2011).

2.4.2.1 Evidence for the Forgetting Fixation theory of incubation

Evidence for Forgetting Fixation theory in the psychology literature

In the psychological literature, most of the evidence for the Forgetting Fixation account comes from studies showing that incubation can relieve experimentally induced fixation (Koppel & Storm, 2014; Smith & Blankenship, 1991; Vul & Pashler, 2007). In the first study to demonstrate this effect, Smith and Blankenship (1991) had participants carry out RAT problems whereby they were presented with three cue words (e.g. cottage, swiss, cake) and asked to find a fourth word associated with each cue (i.e. cheese). In some trials, participants were presented with misleading associates (e.g. house, knife, chocolate) designed to distract participants from the solution and induce fixation. It was observed that an incubation period (five minutes of story reading) facilitated subsequent RAT performance but only for trials with fixation-inducing distractor words, which is consistent with the beneficial forgetting view that incubation specifically serves to alleviate fixation.

Furthermore, there is evidence to indicate that incubation helps break fixation specifically through the forgetting of highly accessible but irrelevant memory associates. As noted in the previous section, contents that are highly accessible in memory will block the retrieval of less accessible contents (i.e. retrieval induced forgetting), which may stifle creativity and cause fixation. Indeed, some studies have found that individuals who are more proficient in inhibiting irrelevant memory contents are also less likely to become fixated (Storm & Angello, 2010). Interestingly, Koppel and Storm (2014) found that when participants continuously (i.e. without incubation) worked on RAT problems with distractor words, their ability to inhibit irrelevant information (measured before the task) was positively associated with RAT performance. However, when participants were given an incubation period, memory inhibition and RAT performance were only correlated in the pre-incubation phase. In other words, participants were able to break fixation post-incubation irrespective of their ability to inhibit memory contents. This has been taken as evidence that incubation allows the individual time to forget irrelevant memory associates, since the need for inhibition in order to break fixation appeared to be unnecessary following an incubation period.

Despite the empirical support for the theory outlined above, there are also a number of limitations with the evidence gathered from the psychology literature. Firstly, some studies using similar tasks/paradigms find incubation effects regardless of whether or not participants are fixated (e.g. Morrison et al., 2017), which casts doubt over the proposition that incubation benefits performance specifically by alleviating fixation. Secondly, most of evidence in favour of this account comes from studies using the RAT, which is problematic given that this measure has been criticised for its poor predictive validity with respect to predicting real life creativity (Beaty et al., 2014a; Lee et al., 2014).

However, a study by Chiang and Chen (2017) did use fixation cues with a divergent thinking task (generating model names for a cell phone) and found that incubation facilitated performance when fixation cues were weak, but not strong. This provides only partial support for Forgetting Fixation theory, suggesting that incubation can relieve mild, but not strong, fixation on divergent thinking tasks. One important factor to consider here, however, is that the majority of incubation studies using a divergent thinking task appear not to have measured participants' fixation levels and it is possible that fixation has played an important role in such studies, but that these have gone unnoticed by the researchers. Thus, it is important not to prematurely rule out a potential role for forgetting fixation in divergent thinking tasks.

Evidence for Forgetting Fixation theory in the design literature

In the design literature, a handful of studies have also examined whether incubation can relieve design fixation, typically induced via exposure to example solutions. In one study, Cardoso and Badke-Schaub (2009) had two groups of industrial design students generate concepts for a device to allow people to pick up an 'out of reach' book from a shelf. One group was exposed to example solutions in pictorial form, the other in written form. In addition, both groups were given an incubation period half-way through idea generation in which an unrelated task was carried out. In addition to the two experimental groups, a third group of design students (control group) were not presented with example solutions, nor were they given an incubation period.

As expected, the two experimental groups had a greater tendency to incorporate features of the example solutions into their ideas compared to the control group, suggesting that fixation had been successfully induced. Importantly, however, incubation did not appear to be effective in reducing this effect, as the experimental groups exhibited a similar level of fixation before and after the incubation period.

These findings run contrary to the Forgetting Fixation theory, which would predict reduced fixation following an incubation period. Note, however, that this study did not include a continuously performing control group who were also exposed to fixating stimuli, thus the overall impact of incubation on fixation is not clear here. It might be the case, for instance, that incubation does relieve induced fixation relative to a continuously performing control group. Another limitation of this study, acknowledged by the authors, is that it used a small sample size (eight participants per group) which limits the generalisability of the findings.

In another study, Tsenn et al. (2014) had a group of mechanical engineers perform an ideation task (with example solutions) over two sessions separated by a long incubation period (two days). Following incubation, participants were found to borrow significantly less features from the provided examples compared with the first ideation phase, showing some support for the Forgetting Fixation hypothesis. Further examining the effects of incubation, Tsenn et al. (2014) then compared ideation performance of the incubation group with a control group and found that the incubation group generated higher fluency, but lower quality and novelty ideas. While this argues against the facilitative effects of incubation, there are again some limiting factors to be considered. Firstly, the incubation group were presented with an example solution to the task, whereas the control group were not. Therefore, it is possible that the control group may have exhibited higher performance due to the absence of fixating stimuli. In addition to this, the authors also highlight, there are several other differences between the incubation and control group which limit making a direct comparison, such as the overall idea generation time (control = 120 minutes, incubation = 100 minutes), and the number of participants in each group (control = 23, incubation = 18).

Finally, a few design studies have not explicitly examined the Forgetting Fixation theory of incubation, but have examined whether incubation results in increased variety, i.e. amount of solution space explored (Shah et al., 2003a). This is relevant since design fixation is held to involve a limited exploration of the solution space (Crilly & Cardoso, 2017). In one study, Vargas-Hernandez et al. (2010) compared ideation performance between an incubation group (who were given a three day interval halfway through the task) and a continuously performing control group.

The incubation group were found to show greater variety than the control group, which might suggest that incubation reduced fixation (e.g., on existing solutions and/or previously generated ideas) and allowed more of the problem space to be explored. A caveat to this explanation is that Vargas-Hernandez et al. (2010) used a long incubation period and there are potentially many other factors that could have played a role here, such as participants engaging in conscious or unconscious work during the incubation period, or spontaneously encountering inspirational stimuli in the environment. Indeed, Vargas-Hernandez et al. (2010) also found incubation to benefit several other aspects of ideation performance including quality and novelty, which may further support the view that there were a multitude of factors at play here.

In a final study by Starkey et al. (2020) engineering design students engaged in two 20-minute ideations sessions separated by a 15-minute incubation period. During incubation, one group of participants performed a product dissection task (i.e. taking apart and inspecting virtual models of products), an activity which has previously been found to increase design novelty (Toh & Miller, 2013). Another group were simply required to complete a personality questionnaire, an activity which has been used as a non-demanding incubation task in previous research (Ellwood et al., 2009).

The results found that both groups showed an increase in variety of solutions generated after the incubation period (as compared with before), and this effect did not appear to be influenced by incubation task type. Consistent with the Forgetting Fixation theory, this may suggest that the incubation period mitigated the effects of initial task fixation and allowed participants to subsequently generate a broader and more diverse range of solutions. However, an important caveat is that this study did not have a control group continuously work on the task without incubation. Therefore, it cannot be ruled out that participants in this study showed increased variety during the second phase simply because of a tendency to explore more solution space over time. Such an interpretation would be consistent with the ‘serial-order effect’, which refers to the fact that people tend to become more creative with increasing time on task (Beaty & Silvia, 2012; Christensen et al., 1957).

In sum, evidence for the Forgetting Fixation theory in a design context is mixed. While there is some evidence that incubation can reduce example-induced fixation, other research has found no such effect. Note that several studies have shown that incubation can increase variety, which may be considered indirect evidence that incubation can help relieve design fixation. Overall, there is a need for more well-controlled studies in this area before firm conclusions can be drawn.

2.4.3 Unconscious Work theory of incubation

The Unconscious Work theory is the oldest of the main incubation theories and makes the proposition that processing of the task continues during the incubation period in the form of unconscious work. The idea of unconscious work during incubation featured in Wallas’ original model of the creative process (see section 1.2 for an overview) and has been included in many subsequent perspectives on incubation

(Campbell, 1960; Dijksterhuis & Nordgren, 2006; Gilhooly, 2016; Hélie & Sun, 2010; Ritter & Dijksterhuis, 2014).

While the notion of unconscious work may be deemed as mysterious or obscure, in fact the existence of unconscious processing during cognitive tasks is a well-documented phenomenon in psychology. As pointed out by Ritter and Dijksterhuis (2014), there is extensive evidence that a range of higher order processes including inhibition, working memory, conflict resolution and error detection can take place unconsciously (see Hassin, 2013 for a review), and thus it is reasonable to propose that cognitive processes contributing to creativity may also operate unconsciously (Ritter & Dijksterhuis, 2014).

Most perspectives within the unconscious work theory have assumed that unconscious processing is diffuse and associative in nature (Dijksterhuis & Nordgren, 2006; Gilhooly, 2016; Hélie & Sun, 2010; Ritter & Dijksterhuis, 2014; Wallas, 1926). A number of accounts (e.g. Gilhooly, 2016; Yaniv & Meyer, 1986) have placed emphasis on spreading activation during incubation, such that activation spreads through semantic networks without conscious guidance (e.g. 'beach' activates 'sand', which activates 'time'). The activation of increasingly remote associates will thereby increase the likelihood that more novel combinations can be generated by the individual, including ones which would not have been considered on the basis of the preliminary conscious work alone.

Aside from incubation, semantic spreading activation has been used to account for a wide range of psychological phenomena including semantic priming effects, whereby one is more likely to respond faster to a concept if they have previously been presented with another concept from the same semantic category (Collins & Loftus, 1975). As argued by Sio and Ormerod (2015), although spreading activation has traditionally been assumed to have short-lived effects, there is also evidence of spreading over more extended time periods, such as in the case of long-term semantic priming (e.g. Tse & Neely, 2007). Thus, semantic spreading remains a potential explanation for unconscious processing even over long incubation periods (Sio & Ormerod, 2015).

The notion of implicit, unconscious associative thought has also been incorporated into several dual-process models of incubation (e.g. Dijksterhuis & Nordgren, 2006; Hélie & Sun, 2010). For instance, in Dijksterhuis and Nordgren's (2006) Unconscious-Thought theory, it is argued that conscious thought is convergent (i.e. focused, deliberative), whereas unconscious thought is divergent (i.e. diffuse, associative). It is this characteristic of increased divergence that is proposed to underlie incubation effects, since the unconscious is capable of generating more unique and unusual associations as compared with consciousness, which can only focus on a limited range of information at any given time. Indeed, in a series of experiments, Dijksterhuis and Nordgren (2006) found that compared with task-related conscious thought, unconscious thought lead to the subsequent generation of more unusual answers on a category fluency task (i.e. generate Dutch place names), as well as more novel responses on the alternative uses task (i.e. generate unusual uses for a brick).

In terms of design perspectives on the role of unconscious processing during the incubation period, relatively little has been written about in this regard. In general, there is good reason to suppose that unconscious processing plays an important part of the ideation process. The importance of insight in design creativity, or what some theorists have termed “sudden moments of inspiration” is well documented in the literature (Chandrasekera et al., 2013). Since designers often report that they had little awareness of where such inspiration came from (e.g. Dorst & Cross, 2001), it is reasonable to assume that unconscious processes play a role in this.

Likewise, several theorists (Badke-Schaub & Eris, 2014; Cross, 1999) have recognised that design ideation involves a significant degree of "intuition" and "unconscious and mainly inaccessible processes that allow the designer to make quick and often effective decisions without building on explicit rationale" (Badke-Schaub & Eris, 2014, p. 353). Finally, recent work has aimed to establish a dual process model of design ideation (Goncalves & Cash, 2021), highlighting that ideation involves the interplay of type 1 (i.e. implicit, unconscious) and type 2 (i.e. effortful, deliberate) processes. An example of the former may be rapid, associative idea generation (e.g. intuitively retrieving a concept from memory with little conscious thought), whereas an example of the latter may be deliberate engagement in problem re-framing (e.g. as an attempt to 'break free' from the influence of initially generated concepts; Goncalves & Cash, 2021).

The above perspectives emphasise the importance of unconscious processing in design ideation though do not make specific reference to incubation in facilitating this. In a few cases, design researchers have suggested a role for unconscious processes during incubation (e.g. Chandrasekera et al., 2013; Tsenn et al., 2014), though no precise predictions have been made with regards to the nature of such processes. In light of the evidence that design ideation and domain general creativity draw on similar cognitive and neural processes (Hay et al., 2017b; 2019a), it can be hypothesised that unconscious processes have similar properties across both domains, i.e. associative, implicit, and divergent.

2.4.3.1 Evidence for the Unconscious Work theory of incubation

Evidence for the Unconscious Work theory in the psychology literature

Although the Unconscious Work theory may be the oldest of all incubation theories, it is only in recent years that evidence in its favour has begun to accumulate. One interesting line of evidence concerns the similarity effect, which is the finding that incubation tasks that are similar to the main task result in weaker incubation effects (Ellwood et al., 2009; Gilhooly et al., 2013). For instance, Gilhooly et al. (2013) found that verbal creativity, as assessed by fluency and creativity of AUT responses, benefited more positively from a spatial interpolated task as compared with a verbal interpolated task. However, when the main creativity task was spatial (mental synthesis) the opposite effect occurred, i.e. a verbal incubation task was found to be more effective. The Unconscious Work theory can account for such an effect by arguing that similar incubation tasks interfere with cognitive resources which would be otherwise directed towards solving the main task. By contrast, the beneficial forgetting account would predict that similar incubation tasks are conducive to subsequent performance through their interference with existing mental sets and misleading assumptions developed before the incubation (Gilhooly, 2016).

Another paradigm that has been particularly useful is the immediate incubation paradigm, which is a variant of the classic delayed-incubation paradigm. In the classic paradigm, participants undergo an incubation period *after* a period of preliminary conscious work. In the immediate incubation paradigm, participants receive the incubation period immediately after being presented with the problem, with conscious work then taking place after the immediate incubation period. Studies have shown that an immediate incubation period has a beneficial impact on subsequent creative performance in both divergent thinking (Dijksterhuis & Nordgren, 2006; Gilhooly et al., 2012) and convergent thinking tasks (Dijksterhuis & Nordgren, 2006). The Forgetting Fixation theory argues that incubation facilitates creativity by providing an opportunity to forget unhelpful or misleading information that has become activated during initial attempts at problem solving. However, in the case of immediate incubation, such an explanation is not viable since there is no initial problem-solving phase. Thus, the

Unconscious Work theory has been invoked as an alternative explanation for these findings (Gilhooly et al., 2012).

In terms of the nature of unconscious work during incubation, researchers have also set out to explore the notion that this takes the form of unconscious, associative processes. That unconscious work operates in this way was initially inferred from meta-analytical findings showing that easy incubation tasks tend to elicit stronger incubation effects than difficult tasks (Sio & Ormerod, 2009). On this basis it was reasoned that easier tasks may foster a diffuse, associative mode of thought which allows unconscious processing to continue during incubation (Sio & Ormerod, 2009; 2015).

More direct evidence has been obtained from studies using tasks which actively stimulate remote associative processes during incubation. For example, Baird et al. (2012) found that an incubation task designed to elicit mind wandering resulted in a significantly stronger incubation effect (compared with a non-wandering task). Since mind-wandering has been shown to foster a diffuse, associative mode of thought (Smallwood et al., 2003), engaging in this during the incubation period may facilitate unconscious associative processes and aid subsequent creative performance. A further study by Hao et al. (2014) examined the influence of a wide variety of tasks during the incubation period and found that the most effective incubation tasks were those which stimulated semantic spreading activation, such as solving word puzzles, and reflecting on previously generated ideas.

Another interesting study carried out by Hao et al. (2015) is particularly relevant to this thesis since it concerns the role of mood during incubation. In this study Hao et al. (2015) examined the impact of three different emotion inductions (positive, negative, neutral) during a brief incubation interval (30 seconds) on subsequent divergent thinking performance. While a general incubation effect was observed such that the three incubation groups outperformed a continuously working control group, response novelty was found to be highest following the positive emotion induction. In light of the evidence that positive moods facilitate remote associative processes (Friedman & Förster, 2010; Storbeck & Clore, 2008), the authors suggested this evidence provided evidence in favour of the Unconscious Work hypothesis.

Finally, a number of studies have also suggested that unconscious processing is involved in convergent insight problems such as the RAT (Cai et al., 2009; Leszczynski et al., 2017; Morrison et al., 2017; Zhang et al., 2019). As discussed, this task is commonly used as evidence for the Forgetting Fixation theory in light of the evidence that incubation tends to selectively improve performance on RAT trials that were previously fixated (Smith & Blankenship, 1991; Vul & Pashler, 2007). Casting some doubt on this interpretation, however, Morrison et al. (2017) observed that an incubation period facilitated RAT problems regardless of participants' level of fixation. In addition, participants reported a stronger feeling of insight ('aha' experience) when problems were solved following an incubation period rather than during continuous problem solving. Given that insight has been linked to unconscious semantic integration (Jung-Beeman et al., 2004; Kounios et al., 2008), the authors suggested that incubation on RAT problems involves a switch to unconscious associative processes which allows one to make connections between semantically distant concepts.

There is other evidence that is consistent with the above interpretation. For instance, a study by Cai et al. (2009) found that previously unsolved RAT problems were facilitated by a period of REM sleep, a process which is thought to enhance the formation of associative networks and semantic integration processes (Ritter & Dijksterhuis, 2014). In addition, Leszczynski et al. (2017) found that increased levels of mind wandering during incubation were associated with subsequent enhanced performance of the RAT task. As discussed, mind wandering has previously been linked with unconscious semantic spreading activation during the incubation period (Baird et al., 2012). Overall, these studies suggest that convergent thinking, like divergent thinking, may benefit from unconscious processes occurring during incubation.

Evidence for the Unconscious Work theory in the design literature

In the design literature, very few studies have been conducted that are suitable tests for the Unconscious Work theory. One contributing factor to this is that several studies have used long and unsupervised incubation periods (Moreno et al., 2016; Tsenn et al., 2014; Vargas-Hernandez et al., 2010) which render it difficult to demonstrate any potential mechanisms that may be operating during the incubation period. However, one well-controlled study may provide some support for the Unconscious Work theory of incubation. In a sample of industrial design students, Al-Shorachi et al. (2015) examined the effects of two types of incubation task on subsequent ideation performance, assessed using a range of performance metrics including fluency, originality, feasibility, usefulness and overall creativity (a broad measure encompassing the average of scores across all other metrics). The results revealed that, compared to a continuously performing control group, only the maths task was found to induce incubation effects - specifically in terms of fluency and creativity. However, the authors also noted that participants performing the storytelling task showed significantly greater originality after, as compared to before, the incubation period.

The results of this study may be seen to support the Unconscious Work theory of incubation two main ways. Firstly, participants were not informed that following the incubation period they would return to the ideation task, suggesting that any task related thought occurring during incubation would likely have been unconscious. Secondly, with specific regards to the storytelling task, this exercise involved combining random images to make stories and arguably could have stimulated unconscious remote associative processes during incubation. This would be one explanation for why the storytelling task appeared to be particularly effective in stimulating subsequent originality, as studies in the psychology literature using associative, low-demand incubation tasks (e.g. mind-wandering) have observed similar effects (Baird et al., 2012; Hao et al., 2014).

2.4.4 Opportunistic Assimilation theory

The theories reviewed thus far have all explained incubation effects in terms of internal cognitive processes, such as forgetting mental sets or unconscious processing of the task. However, another perspective is that the effect arises from the problem solver having serendipitous encounters with inspiration stimuli in the environment during incubation. This theory was proposed by Seifert et al. (1995) who argued that initial problem-solving attempts ending in impasse (or fixation) result in the formation of *failure indices,* i.e. partial representations of the problem stored in memory which remain primed to receive new information. During incubation, encounters with objects or events relevant to the problem trigger failure indices, allowing the new information to be integrated with the existing problem representation. This process of integration may occur through direct assimilation (e.g. like adding a missing jigsaw piece), or through a complete re-configuration of the problem representation. In either case, integration with the new information is hypothesised to increase the individual's chance of success in subsequent problem-solving (Seifert et al., 1995).

Similar to the Forgetting Fixation account, the Opportunistic Assimilation theory assumes that incubation effects will only be observed after a period of considerable initial conscious work culminating in fixation. If fixation is not reached, a stable problem representation (i.e. failure indices) will not be formulated and the individual will not be primed to receive new information from the environment. The notion that fixation serves to reinforce one's memory representation of the problem is supported by the empirical observation that peoples' recall tends to be higher for unsolved versus solved problems (Zeigarnik, 1927). It is argued that this heightened level of accessibility for fixated problems increases the likelihood that external cues will be noticed by the solver and assimilated with the existing problem representation. As argued by Smith (2011), the theory can also be considered a variant of the Unconscious Work theory, in that during incubation, failure indices remain just below the level of consciousness and remain so until they are triggered by the chance encounter with external stimuli. After this, conscious work on the problem resumes, whereby the new information is consciously assimilated with the existing problem representation and aids in the generation of a novel solution.

The theory of Opportunistic Assimilation has important implications for design, in which the role of external stimuli is held to have substantial importance (Cardoso & Badke-Schaub, 2011; Gonçalves et al., 2016; Goucher-Lambert et al., 2019). There is much anecdotal evidence that designers opportunistically draw inspiration from the environment, either by habitually collecting sources that may be relevant in the future (Eckert & Stacey, 2003), or through spontaneous encounters with stimuli that are relevant to a problem at hand (Keller et al., 2006). Drawing inspiration from the environment may be of particular importance at the early stages of design ideation in which design requirements are ill-structured and/or poorly defined (Gonçalves et al., 2016). In terms of empirical evidence, numerous studies have explored the influence of external stimuli on the ideation process. Much of this has focused on the role of visual stimuli (Cardoso & Badke-Schaub, 2011; Casakin & Goldschmidt, 2000; Goldschmidt & Smolkov, 2006), given the widely assumed prominence of the visual modality in design, although evidence for the positive impact of non-visual stimuli has also been noted (Goldschmidt & Sever, 2011). The findings of such studies tend to show that designers are more creative when performing in environments rich with stimuli (e.g. sketches, images, texts, web databases) compared with stimuli-deprived environments. Furthermore, there is evidence that stimuli distantly related to the problem are more beneficial than closely related stimuli (Dahl & Moreau, 2002; Wilson et al., 2010), which is related to the notion that stimuli in the form of existing solutions to the problem stifles creativity and causes fixation.

While such empirical research has examined the role of external stimuli during active work on the problem, it is plausible to assume that designers also derive inspiration from the environment even when conscious work on the task is suspended, as would be predicted by the Opportunistic Assimilation theory. Indeed, several theoretical perspectives within the design literature have been developed which are closely related to this account. Gonçalves et al. (2016), for example, highlight the importance of passive search in design, i.e. "random encounters with relevant stimuli, which are consciously integrated into the design process" (p. 310). Additionally, the concept of open goal, though initially applied to simple problems in the psychology literature (Moss et al., 2007), has also been influential in a design context (Smith et al., 2011; Tseng et al., 2008). Open goal is defined as a "goal which has been set but for which the associated task has not been complete" (Moss et al., 2007, p. 876). The state of having an open goal is held to prime one into a state of readiness to receive relevant external cues, and so is highly related to the notion of failure indices within Opportunistic Assimilation theory.

In another account, Kolodner and Wills (1996) introduce the concept of 'serendipitous recognition', whereby random external stimuli (including objects, functions, behaviours) are encountered and recognised as potential solution to an incubating problem. Kolodner and Wills (1996) highlight two key cyclical and interactive phases that the designer progresses through during the early stages of ideation, which are preparation and assimilation. During *preparation*, the problem is defined, explored and elaborated which serves to highlight key properties to look for in potential solutions. This process may refine subsequent search for inspirational material and prevent the designer from being overwhelmed by the volume of stimuli present in the environment. This stage can also be likened to the formulation of failure indices in Opportunistic Assimilation theory which guide subsequent searching for the solution. In the next stage of the model, *problem assimilation*, a number of candidate solutions are then explored, evaluated and compared based on the criteria identified in the preparation stage. Crucially, some of these solutions may have been discovered by chance during the performance of other activities, i.e. through serendipitous recognition.

2.4.4.1 Evidence for Opportunistic Assimilation theory

Evidence Opportunistic Assimilation theory in the psychology literature

Early studies examining the role of clues during incubation were generally unsupportive of the Opportunistic Assimilation theory. Several studies found that visual cues during incubation did aid performance, though the same studies also found that visual cues were helpful when presented at any time during the experiment, without any additional advantage of incubation (Dominowski & Jenrick, 1972; Mednick et al., 1964). Subequently, a number of studies have suggested that cues can be useful during incubation but only if participants are instructed to use them (Dodds et al., 2002; Smith et al., 2012). This does not provide full support for the Opportunistic Assimilation theory, which suggests individuals utilise cues automatically during incubation, without explicit instruction.

Other studies in the psychology literature have observed effects more consistent with the notion of Opportunistic Assimilation though only under particular circumstances. For instance, Moss et al. (2011) found that insight problems were facilitated by cues during incubation if participants temporarily suspended problems right at the point of reaching impasse. Cues were not effective if participants suspended problems before reaching impasse (consistent with Opportunistic Assimilation), and also if they continued working beyond impasse before taking a break. Accounting for the latter effect, the authors suggested this was because working beyond impasse serves to reinforce a fixated mindset to such an extent that subsequent cues are no longer sufficient to break out of this.

Additionally, there is also evidence that the influence of cues is moderated by both main task and incubation task difficulty. Sio and Ormerod (2015) found successful cue assimilation during difficult RAT problems was higher when interrupted by a low-demand incubation task. However, when RAT problems were easy, a high-demanding incubation task was more conducive to cue assimilation. The authors proposed that this interaction reflects the different strategies that may be used for hard versus easy RAT problems. For difficult RAT problems, in which words and their target are more semantically distant, a broad, diffuse attentional style may be adopted. A task requiring less cognitive resources may allow this strategy to continue during incubation, thus allowing cue assimilation to take place. On the other hand, easy RAT's may benefit from a narrower and more focused approach since less remote association processes are required. During incubation, a more cognitively demanding task may help participants to maintain this attentional state and make them more susceptible to relevant cues.

In sum, it can be concluded that there is some supporting evidence for the Opportunistic Assimilation theory in the psychology literature though this has only been observed specific circumstances. It might be noted that tests of the theory are currently limited to somewhat contrived settings (such as RAT problems followed by an incubation task with cue words included) and this may have little resemblance to cue assimilation as it occurs in real life, where encounters with stimuli are likely far less structured and more natural. A further problem is that, as with the Forgetting Fixation hypothesis, the majority of studies testing the Opportunistic Assimilation theory are disproportionately focused on convergent thinking tasks.

Evidence for Opportunistic Assimilation theory in the design literature

In the design literature, some support for the Opportunistic Assimilation theory may be found in studies that have examined the role of timing in the presentation of external stimuli. As discussed in section 2.4.4, much research has investigated the impact of different types of external stimuli (e.g. images, texts) on ideation. In addition to this, research has also explored whether there is an optimum time at which the designer should be exposed to external stimuli. A number of studies have shown that external stimuli are more beneficial for performance if presented during ideation rather than at the start (see Vasconcelos & Crilly, 2016; for a review). In one study, Perttula and Liikkanen (2006) found that designers produced a more diverse range of solutions when presented half-way through ideation (compared to at the outset). Further evidence has indicated that stimuli may be most beneficial for novel idea generation when designers are aware they are fixated and request to see external stimuli, as opposed to receiving this at fixed intervals (Siangliulue et al., 2015). The findings of these two studies are consistent with the Opportunistic Assimilation theory's proposal that a period of preliminary work is necessary before one can take full advantage of environmental cues. However, it is important to emphasise that they were not incubation studies since participants remained engaged in ideation when the stimuli were presented. In addition, Siangliulue et al.'s (2015) findings argue against the notion that optimal cue assimilation occurs spontaneously and automatically, since participants who explicitly requested to see the stimuli appeared to benefit most.

More convincing evidence for Opportunistic Assimilation can be found in the literature on analogical reasoning in design. Analogical reasoning involves mapping information from one situation (source) to another (target) on the basis of relationships existing between the two (Gentner, 1983; Moreno et al., 2014). It is well-known that designers often draw on analogous situations in order to generate novel and innovative ideas (Casakin & Goldschmidt, 1999; Christensen & Schunn, 2007). There are many classic examples of this including the Hubble space telescope repair, which was based on an analogy with an extendable shower head and Velcro, inspired by the structural properties of the burr plant (Smith et al., 2011). In addition, many design tools such as Design-by-Analogy (McAdams & Wood, 2002) and WordTree (Linsey et al., 2009; Linsey et al., 2008) also aim to support designers identifying and utilising analogies in order to solve design problems.

Despite the utility of analogies, it is well known that people generally have difficulty recognising and using information that is analogically related to the problem at hand. As such, evidence in the design literature (and in psychology more generally) has demonstrated that the use of analogies is facilitated if participants work on the target problem for a period of time and are then subsequently exposed to the source analogy during an incubation period (Christensen & Schunn, 2005; Keane, 1985; Moss & Cagan, 2007; Tseng et al., 2008)). In one study demonstrating this effect, Tseng et al. (2008) had mechanical engineering students perform a concept generation task accompanied by stimuli that were not closely related to the problem at hand. When the stimuli were presented at the outset, participants did not appear to be influenced by the stimuli.

However, when this was presented during an incubation period, participants were much more likely to draw analogies from them, resulting in the generation of more novel solutions. The authors took this as support for the notion that a period of preliminary work allows one to construct an open goal (see section 2.4.4), i.e. an unfulfilled problem-solving goal that primes one to draw inspiration from environmental cues (Moss & Cagan, 2007). The findings may also be taken as support for Opportunistic Assimilation theory, which similarly proposes that initial attempts at problem solving are required for the individual to take full advantage of stimuli encountered during the incubation period.

2.5 Conclusion

From the evidence reviewed it is clear that incubation can facilitate novel idea generation and creative problem solving. In the psychology literature, this applies to convergent insight problem solving as well as open-ended divergent thinking tasks. In the design literature, fewer incubation studies have been conducted, although some of the existing work suggests that incubation may be a useful tool for overcoming fixation (e.g. Tsenn et al., 2014) as well as a means of enhancing novelty (Al-Shorachi et al., 2015; Vargas-Hernandez et al., 2010) and variety (Starkey et al., 2020; (Vargas-Hernandez et al., 2010). In addition, there is some evidence to suggest that incubation can facilitate encounters with inspirational stimuli in the environment, which is also beneficial to subsequent to creativity (Tseng et al., 2008). It should be noted, however, that some findings have been less supportive of incubation as a means of enhancing design ideation (e.g. Cardoso & Badke-Schaub, 2009; Tsenn et al., 2014). For example, Tsenn et al. (2014) found that an incubation group generated ideas of lower novelty and quality than a continuously performing control group. Such findings highlight the need for further research to investigate the utility of incubation in a design context.

The main theories of incubation and associated empirical research suggests that there at least three key ways in which incubation may facilitate ideation. Firstly, in line with Forgetting Fixation theory, incubation may provide relief from fixation by allowing the individual time to forget existing solutions to the problem as well as an opportunity to break away from ineffective and misleading strategies (Smith & Linsey, 2011). While it is true that some of the studies reviewed here found no evidence that incubation can relieve design fixation, it should be noted that these had important methodological limitations relating to small sample size and lack of appropriate control groups. It is important for further studies examining the positive impact of incubation on design fixation to address these limitations.

Secondly, incubation may provide designers an opportunity to encounter inspirational stimuli in the environment. The role of environmental stimuli is held to have substantial influence in design and may be particularly important at the early stages when the problem is ill-defined (Gonçalves et al., 2016). Much of the evidence reviewed here indicates that participants are most receptive to external stimuli after a period of preliminary work (Perttula & Liikkanen, 2006; Tseng et al., 2008), suggesting that incubation may be an opportune time period to seek out inspiration in the environment. This could take a number of forms including active search during incubation, whereby the designer actively seeks out stimuli through various sources (databases, webpages, books etc.), or passive search over a more extended incubation period, whereby the designer completely puts the problem aside with the aim of encountering stimuli more spontaneously (Goncalves et al., 2016).

Thirdly, incubation may be used as an opportunity to stimulate unconscious processing of the task which then improves the novelty of subsequently generated ideas. In the existing design literature, the role of unconscious processes during incubation has received little attention, with Al-Shorachi et al.'s (2015) study on industrial design students perhaps the only evidence for such processes. However, the wider psychology literature indicates that this may be a highly effective way to enhance ideation.

There are a number of possible ways to explore the role of unconscious processes during incubation in a design setting. Many of the tasks used to stimulate unconscious process during incubation in the psychology literature (e.g. mind wandering, word puzzles) have been straightforward and would be easy to implement in a design setting. Additionally, an immediate incubation paradigm, which is also thought to involve unconscious processes, could easily be utilised in a design context, i.e. by giving participants an incubation period immediately after seeing the design brief.

An alternative approach, which will be examined in this thesis, is to investigate the impact of a positive mood induction during incubation on subsequent ideation. As indicated by the review, there is evidence that a positive mood induction during the incubation period can stimulate remote associative processes during incubation and improve subsequent divergent thinking (Hao et al., 2015), but it is not clear whether similar effects could be observed in a design context. For a full explanation of the rationale for exploring mood during incubation in a design context, the reader is referred to chapter 1 (section 1.4).

Before concluding this review, there are a number of limitations with the existing incubation research to be discussed. In the design literature, these have already been highlighted and include a) small sample sizes, b) lack of appropriate control group and c) use of long, unsupervised incubation periods. On the latter point, the use of long incubation periods is not necessarily a limitation and indeed, may more closely reflect incubation periods as they occur in real life. However, studies employing long incubation periods (e.g. 2 days) that cannot be supervised by the researcher make it highly difficult to determine what activities the designer performed and whether these had any influence on the results. Therefore, researchers using long incubation periods may wish to use additional methods to account for the activities participants performed during the interval, such as requiring participants to keep a journal of their activity during incubation, which may help identify factors that influence subsequent performance.

In the psychology literature, there are also several limitations with the existing research. A significant problem that needs to be addressed is a lack of heterogeneity across types of creativity task used to test each respective theory. This is a particularly salient problem with regards to the Forgetting Fixation account and Opportunistic Assimilation accounts, which have generally been examined with convergent problems (most commonly the RAT). This is an issue because firstly, creativity is thought to rely on a combination of both convergent and divergent processes (Dietrich, 2019), thus the effects of incubation should be examined with respect to both task types. Furthermore, many questions have been raised with regards to the validity of the RAT and its relationship to real life creativity. Beaty et al. (2014a) for example, found that performance on insight tasks predicted neither creative achievement nor every day creative behaviour.

For the above reasons, more studies should aim to test the Forgetting Fixation and Opportunistic Assimilation theories using more open-ended tasks. This raises the interesting question of how these respective theories could be examined with a divergent thinking task. The Forgetting Fixation account could be examined using the alternative uses task e.g. by concurrently presenting a list of commonly known uses for the object to induce fixation (see George & Wiley, 2020). It could then be examined whether or not an incubation period reduces this effect. As discussed, an existing study has used a similar approach already (Chiang & Chen, 2017) although the task used is not a validated measure of creativity. With regards to the Opportunistic Assimilation theory, one could present images of common objects carrying out unusual functions during incubation in order to provide inspiration.

A more general criticism of the existing incubation literature in psychology is that studies have mainly focused on the use of verbal creativity tasks with less focus on other forms of creativity, such as visual creativity. This was highlighted in Sio and Ormerod's (2009) meta-analysis of incubation studies and remains a salient issue in the literature. Related to this, there is also a need to move beyond standardised creativity tasks and also examine incubation using tasks that reflect applied, domain-specific creativity. To some extent, this issue is being addressed by the growing number of studies examining incubation in the design field. However, there are still many other domains of creativity where its effects have not been investigated, such as poetry writing and musical improvisation. It is important for future research to address this given that the processes involved in standardised creativity tasks do not necessarily reflect creative processes carried out by professionals in their respective fields (Baer, 1998; Dietrich, 2019). As such, it is reasonable to propose that incubation may have different effects in more applied, domain-specific settings.

In conclusion, the current review of the main theoretical accounts of incubation and associated empirical research demonstrates that there are a number of ways in which incubation can facilitate design ideation and creative cognition more generally. Nonetheless, the number of studies conducted on incubation in a design context remains relatively small. In addition, due to mixed findings and in some cases methodological shortcomings, the extent to which incubation actually facilitates design ideation remains open to further examination. Related to this, there are still many questions around the factors that may influence incubation in a design context and potentially lead to enhanced incubation effects. As discussed, this thesis aims to explore the role of mood during the incubation period, but this review has also highlighted other interesting avenues for future research. Finally, in terms of incubation research generally, there is a need for greater focus on how incubation facilitates creativity in more applied, domain-specific tasks of the type typically carried out by creative professionals.

Chapter 3. Empirical Investigation of the Cognitive Processes Involved in Design Ideation

3.1 Introduction

This thesis aims to investigate whether incubation in general facilitates design ideation, as well as to additionally assess whether a positive mood induction during incubation has a particularly beneficial impact on subsequent performance. The effects of mood during incubation may depend to a large extent on what cognitive processes actually contribute to the generation of novel design concepts, and whether they can be influenced by positive mood. For example, positive moods have been shown to improve a range of cognitive processes including semantic association (Topolinski & Deutsch, 2013), controlled memory retrieval (Bartolic et al., 1999), and working memory (Storbeck & Maswood, 2016). Such processes could potentially play a critical role both during and after the incubation period, and their stimulation - i.e. through positive mood - could lead to enhanced incubation effects.

Currently, however, it is difficult to make predictions regarding the interaction of mood and cognition during the incubation period, as there is a lack of clarity around the nature of the cognitive processes that contribute to design ideation (Duffy et al., 2019; Hay et al., 2017b; Jin & Benami, 2010). As discussed in Chapter 1, this is due to a multitude of factors including a dearth of scientifically robust theories of design cognition (Cash, 2018; Dinar et al., 2015; Hay et al., 2017b), as well as poor terminological consistency regarding key concepts across studies (Hay et al., 2017a; 2017b), which has made it difficult to integrate research findings and form a cohesive body of knowledge (Cash, 2018). It has also made it more difficult to generate testable predictions based on the existing literature (Cash & Kreye, 2017). A further issue concerns the predominance of the protocol analysis method in design research. While protocol analysis has a number of advantages, and has undoubtedly led to progress in the field, it is important to be aware of the limitations of this method. In the context of this thesis, a particularly salient limitation is that not all cognitive processes can be verbalised. This is important because many of the cognitive processes that are relevant to incubation and mood could be implicit and automatic, occurring outside of conscious awareness. Thus, the involvement of such processes in design ideation may have remained largely undetected by previous research.

The above factors highlight a number of shortcomings regarding our existing knowledge of design cognition and show the need for further work in this area. Given that clarity regarding the cognitive processes involved in design ideation is of central importance to the issue of incubation and mood, it was deemed important to conduct a preliminary study investigating the cognitive processes involved in the generation of novel design concepts. This involved the use of a relatively novel approach in the design literature which aimed to address several of the limitations associated with previous work.

Specifically, a large sample of designers (n=101) carried out a series of ideation tasks as well as a range of cognitive tests, each assessing a different cognitive process. Relationships between ideation performance and performance of the cognitive tests were then explored using a variety of methods including correlations, multiple regression, and moderation analysis. A similar approach has been applied extensively in the psychology literature on creativity and has proved useful in establishing relationships between various cognitive processes and creative ideation, including processes that may operate relatively automatically and unconsciously (e.g. semantic association, inhibition; Beaty et al., 2014b; Benedek et al., 2012b; 2014b). Findings from such studies have also contributed to the development of scientifically robust neuro-cognitive models of the creative process (e.g. Beaty et al., 2016). It is important to highlight that in the design literature, a number of studies have also adopted this research approach although they have tended to only explore a narrow range of cognitive processes; for instance, visual reasoning (Kim et al., 2005) and divergent thinking (Casakin et al., 2010).

A variety of cognitive processes were assessed in the present study, which were identified on the basis of existing literature from two broad domains of research. These were: a) research on cognitive processes involved in domain-general creativity and b) research on the cognitive processes involved in design ideation. In the following section, research from both domains are reviewed, including both behavioural and neuroimaging work.

3.2 Review of cognitive processes involved in design ideation

Before reviewing the relevant research literature, it is important to clarify that a key assumption of this review is that since design ideation is regarded as a creative behaviour (e.g. Dorst & Cross, 2001), the literature examining the cognitive processes involved in creativity can also shed light on the cognitive processes that contribute to design ideation. Studies on domain-general creativity typically study creative performance using divergent thinking tasks, which involve producing many different answers to an open-ended problem. Divergent thinking tasks are considered a measure of creative potential, i.e. a person who scores highly on this task is thought to have high potential to produce creative work at some point in their life (Runco & Acar, 2012). Consistent with this, higher divergent thinking scores have been shown to predict higher creative achievement in real life (Althuizen et al., 2010; Beaty et al., 2018; Runco, 1986).

Furthermore, many design researchers have suggested that design ideation involves divergent thinking (Liu et al., 2003; Tversky & Chou, 2010) and protocol evidence suggests that it plays a prominent role in ideation (Goldschmidt, 2016). In addition, there is some evidence that divergent thinking ability predicts design ideation performance (Casakin et al., 2010; Kwon et al., 2017). Thus, it is fair to assume that some knowledge on design cognition can be obtained from the creativity literature in psychology.

However, this is not to argue that divergent thinking and design ideation are essentially the same and it is important to acknowledge that there are limits to how much knowledge about design ideation can be obtained by studying divergent thinking tasks. Dietrich (2019), for instance, points out that the processes involved in domain-specific fields of creativity (e.g. musical composition, dancing, design) are too diverse to be captured by generic divergent thinking tasks. Similarly, several researchers have pointed out that divergent thinking assessments cannot account for the array of factors that contribute to creative ability and performance, such as training, education, domain knowledge, social context, and personality (Baer, 1998; Brown, 1989; Frith et al., 2019; Silvia et al., 2008).

In addition, Shah et al. (2012) has highlighted key features of design tasks that are not captured by standardised divergent thinking tasks and therefore render them unsuitable as a direct measure of design ideation performance. For instance, divergent thinking tasks typically do not highlight a problem that needs to be addressed, along with specification of requirements and constraints. Moreover, they do not require any technical or domain-specific knowledge in order to successfully solve them. Thus, it is important to acknowledge that evidence from the creativity literature may only give a partial insight into the processes involved in design ideation.

A final point to note is that definitions used for cognitive processes in the cognitive psychology literature tend to be more standardised and consistent than they are in the design literature (Hay et al., 2017b). Therefore, this review will firstly introduce cognitive processes as they are described in the cognitive psychology literature, along with relevant theory and evidence linking such processes to creative ideation. Following this, behavioural research conducted specifically in a design setting will then be reviewed. The review will then finally focus on relevant neuroimaging research conducted on general creativity and design cognition.

3.2.1 Review of behavioural literature on creative ideation

Of all the cognitive processes that have been linked with creative ideation, semantic memory may be viewed as one of the most prominent. Semantic memory is a long-term memory system that includes knowledge of facts and concepts (Martin, 2009). Both traditional and modern theories of creativity argue that the ability to flexibly retrieve concepts stored in semantic memory, particularly those which are distantly related, is key to the generation of novel ideas (Benedek et al., 2012b; Kenett & Faust, 2019; Mednick, 1962). For instance, in his seminal model of creativity, Mednick (1962) defined the creative process as "the forming of associative elements into new combinations which either meet specific requirements or are in some way useful. The more mutually remote the elements of the new combination, the more creative the process or solution" (p. 221).

Mednick further proposed that non-creative individuals had steeper associative hierarchies, such that for a given concept (e.g. table), the individual would have high access to conventional, stereotypical associations (e.g. chair) and low access to more distantly related concepts (e.g. leg). Conversely, creative individuals were argued to have flatter associative hierarchies, such that they had similar levels to assess both close and remote associations. This difference in the organisation of semantic networks was held to underpin the latter group's ability to form more novel, unique associations between concepts (Benedek & Neubauer, 2013; Mednick, 1962).

Since then, there has been much evidence to show that that the ability to form associations between semantically distant concepts is associated with creativity (Beaty et al., 2014b; Benedek et al., 2012b; Benedek & Neubauer, 2013). For instance, Benedek et al. (2012b) observed that performance on a variety of semantic word association tasks positively predicted divergent thinking ability. Moreover, research using computational modelling also suggests that, in line with Mednick's (1962) theory, high creative individuals' semantic memory networks are more highly interconnected than low creative individuals', which may underpin their ability to form more remote associations between concepts (Kenett et al., 2014; Kenett & Faust, 2019).

Another important long term-memory system that is thought to support creativity is episodic memory, which stores information relating to events that one has experienced (Tulving, 1983; Wheeler, 2001). Episodic memory plays a key role in many aspects of cognition beyond mere recollection of the past (Madore et al., 2019; Moscovitch et al., 2016; Schacter et al., 2017). For instance, Moscovitch et al.'s (2016) review demonstrates how episodic memory contributes to diverse domains such as language processing, perception and decision making. In addition, it has been suggested that the retrieval and recombination of episodic details contributes to a range of imaginative processes such as mentally simulating future events (episodic constructive hypothesis; (Schacter et al., 2017; Schacter & Addis, 2007).

There is also increasing evidence to implicate episodic memory in creative ideation (see Beaty & Schacter, 2018; for a review). In one of the few protocol studies conducted on the Alternative Uses Task (AUT) Gilhooly et al. (2007) observed that participants frequently retrieved memories of past experiences with the object in order to generate unusual uses for it. Further evidence comes from the finding that amnesic patients with episodic memory deficits have also showed impaired divergent thinking performance (Duff et al., 2013). Finally, administering an episodic memory specificity induction (which improves the ability to recall episodic information) has been shown to have a beneficial impact on subsequent divergent thinking performance (Madore et al., 2015; 2016a; 2016b).

Semantic and episodic accounts tend to emphasise the relatively diffuse, associative nature of creative cognition (e.g. Beaty et al., 2020). Conversely, other perspectives have emphasised that creativity is also to some extent a top-down strategically controlled process that involves executive functions (Beaty et al., 2014b; Benedek et al., 2014b; Dietrich, 2004; Mumford et al., 2012). Executive functions refer to a set of top-down higher order processes that enable the control of thought and action (Gray-Burrows et al., 2019; Snyder et al., 2015). This includes processes such as inhibition, working memory, planning, goal setting and set shifting (Diamond, 2013; Miyake et al., 2000). Executive functions are argued to facilitate a number of key aspects of creativity, such as the co-ordination of attention, the online maintenance and manipulation of information, switching between strategies and setting goals (Benedek et al., 2014b; Dietrich, 2004; Mumford et al., 2012). In addition, the evaluation of generated ideas, which is thought be an integral part of the ideation process (Hunt, 1994), is argued to rely on input from executive functions (Beaty et al., 2016; Kleinmintz et al., 2019).

The link between executive processing and creativity is supported by evidence showing positive associations between divergent thinking and a range of executive functions. For instance, numerous studies have observed a positive correlation between divergent thinking performance and working memory (Benedek et al., 2014b; de Dreu et al., 2012; Oberauer et al., 2008), although it should be noted that some studies have failed to find a relationship (Lee & Therriault, 2013; Takeuchi et al., 2011). de Dreu et al. (2012) argue that working memory supports creative cognition in a number of key ways, such as maintaining novel information in consciousness, and in prioritizing task relevant information. Benedek et al. (2014b) also argues that high working memory capacity supports associative combination, given that a higher number of concepts can be maintained and manipulated during ideation.

In addition, several studies have found a positive relationship between divergent thinking and response inhibition (Benedek et al., 2012a; Benedek et al., 2014b; Groborz & Nęcka, 2003). It is proposed that inhibition facilitates creativity in that it allows for the suppression of unoriginal ideas, and may also help manage interference from task irrelevant information and previously generated responses (Benedek et al., 2012a). However, there is also an alternative perspective which argues that creativity is in fact supported by lower levels of inhibition (Eysenck, 1993; Martindale, 1995). Within this account, it is argued that decreased inhibition leads to increased associative spreading activation across semantic networks, thereby increasing the likelihood of forming novel association (Martindale, 1995). In support of this view, a study by Carson et al. (2003) reported that lower levels of inhibition were associated with higher creative achievements.

A final executive function that has shown positive correlations with divergent thinking is broad retrieval ability (Gr, Beaty et al., 2014b; Frith et al., 2019; Gilhooly et al., 2007; Silvia et al., 2013), i.e. the controlled retrieval and selection of information from long term memory (Carroll, 1993). Gr is often assessed using verbal fluency tasks (e.g. generate as may words as possible beginning with ‘A’). While Gr is thought to rely on semantic retrieval processes to some extent (e.g. Rosen & Engle, 1997; see section 3.5.2 for further discussion), many theorists consider it to be a measure of executive ability given that Gr tasks require top-down control processes such as response monitoring, strategy shifting and interference management (Benedek, et al., 2012a; Gilhooly et al., 2007; Nusbaum & Silvia, 2011; Silvia et al., 2013).

Creativity researchers have also focused on the relationship between intelligence and creativity. A number of broad definitions for intelligence as a unitary construct exist (see Legg & Hutter, 2007), such as the "capacity to think, to solve novel problems, to reason and to have knowledge of the world" (Anderson, 2006). However, a common distinction is made in the literature between fluid intelligence (Gf) and crystallised intelligence (Gc, Carroll, 1993; McGrew, 2005). Gf involves the ability to use logic and abstract reasoning to solve new problems and adapt to novel situations (Jaeggi et al., 2008; Sanginabadi, 2020). Gc, by contrast, refers to breadth and depth of acquired knowledge (Cattell, 1963; McGrew, 2005).

Both Gf and Gc are thought to play a role in the generation of creative ideas. With regards to Gf, its relevance to creativity can be found in several theoretical models of creative cognition. For instance, Hélie and Sun's (2010) model argues that creativity involves the application of both implicit and explicit knowledge. The latter involves rule-based processes such as logical reasoning, hypothesis testing and hard constraint satisfaction, all of which can be related to Gf. Similarly, convergent thinking, which involves analytical thought and logical reasoning processes in order to arrive at a single correct answer (Cropley, 2006; Guilford, 1957), is argued to play a role in creative ideation (Cropley, 2006; Dietrich, 2007; Jaarsveld & Lachmann, 2017; Nusbaum & Silvia, 2011). Empirical evidence is also suggestive of a relationship between Gf and creativity, with several studies finding positive relationships between the two (Beaty et al., 2014b; Cho et al., 2010; Frith et al., 2019; Kim, 2005; Nusbaum & Silvia, 2011). In addition, there is also evidence to suggest that Gf aids in the implementation of useful strategies during ideation. For instance, Nusbaum and Silvia (2011) observed that individuals higher in Gf were more likely to effectively use a helpful strategy given to them by the researchers when performing a divergent thinking task.

With regards to crystallised intelligence (Gc) i.e. breadth and depth of acquired knowledge (Cattell, 1963; McGrew, 2005), several studies have observed positive correlations between this ability and creativity (Batey et al., 2009; Beaty & Silvia, 2013; Cho et al., 2010; Frith et al., 2019; Silvia et al., 2013). As an explanation for why Gc might facilitate creativity, Frith et al. (2019) propose that individuals higher in Gc have a broader range of knowledge and experiences to draw upon which allows them to adopt more novel perspectives and go beyond the conventional meaning of concepts. Likewise, Batey et al. (2009) contends that having an extensive knowledge base is required in order to form associations between different concepts during design ideation.

A final cognitive process of key importance in the ideation process is visual mental imagery, which involves the ability to form a mental representation of a visual entity that is not physically being viewed (Kosslyn & Thompson, 2003). Kosslyn (1995) outlined four different types of mental imagery processes including image generation (forming an image based on recently encountered perceptual input or through long term memory retrieval); image inspection (focusing attention on specific features of an image); image maintenance (holding a representation of the image in memory) and image transformation (modifying features of a mental image e.g. resizing, rotating).

Mental imagery is held to play a key role in creative cognition (Abraham & Windmann, 2007; Finke, 1990; Pidgeon et al., 2016). A range of anecdotal evidence indicates that mental imagery played a key role in the creative process of distinguished individuals in a wide variety of fields including science, music, art and literature (LeBoutillier &

Marks, 2003). However, empirical evidence for the link between mental imagery and creativity was initially unfavourable. For instance, a meta-analysis of the literature by LeBoutillier and Marks (2003) found that self-reported mental imagery ability only explained 3% of the variance in divergent thinking performance, leading the authors to conclude that there was not sufficient evidence for the view that mental imagery processing contributes to creativity.

On the other hand, more recent evidence has suggested that there is a relationship between the two. Palmiero et al. (2015) found that scores on the Paper Folding Task (a measure of visual imagery ability) were positively associated with originality scores on Finke's (1996) Creative Mental Synthesis task. Gilhooly et al. (2007) also found that mental imagery was used by participants in his protocol analysis of the Alternative Uses Task. Furthermore, the importance of a range of behaviours thought to involve mental imagery, such as imagination of events and daydreaming, have also been linked with creative achievement in various domains (Palmiero et al., 2016). Finally, the role of visuo-spatial imagery in creative tasks that require motor planning has also been noted (Aziz-Zadeh et al., 2013; Frith et al., 2019).

In sum, creative ideation appears to draw on a wide range of different cognitive processes including semantic and episodic memory, executive functions, intelligence (fluid and crystallised) and mental imagery processing. It should be noted that this is not intended to give an exhaustive account of the cognitive processes involved in creativity and there may be others which have not been discussed here. Nonetheless, the literature reviewed above highlights that creativity draws on diverse aspects of cognition and aligns with the general perspective that creativity is a complex, higher-order behaviour requiring input from multiple interacting processes (Liu et al., 2018b).

3.2.2 Review of behavioural literature on design ideation

This review now turns to the literature specifically focused on design cognition. As discussed in Chapter 1, much of the knowledge we currently have regarding design cognition is based on protocol studies. The Imagine-D project has published two systematic reviews of protocol studies conducted on cognition in the conceptual design phase of the design process (Hay et al., 2017a; 2017b), of which ideation is a part. The main findings from these reviews will be briefly summarised here, followed by a review of design cognition research on ideation conducted since then.

In the first review conducted by Hay et al. (2017a), which examined 47 protocol studies on conceptual design, one of the key findings was that there was considerable lack of terminological consistency and theoretical cohesion across studies. Similar conclusions have also been drawn by other researchers in the field (e.g. Cash, 2018). Despite such inconsistencies, Hay et al. (2017a) were nonetheless able to identify three broad approaches to the study of conceptual design cognition, which they respectively termed as ‘design as search’, ‘design as exploration’ and ‘design activities’. A brief explanation of each approach is outlined below, though see Hay et al. (2017a; 2017b) for a more in-depth discussion.

‘Design as search’ conceives of conceptual design as a linear progression through a series of knowledge states until a final ‘goal state’ i.e. solution is reached. Researchers from this perspective tend to view the designer as an information processing system that transforms information from input to output via the execution of operators, defined by Stauffer and Ullman (1991) as “fundamental processes of design that are applied to the design state to produce a new state”(p.117). Conversely, in ‘design as exploration’, conceptual design is characterised as iteration between exploration of the problem and exploration of the solution, two processes which are held to interact with one another, such that explorations of solutions leads the designer to change their representation of the problem requirements, which then influences the search of subsequent solutions (and so on; Dorst & Cross, 2001a; Jin & Chusilp, 2006; Maher & Tang, 2003). A final approach known as 'design activities', focuses more generally on the goal-directed actions performed by the designer at both the physical and cognitive level (e.g. Sim & Duffy, 2003). At the cognitive level, Hay et al. (2017a) identified a number of key design activities occurring during the conceptual design process including problem analysis, concept generation and synthesis, and concept evaluation.

In the second review, Hay et al. (2017b) reported that certain cognitive processes were repeatedly identified among protocol studies conducted across the three perspectives, which the authors then used to develop a generic classification of cognitive processes involved in conceptual design. By using standardised definitions of each process (derived from the cognitive psychology literature), the proposed classification aimed to provide a more shared understanding of the cognitive processes involved in conceptual design. Overall, a total of 35 processes were identified, which were broadly placed under 6 categories: (1) long-term memory; (2) semantic processing; (3) visual perception; (4) mental imagery processing; (5) creative output production and (6) executive functions.

Since the publication of the reviews by Hay et al. (2017a; 2017b), subsequent work has further extended knowledge of the key cognitive processes involved in conceptual design. Given that this thesis is focused on design ideation (rather than the entire conceptual design phase), the remainder of this section will focus on recent literature conducted on design ideation specifically. Research in this area has continued to emphasise the importance of long-term memory retrieval during design ideation. In a protocol study by Sarkar and Chakrabarti (2017), it was found that designers most commonly approach a design problem by retrieving an existing product from memory and then modifying it to meet the current problem requirements (a process they refer to as 'find and modify'). Such a process may draw on both semantic memory (e.g. knowledge about a particular product's function) and episodic memory (e.g. information pertaining to specific experiences with a product).

Also demonstrating the importance of semantic associative processes in design ideation, Georgiev and Georgiev (2018) analysed levels of semantic similarity during conversations of design students and instructors while they were engaged in design idea generation. Semantic similarity was measured by the level of semantic relatedness between nouns used during the conversations. Interestingly, conversations that lead to more creative ideas where characterised by greater semantic divergence, in that the semantic relatedness of nouns used between participants increased over time. For non-creative ideas, the opposite effect was observed, i.e. conversations were characterised by semantic convergence. This clearly relates to the well-established notion that more creative ideas tended to stem from associations between distantly related concepts (Mednick, 1962).

There is also growing evidence to indicate that design ideation, like creative ideation, is a top-down, strategically controlled process. For instance, a recent review by Ball and Christensen's (2019) demonstrated how designers continually monitor their own cognition and adopt strategies in order to cope with the ill-structured nature of design problems. An example of this is the adoption of problem framing (selecting specific aspects of the solution to develop and explore; Schon, 1983) which has been identified in many studies on design ideation (Adams et al., 2018; Goel & Pirolli, 1992), and is associated with positive design outcomes (Lloyd & Oak, 2018).

With regards to working memory, a key aspect of executive functioning which has been linked with creativity, this cognitive process has received relatively little attention in the protocol literature on conceptual design, and was not included in Hay et al.'s (2017b) afore mentioned generic classification of conceptual design cognition for this reason. A study by Bilda and Gero (2007) did, however, show that ideation without concurrent sketching led to a significant decrease in cognitive activity over the course of the task (as compared with an 'ideation with sketching condition'). On the basis of this, the authors suggested that ideation overloads visual working memory, and that sketching may provide a key means for offloading working memory constraints. More recently, Dumas et al. (2016) proposed that working memory is important during design ideation given that ideation tasks generally involve simultaneous processing and consideration of a high volume of information. Showing some support for this claim, the authors found that working memory capacity was positively correlated with both fluency and novelty on an engineering ideation task. Overall, while empirical studies examining the role of working memory during design ideation are still somewhat lacking, studies that have investigate this issue have suggested that working memory does play a significant role.

Much recent work has also highlighted the importance of logical reasoning during ideation (Ball & Christensen, 2019; Choi & Kim, 2017; Cramer-Petersen et al., 2019), indicating an important role for fluid intelligence (Gf). Two key forms of reasoning appear to be abductive and inductive reasoning. Abductive is a form of logical inference in which one proposes the best and simplest explanation for a given scenario (Peirce, 1960). In their review of design cognition literature, Ball and Christensen (2019) argue that abductive reasoning and design ideation are closely related in that design ideation involves the generation of 'solution conjectures' i.e. speculative solutions in response to the available information. The 'available information' here refers to the requirements and constraints specified in the design problem.

Inductive reasoning, conversely, involves forming conclusions based on prior knowledge or experience rather that direct observation (Krawczyk, 2018). The use of analogical reasoning during ideation is considered to be a form of inductive reasoning in that the designer uses existing knowledge (e.g. relating to a previous design problem) to inform their understanding of the current problem (Hay et al., 2017b). Highlighting the importance of this, Choi and Kim (2017) found that training design students to engage in analogical reasoning resulted in more creative design thinking (identified through protocol analysis), as well as more transformations and mutations in students' sketches.

The role of relational reasoning i.e. "the ability to discern patterns of relational similarity among multiple pieces of information" (Dumas et al., 2016; p. 53), has also been explored in a design context (Dumas et al., 2015, 2016; Dumas, 2017). For instance, Dumas et al. (2015) found that relational reasoning ability positively predicted originality on an ideation task. Moreover, individuals higher in this ability were more likely to successfully implement an ideation method (TRIZ; Altshuller et al., 1996) during the task. This ties in with Nusbaum and Silvia's (2011) study (discussed in section 3.2.1) showing that individuals higher in Gf were more likely to take advantage of an ideation strategy during divergent thinking.

Researchers have also further sought to explore the importance of mental imagery in design ideation. The role of mental imagery is often discussed in the context of sketching. Goldschmidt (2017), for instance, notes that mental images, though highly useful, are short lived and rely on sketching as a form of 'external memory' to store them. This process is suggested to be interactive in that externalisations then serve to stimulate further explorations of the design problem through mental imagery. In addition, several authors have argued that the inherent ambiguity of visual forms in sketches stimulates mental imagery processes and leads to spontaneous visual discoveries (Goldschmidt, 1991; Liu, 1996; Suwa et al., 2000). As evidence, Goldschmidt (2014) discusses a case study of an architect who discovered the raw outline of a nursery floor plan simply by making repeated sketches of his own signature. In addition, Tseng (2018) observed that expert designers tended to generate more creative ideas when presented with sketch images with increased levels of visual ambiguity. Interestingly, this effect was not found in novice designers, suggesting that the ability to harness visual ambiguity in sketches during ideation is acquired through extensive experience.

Finally, it should be noted that some of the cognitive processes identified as key contributors to domain-general creativity have received very little attention in a design context. For example, there is a lack of knowledge regarding the role of crystallised intelligence (i.e. acquired general knowledge) during design ideation. Much research has focused on the importance of domain-specific knowledge in the ideation process (e.g. Ball et al., 2004; Christensen & Ball, 2016; Cross, 2004), though it is not clear whether more broad knowledge of general facts and concepts unrelated to design can facilitate ideation.

Likewise, the process of inhibition has received relatively little attention in the design literature. This may be due to the fact that it is difficult to detect using protocol analysis, since inhibition can occur automatically (Howard et al., 2014) and the processes involved may be difficult to identify and verbalise. It is theoretically conceivable that either increased inhibition or conversely, decreased inhibition could contribute to ideation. As noted, increased inhibition is thought to be useful in supressing unoriginal or inappropriate ideas (Benedek et al., 2014b), and is also thought to be instrumental in managing interference from irrelevant memory contents that cause fixation (Koppel & Storm, 2014; Smith & Blankenship, 1991). However, there is also the view that disinhibition leads to increased spreading activation and thereby more novel associations being generated (Eysenck, 1995; Martindale, 1995, 1999). Thus, decreased rather than increased levels of inhibition could be more favourable to the generation of design concepts.

In sum, the existing behavioural literature suggests that design ideation relies on a multitude of cognitive processes, many of which have been implicated in general creativity. This suggests that there may be substantial cognitive overlap between design ideation and domain-general creativity. However, it should be acknowledged that even though similar cognitive processes have been implicated in these two forms of creativity, it is not necessarily the case that they are deployed in the same way, or engaged at the same times during the ideation process (see section 3.2.4 for further discussion of this point). Finally, the above review highlights that several processes emerging as key in the creativity literature have been given little attention in design research, such as crystallised intelligence and inhibition. Future research is needed to address whether and how such processes are related to design ideation.

3.2.3 Neuroimaging research on ideation

The behavioural evidence discussed above has undoubtedly shed light on the cognitive processes underlying design ideation. However, behavioural methods on their own may be limited in terms of how much they can reveal about design cognition. Consequentially, a growing number of researchers in the field are recognising the potential benefits of neuroimaging tools in a design context. Neuroimaging investigations can both strengthen and challenge findings from existing behavioural work (Nguyen et al., 2018) and may also lead to the development of more advanced ideation support tools, such as Computer Aided Design (CAD) systems that can directly interact with designers' neural activity (Duffy et al., 2019).

However, as noted by Vieira et al. (2020), neuroimaging research in the design field is in a less advanced stage than in the field of creativity. In the creativity literature many neuroimaging studies have been conducted and there is a relatively comprehensive understanding of the complex brain network dynamics that underlie creative ideation. For instance, using functional magnetic resonance imaging (fMRI), Beaty and colleagues (Beaty et al., 2015; 2016; 2018) have recently revealed three core networks that are of high importance during creative ideation: a) the Default Mode Network (DMN), which is involved in the spontaneous generation of ideas, particularly through the retrieval and combination of semantic and episodic memory contents (Beaty et al., 2020); b) the Executive Control Network (ECN), which underlies top-down aspects of creativity (goal setting, decision making, evaluation); and c) the Salience Network (SN), which mediates communication between these two networks, identifying potential ideas arising from the DMN and relaying them on to the ECN for evaluation. Beaty et al. (2018) found that higher connectivity between these three networks predicts individual creative ability. Their involvement has also been extended to domain-specific forms of creativity such as musical improvisation (Pinho et al., 2016) and poetry writing (Liu et al., 2015).

While there is currently less knowledge on the neural regions and networks underlying design ideation, there has nonetheless been a growing number of studies seeking to address this in recent years. In one of the first fMRI studies examining product design ideation, Goucher-Lambert et al. (2019) found that ideation with accompanying inspirational stimuli (in the form of words) compared to ideation without stimuli was associated with increased activity in semantic processing regions (middle temporal, superior temporal gyrus). This suggested that inspirational stimuli may facilitate semantic search and retrieval processes during ideation.

In a study using a similar experimental design, Fu et al. (2019) also examined the neural regions associated with design fixation (induced by presenting designers with existing example solutions to the problem). Compared to an ideation condition with no examples presented, the 'example' condition was associated with higher activity in the right inferior frontal gyrus, left middle occipital gyrus as well right superior parietal lobule regions including the precuneus. The authors suggested that activation in key visual processing regions (notably the middle occipital gyrus and parietal lobule) may have reflected the fact that in the fixation condition participants spent more effort on processing features of the example solutions. In addition, they suggested that the precuneus activation was due to participants retrieving memories relating to their experiences with the example solution.

The above two studies are highly useful in revealing neural regions associated with ideation-related phenomena such as the role of external stimuli and the neural underpinnings of fixation. However, both studies involved comparing one form of ideation (i.e. with external stimuli) versus another form (i.e. without external stimuli) and so they are limited in the extent to which they can reveal information about the neurocognitive processes involved in ideation per se.

However, the Imagine-D project has carried out two fMRI studies which aimed to uncover the neural regions that contribute to design ideation specifically (Campbell et al., In preparation; Hay et al., 2019a). In Hay et al.'s (2019a) study, professional product design engineers performed a series of open-ended and constrained design ideation tasks, as well as an image manipulation control task. While open-ended and constrained tasks were not found to differ in terms of neural activity, an ideation condition (collapsing across open-ended and constrained tasks) versus the control condition was found to be associated with greater activation in the left anterior cingulate cortex (ACC) and right superior temporal gyrus (STG), though the latter did not meet a corrected threshold. The ACC was argued to be involved in the cognitive control aspects of ideation, given its known role in processes such as inhibition (Braver, 2001) and conflict monitoring (Kerns et al., 2004). Though the STG activation may only be considered a preliminary finding, it has previously been associated with creative insight (Shen et al., 2017) which is a well-documented phenomenon in design (Chandrasekera et al., 2013).

In the second study, Campbell et al. (In preparation) recorded brain activity of professional product design engineers during a series of ideation tasks in which they were asked to generate novel and feasible concepts in response to open ended problems. Brain activity in the ideation condition was contrasted with a 2-back memory task and a mental rotation task, as well as a rest condition. Comparisons between the ideation and all three controls revealed consistent activations in prefrontal areas such as the superior, inferior and middle frontal gyrus, regions which may contribute to aspects of cognitive control during ideation, such as inhibition (Swick et al., 2008) and attentional control (Petrides, 2015). In addition, activations were found in regions such as bilateral lingual gyrus and left fusiform gyrus which are known to play a role in visual imagery (Fulford et al., 2018; Zhang et al., 2014a). Interestingly, these regions were not activated when comparing ideation with mental rotation, further suggesting that they were contributing specifically to the visual imagery aspects of ideation. Finally, consistent activations were observed in the parahippocampal gyrus, a region known to be involved in episodic memory (Reber et al., 2002). This aligns with evidence from the protocol literature suggesting that designers engage episodic memory during design, for instance, when drawing on experiences related to a previous design project (Hay et al., 2017b).

Having examined direct comparisons between the ideation and control conditions, Campbell et al. (In preparation) then explored patterns of functional connectivity in designers using psycho-physiological interactions (PPI), the first study to do so in a product design context. The results revealed interactions between default regions (such as the precuneus) and executive control regions (e.g. superior frontal gyrus), which is consistent with results in the creativity literature suggesting executive-default coupling reflects generation (in the DMN) and evaluation (in the ECN) of ideas. It was also found that the insula (a key hub of the salience network) had interactions with regions in both the DMN and ECN, which supports the view that the salience network mediates communication between the DMN and ECN. The results suggest there may be considerable overlap between neural patterns occurring during design creativity and other forms of creativity, where similar trends have emerged. However, there is much scope to further uncover the nature of functional connectivity during design ideation, as there may be particular regions or patterns activity that are specific to design ideation. Comparisons between different domains of creativity tend to suggest that while there is some neural overlap across domains, domain-specific contributions are also apparent (Boccia et al., 2015; Chen et al., 2020; Zhu et al., 2017).

In addition to fMRI, electroencephalography (EEG) has also been applied in a design context. In fact, there is a longer history of EEG research in the design field, with the first study on design being carried out in the late 1990's by Göker (1997). This study observed that design experts, as compared with novices, tended to show more activity in the right parietal regions during a design problem solving task. The authors suggested this reflected greater use of visual processing by the experts, a finding supported by verbal protocol also suggesting that experts were more likely to use visual strategies.

In more recent years, Nguyen and colleagues (Nguyen et al., 2018; Nguyen & Zeng, 2010; 2012; 2014a; 2014b) have used EEG across a series of experiments which broadly focus on temporal changes in mental states (e.g. effort, stress, fatigue, concentration) throughout the design process, since certain EEG features (e.g. particular changes in frequency range) can be used to indicate the occurrence and intensity of certain mental states. In one study, Nguyen et al. (2018) used EEG to record designers' brain activity across a long ideation session (up to 2 hours) consisting of many different tasks. Mental effort was found to be highest at the beginning and end of the design session. The authors suggested that high mental effort at the beginning reflects an 'ice-breaking' phenomenon such that designers always require high effort at the beginning of an ideation session regardless of task difficulty. The high effort at the end may be more simply be explained as an attempt to overcome fatigue caused by long task duration. Another interesting finding was that concentration levels were the highest during points in the ideation session where designers engaged in partial or full re-evaluation of their design concepts. The observation that design evaluation requires more focus and attention may be taken as support for the notion that evaluation is an executively demanding aspect of the design process (e.g. Kleinmintz et al., 2019).

In addition, EEG has been used to examine changes in neural activity as a function of the type of task presented. For instance, Liu et al. (2018a) found that open-ended and constrained design tasks were found to elicit differences in EEG signal. The open-ended task was found to be associated with increased alpha activity in the frontal, parietotemporal and occipital regions in open-ended as compared with constrained tasks. The authors suggested these cortical lobes may support semantic search and retrieval processes during open-ended tasks. The frontal lobe activity may also indicate increased cognitive control in the open-ended condition. In another EEG study, Vieira et al. (2020) found open-ended versus constrained tasks were associated with higher transformed power (a measure of EEG signal amplitude) in the right occipitotemporal cortex. The authors suggested that this reflected higher conceptual expansion in the open-ended tasks, which involves making conceptual structures more broad and inclusive and is associated with creativity (Abraham et al., 2012; 2018). In addition, higher activity in the right dorsolateral prefrontal cortex (DLPFC) was also observed in the open-ended tasks, a region known to be involved in cognitive control (Miller & Cohen, 2001). Thus, a common finding in the EEG literature appears to be that open ended design tasks are associated with both greater semantic processing and executive control.

In sum, fMRI and EEG have proved to be highly useful methods in increasing our understanding of the neural basis of design ideation and have served to extend and strengthen insight from the existing behavioural literature. They have also increased knowledge regarding how brain activity is influenced by many factors including the presence of inspirational stimuli, design fixation as well as the nature of the design problem (e.g. open-ended versus constrained). It should be acknowledged that the application of neuroimaging methods in a design context is still in its infancy, though this leaves many exciting avenues for further research. For instance, more work is needed to establish whether any key domain-specific neural contributions exist in design ideation (as compared with other forms of creativity). In addition, it could be examined whether patterns of functional connectivity in design ideation change over time (e.g. using temporal connectivity analysis, see Beaty et al., 2015). Finally, along with the general advancement of neuroimaging methods and as more studies are conducted on designers, there is also the possibility that findings can be used to radically improve the support tools available for designers (Duffy et al., 2019).

3.2.4 Literature review conclusion

The review suggests that ideation involves a wide variety of cognitive processes including semantic association, executive processing (e.g. general retrieval; working memory; inhibition), fluid and crystallised intelligence, and mental imagery. The involvement of several of these processes in design ideation can be inferred from much of the behavioural work conducted in a design context, such as studies using the protocol method or analysis of designers' conversations during ideation. A select few processes have been given little attention in the design literature (e.g. crystallised intelligence, inhibition) although the behavioural literature on general creativity gives an indication that they may also be involved in design ideation. Finally, neuroimaging studies have helped shed light on the brain regions and networks that underlie much of these key cognitive processes, as well as give an insight into how such processes may dynamically interact during ideation. Overall, insights from these diverse bodies of literature were used to inform the cognitive processes assessed in the current empirical study.

A salient issue highlighted by this review is that there appears to be considerable overlap between the cognitive processes involved in design ideation and those contributing to general creativity. To some extent, this may be taken as support for the domain-general view of creativity, which argues that all forms of creativity draw on the same cognitive processes (Root-Bernstein & Root-Bernstein, 1999; Simonton, 2007). However, while a similar set of processes may be involved in design ideation and divergent thinking, this does not necessarily mean that they are deployed in the same way across both tasks, or are all involved to a similar degree. For instance, there may be certain processes that are likely more important specifically in a design context, as compared to more general divergent thinking tasks (and vice versa).

For instance, it may be the case that mental imagery is more important in design tasks, given the assumed prominence of the visual modality during design ideation (Dahl et al., 2001), and the fact that ideation often results in the production of an external visual form (e.g. sketch; Goldschmidt, 2017). In addition, simultaneous ideation and sketching (which does not generally occur in divergent thinking tasks) is held to stimulate mental imagery processes (Goldschmidt, 1991, 2014; Suwa et al., 1998). The act of concurrent sketching during ideation may also require a higher degree of motor planning than is necessary for divergent thinking tasks.

In addition, both creativity and design researchers have proposed that executive functions contribute to evaluative processes during ideation (Beaty et al., 2016; Chrysikou, 2018; Hay et al., 2017b; Kleinmintz et al., 2019). In generic divergent thinking tasks, participants may self-evaluate responses in terms of novelty and/or appropriateness (Benedek al., 2014a; Kleinmintz et al., 2019). While these are also relevant in design tasks, additional factors beyond this may also need to be considered such as problem requirements and constraints (Jin & Chusilp, 2006), functional and technical considerations (Shah et al., 2003a) and aesthetics (Chandrasekera et al., 2013). In this sense, design ideation may be overall a more executively demanding task due to the fact that there are more criteria against which outputs must be evaluated. Overall, the above considerations highlight some potential ways in which design ideation may differ from domain-general creativity in terms of the underlying cognition involved. However, it is important to highlight that these are speculative and that further research is needed to examine the issue directly.

3.2.5 Present study

The literature reviewed provides insight into the cognitive processes involved in design ideation, although there is also need for further research in this area, as discussed. As noted at the outset of this chapter, clarity regarding the cognitive processes involved in idea generation is of key importance to this thesis, which aims to test whether a mood induction (performed during an incubation period) can improve subsequent design ideation. The effects of mood during incubation are likely to be dependent on what cognitive processes are involved in idea generation and whether they are enhanced by mood. Therefore, the empirical study reported in this chapter directly investigated this issue, using an approach which aimed to address some of the key limitations with previous design cognition research.

The study involved a large sample of product design engineering (PDE) students performing a series of open-ended ideation tasks as well as a broad range of psychological tests assessing separate cognitive processes. This included tests of associative processes, executive functioning, intelligence (fluid and crystallised), mental imagery and divergent thinking. The cognitive tests were developed within psychology and have been widely applied in previous research as measures of cognitive processing, both within the creativity literature and in cognition research more generally.

Relationships between ideation performance and performance of the cognitive tests were investigated using correlations and multiple regression analysis. Correlations were used to assess the strength and direction of the relationship between the cognitive processes and design novelty, as well as to look at the relationships existing among the various cognitive processes themselves. Multiple regression was used to assess how much variance in design novelty could be accounted for by variance in the cognitive processes. This analysis also gave insight into the relative contribution to variance in novelty made by each individual cognitive process.

Relationships between ideation and the cognitive processes were further assessed using moderation analysis. Moderation occurs when the strength or nature of the relationship between two variables is influenced by another, moderator variable (Dawson, 2014; Memon et al., 2019). By using moderation analysis, such moderator variables can be identified, and thereby reveal under what circumstances a given psychological effect exists, as well as the strength of the effect (Hayes & Rockwood, 2017). In the context of the present study, it was examined whether the relationship between a given cognitive process and design novelty was influenced in some way by another cognitive process.

Based on the existing theoretical and empirical literature reviewed, a number of exploratory hypotheses were made. Firstly, it was predicted that semantic associative processes would be positively related to design novelty, based on the associative theory of creativity (Mednick, 1962) and related empirical work (Benedek, et al., 2012b; Hay et al., 2017b; Kenett et al., 2014). Furthermore, working memory was hypothesised as a possible moderator of this relationship. It has previously been suggested that a higher working memory capacity supports associative processing, in that a greater number of associations can be maintained and manipulated at a given time (Benedek et al., 2014b). Thus, the relationship between association and novelty was hypothesised to be stronger when working memory capacity was higher.

In the executive domain, it was hypothesised that Gr would be positively associated with novelty. Moreover, semantic association was proposed as a moderator of this relationship, in that the benefits of being able to fluently and strategically retrieve concepts (Gr) during ideation was proposed to be enhanced for those individuals who were also more adept at generating a higher number of associations between different concepts. In this way, semantic association was hypothesised to influence the Gr-Novelty relationship. A further proposed moderator was mental imagery. During ideation, designers frequently retrieve existing products from memory and then transform certain details or features of the product (Jin & Benami, 2010). This process of long-term memory retrieval likely involves Gr, though is likely further facilitated by mental imagery processes, including the ability to vividly visualise the product, as well as make complex transformations (e.g. resizing, rotating). Thus, Gr was hypothesised to be more strongly related to novel ideation when mental imagery processing was higher.

Regarding the relationship between inhibition and novelty, there is evidence to suggest that the relationship between the two could be positive or negative. Therefore, moderation effects were hypothesised separately for these two outcomes. The notion that high inhibition is positively related to creativity is put forth in modern executive accounts of creativity which suggest that inhibition allows one to suppress unoriginal and/or inappropriate ideas (e.g. Benedek et al., 2012a; Benedek et al., 2014b). If increased inhibition supports the generation of novel design concepts, there may be several processes that moderate this relationship. Firstly, as well as being able to inhibit ideas that are irrelevant or unoriginal, one also has to be capable of generating alternative ideas that are relevant to the task and are novel. Such a process might be facilitated by Gr, since this involves the controlled, strategic selection of task-relevant concepts in long term memory. It may also be aided by divergent thinking, as this may specifically facilitate the generation of ideas that are more novel and unique, as an alternative to those that have been inhibited. Thus, Gr and divergent thinking were hypothesised as moderators of a positive relationship between novelty and inhibition.

On the other hand, alternative accounts have emphasised that a lack of inhibition may be favourable to creative cognition. For instance. It has been proposed that reduced levels of inhibition lead to increased spreading activation across semantic networks, allowing more remote associates to be accessed (Martindale, 1995). Similarly, Carson et al. (2003) argued that the reduced filtering of stimuli associated with low inhibition may facilitate idea generation. Moreover, they suggested this effect was stronger in individuals with higher intelligence. Thus, assuming a negative relationship between novelty and inhibition in the current study, it was hypothesised that this may be moderated by either or both of the intelligence measures (Gf/Gc).

In the intelligence domain, the importance of Gf in developing and executing strategies during ideation has been observed (Nusbaum & Silvia, 2011). Thus, a positive relationship between ideation and Gf was expected. With regards to the processes that may moderate this, Gr was identified as a possibility as this would allow participants to search and retrieve strategies that were developed and used effectively on previous tasks of a similar nature. In addition, higher working memory capacity could also facilitate in the selection of strategies since one can consider a higher number of strategies at once and also better keep track of previously applied strategies that are no longer effective. Thus, Gr and working memory were hypothesised as moderators of the Gf-Novelty relationship.

Regarding Crystallized intelligence (Gc), it has been proposed that individuals higher in Gc may be more creative since they have a wide and diverse range of concepts to draw upon (Batey et al., 2009; Frith et al., 2019). Thus, a positive relationship between Gc and novelty was expected. However, in order for high Gc to fully benefit novel ideation it could be argued that one also needs to be able to fluently retrieve concepts (i.e. Gr), retain multiple concepts 'online' (i.e. working memory) as well as flexibly combine them (i.e. semantic association). Thus, it was proposed that Gr, working memory and/or semantic association may moderate the relationship between Gc and novelty.

Regarding mental imagery processes, these are widely held to play a crucial role in various aspects of design cognition and so a positive relationship between such processes and design novelty was hypothesised. Furthermore, visual working memory capacity was hypothesised as a potential moderator of this relationship. Previous literature has suggested that the visuo-spatial component of working memory supports mental imagery processing during design ideation (Bilda et al., 2006; Bilda & Gero, 2007). Thus, the relationship between mental imagery and novelty may be stronger when individuals have a high visual WM capacity and are capable of holding and manipulating several images online at once.

Lastly, with regards to divergent thinking, it was difficult to predict whether or not this would be related to design novelty in light of controversy around with the divergent thinking tasks actually bear any resemblance to more domain-specific creativity tasks. However, assuming that there was a positive relationship between the two, Gf was proposed as a potential moderator of this relationship. The rationale for this was that divergent thinking is often emphasised as involving playful, imaginative thought (Zabelina & Robinson, 2010). While design ideation tasks may also require this to some extent, there are also more technical aspects of the task to be considered, such as functional requirements and problem constraints (Shah et al., 2012). It is possible that individuals higher in Gf may be better able to develop strategies to combine more playful, imaginative modes of thought with the more rationale, logical approach that is required for the technical aspects of the ideation task. As such, it was hypothesised that the relationship between divergent thinking and design novelty would be moderated by Gf.

A final aim of the present study was to examine divergent thinking rather than design novelty as the dependent variable. As discussed, divergent thinking is one of the most widely used measures of creative performance in psychology, and indeed there is some evidence for its predictive validity e.g. with respect to real life creative achievement (Beaty et al., 2018). However, divergent thinking as a measure of creativity has received a great deal of criticism. Several theorists have noted that the cognitive processes involved in domain specific fields of creativity are too distinct to be adequately captured by divergent thinking performance (Baer, 1998; Dietrich, 2019). Regarding design specifically, it has been argued that divergent thinking tasks are limited as measures of design ideation performance because they lack certain features that are essential components of design tasks, such as the specification of a problem that needs to be addressed, and the requirement that solutions should have some potential to be realised as functional products (Hay et al., 2019a; Shah et al., 2003a, 2012). Given the controversy around the utility of divergent thinking as a measure of creativity, it was therefore important to examine whether the cognitive processes assessed in this study showed similar relationships with divergent thinking as they did with design novelty. This firstly involved examining whether the above hypothesised moderation effects occurred when divergent thinking rather than design novelty was the dependent variable. Secondly, divergent thinking was examined as a dependent variable in the multiple regression analyses in order to examine a) whether the cognitive processes predicting divergent thinking were the same as those predicting novelty and b) whether the cognitive processes overall explained a similar level of variance in divergent thinking as compared with design novelty. Overall, the above analyses provided insight into whether there were any key differences between design ideation and divergent thinking in terms of their respective cognitive underpinnings.

3.2.5.1 Summary of experimental aims and hypotheses

Aim 1. Assess the strength and direction of relationship between the cognitive processes and design novelty (using correlation analysis).

Aim 2. Assess how much variance in design novelty is accounted for by variance in the cognitive processes, as well as establish the relative contribution to variance in novelty made by each individual cognitive process (using multiple regression analysis).

Aim 3. Examine whether the relationship between a given cognitive process and design novelty was influenced by another cognitive process (using moderation analysis). See table 3-1 for a summary of the specific hypotheses made.

Aim 4. Examine whether the cognitive processes assessed in this study showed similar relationships with divergent thinking as they did with design novelty. This involved examining divergent thinking (rather than design novelty) as the dependent variable in both the moderation analysis and multiple regression analysis.

Table 3-1. Hypothesised moderation effects regarding the relationships between the cognitive processes and design novelty

Cognitive process	Hypothesised moderator(s)
Semantic association	Working memory
General retrieval	Semantic association; mental imagery
Inhibition	General retrieval; divergent thinking
Inhibition (negative)	Fluid intelligence; crystallised intelligence
Fluid intelligence	General retrieval; working memory
Crystallised intelligence	Working memory; semantic association
Mental imagery	Visual working memory
Divergent thinking	Fluid intelligence

Note: Relationships between the cognitive processes in the left column and design novelty are hypothesised to be positive unless stated otherwise (in parentheses).

3.3 Methods

3.3.1 Participants

A total of 101 individuals participated in the study (54 males, 47 females; mean age = 21.1782, SD = .50, range = 18 – 40). Participants were undergraduate (2nd year or above) or postgraduate students of Product Design Engineering (PDE), or individuals who had graduated from a PDE degree within 2 years prior to taking part in the study. The majority of participants were recruited from PDE courses of the University of Strathclyde or the University of Glasgow/Glasgow School of Art. The study was approved by the Department of Design, Manufacturing and Engineering Management Ethics Committee. All participants were reimbursed £30 for taking part in the study.

3.3.2 Tasks and Procedure

After providing informed consent, participants completed a series of cognitive tests and open-ended ideation tasks in a session that lasted approximately 3 hours and 40 minutes. The order in which the tasks were performed was varied across participants.

3.3.2.1 Semantic association tests

Associative fluency

For associative fluency, participants were given 1 minute to type in as many words as possible that were associated with a cue word presented on the computer. Participants were asked to avoid proper nouns and phrases when making responses. A total of 5 cue words were presented ('light', 'red', 'mountain', 'street', 'king), which were taken from the Kent-Rosanoff word association test (Kent & Rosanoff, 1910). These words had previously been selected in a German translation of the associative fluency test (Benedek & Neubauer, 2013), as they were deemed to represent a broad range of semantic concepts and also not likely to elicit dominant associations. Associative fluency was calculated for each participant as the average number of distinct responses made across the five cue words.

Associative flexibility

For associative flexibility, participants were presented with a cue word on the computer and asked to generate a chain of linked words (beginning with the cue word) such that each word was related to the previous one. Two words were presented ('music', 'cold'; Beaty et al., 2014b), with participants again given 1 minute to generate as many responses as possible for each cue, with the exclusion of proper nouns and phrases. An associative flexibility score was calculated for each participant as the average number of distinct responses across the two cue words (Beaty et al., 2014b; Benedek, et al., 2012b).

3.3.2.2 Executive functioning tests

General retrieval ability (Gr)

A verbal fluency test was administered as a measure of Gr (Silvia et al., 2013). In this task, participants were presented with a letter of the alphabet and asked to verbalise as many words as possible that start with that letter within 1 minute. The task was administered twice, using 'A' and 'F' as the cue letters (Benton & Hamsher, 1983) fluency score was calculated for each participant as the average number of distinct across the two letters.

Inhibition

The Simon test (Simon & Wolf, 1963) was administered as a measure of response inhibition (Verghese et al., 2018). In this task, the word 'LEFT' or 'RIGHT' was presented on either the left or right side of a fixation cross in the centre of the screen for up to 5s or until the participant made a response. Participants were required to press the 'a' key if the word 'left' was presented, and the 'l' key when 'right' was presented. The task consisted of 150 trials in total, each one separated by a 1s interval. The tendency for responses to be faster when the stimulus word and position are congruent (e.g. word 'left' presented on the left) compared to incongruent (e.g. word left is presented on the right) is referred to as the Simon effect. For each participant, a Simon effect score was generated by calculating the difference in reaction times between incongruent and congruent trials. Lower Simon effect scores indicate higher levels of inhibitory control.

Participants also completed a computerised version of the Stroop test (Stroop, 1935) administered via Psytoolkit (Stoet, 2010). In this task, names of colours ('red', 'blue', 'green', yellow') were presented on screen for up to 2000ms or (until participants made a response) with each word coloured either red, blue, green or yellow. Participants were asked to press a button corresponding to the colour in which the word was presented ('r' for red words, 'g' for green etc.). There were 100 trials in total, with 20 word-colour congruent trials (e.g. the word 'red' presented in red) and 80 word-colour incongruent trials (e.g. the word 'green' presented in red colour). Response times tend to be slower for colour-word incongruent trials, which reflects inhibition of the prepotent response (i.e. naming the word instead of the colour) in this condition (Friedman & Miyake, 2004; Miyake et al., 2000; Vendrell et al., 1995). The Stroop effect was calculated as the difference in reaction time between incongruent and congruent trials.

Visual working memory

The visual patterns test (VPT) was administered as a measure of visuo-spatial working memory (Brown et al., 2006; Della Sala et al., 1999). Participants were presented with a series of grid-based patterns on a computer screen, with half of the squares filled in black, the other half in white. Each pattern was presented for 3s, followed by a 10s delay during which a black blank screen was presented. After the delay period, a prompt word 'Recall' was presented on the screen, and participants were required to reproduce the pattern on a blank grid from memory, marking an 'X' onto each square they recalled as being black. Prior to completing test trials, participants were given three practice with grids consisting of 4 black and 4 white trials (complexity level 4).

The test trials then began at level 4, with two additional squares then being added to the grid with each increasing level of complexity. For each level, three distinct patterns were presented, and the test continued until participants completed the highest level (15) or failed to correctly recall at least one pattern at a given level. Each participant's overall VPT score was then calculated as the average of the three highest scores (i.e. three most recent correct responses) obtained by the participant. The patterns were presented using E-Prime 2.0 and responses were recorded on paper templates.

Visuo-spatial working memory was also assessed using a computerised version of the Corsi blocks task (Corsi, 1973), administered through Psytoolkit (Stoet, 2010). In this test, a series of pink squares were presented on a black background, with two squares then sequentially changing to yellow for 300ms. Participants were required to then reproduce the sequence by clicking on the squares which changed to yellow in the correct order before clicking 'done' to indicate completion. Participants then received visual feedback on the accuracy of their response. If the correct sequence was entered, participants proceeded to the next level, whereby the number of squares to be recalled increased by increments of one. If participants did not enter the sequence accurately, they were then given two further attempts at that level of difficulty before the test was terminated. Visuo-spatial span was recorded as the highest number of blocks for which the sequence was correctly recalled.

Updating

Updating is an executive function which involves the continuous monitoring and updating of information held in working memory (Jonides & Smith, 1997). A common test used to assess updating is the N-Back test (Benedek et al., 2014b; Kirchner, 1958), in which participants are presented with a series of stimuli and required to continuously maintain the stimuli presented N trials ago in memory. In this study, both the 2-back and 3-back versions were administered, each consisting of 100 trials. For each test, a series of 100 letters from a set of 15 were presented on the screen for 2 seconds each. If participants judged the on-screen letter to be the same as N trials ago, they were required to press ‘m’ on the keyboard. If they judged them to be different, they were required to press n. For both the 2-back and 3-back task, participant’s accuracy was scored as number of correct responses/total number of trials. Both tests were administered using Psytoolkit (Stoet, 2010).

3.3.2.3 Intelligence

Fluid intelligence (Gf)

To obtain a measure of Gf, participants completed Set II of the Advanced Progressive Matrices (APM) (Raven et al., 1998). This set consists of 36 multiple choice items where participants are asked to identify the missing piece which completes a presented pattern. Participants were given a maximum time limit of 40 minutes to complete the 36 items. The total number of correct answers was recorded for each participant.

Crystallised intelligence (Gc)

Gc is often measured using vocabulary tests (Beaty et al., 2014b; Frith et al., 2019). In this study, the National Adult Reading Test (NART; (Nelson, 1982) was administered to assess Gc. This test requires participants to presented read out a list of 50 words which become increasingly unusual and difficult to pronounce. The number of pronunciation errors was recorded and used to calculate a verbal IQ score for each participant (Predicted Verbal IQ = 129 – 0.92*(no. errors)).

3.3.2.4 Mental rotation/imagery tests

Mental Rotation Test

Participants completed a redrawn version of Vandenberg and Kuse's (1978) Mental Rotations test (Peters et al., 1995). In this test, participants were presented with a 3D target shape along with four other shapes, two of which were rotated forms of the target. Participants were tasked with identifying which of the two shapes were rotated versions of the target. The test consisted of 24 items, with a maximum time limit of three minutes per each 6 items.

Vividness of Visual Imagery Questionnaire (VVIQ)

The VVIQ (Marks, 1973) consisted of 16 items in which participants were asked to mental visualise a range of scenarios (e.g. a rising sun) and then rate the vividness of the image from 1-5. Participants' individual score for each item was then summed to give an overall VVIQ score.

Paper Folding Test

In this multiple-choice task developed by Ekstrom et al., (1976), participants were presented with images of pieces of paper which had been folded several times and punched with holes. For each image, participants had to choose from 5 alternatives the image corresponding to how the paper would look when unfolded. A total of 20 items were presented and participants had 6 minutes to complete as many items as possible.

3.3.2.5 Divergent thinking

Participants completed the Abbreviated Torrance Test for Adults (ATTA; Goff & Torrance, 2002; Torrance, 1974) as a measure of divergent thinking. This test consists of three activities (one verbal, two visual/figural). In the first activity, participants were asked to write down as many problems as possible that would result from having the ability to fly or walk on air. In the second activity, participants were presented with incomplete fragments of pictures and required to complete these by adding more details. In the third activity, participants were presented with triangles and asked to add detail in order to generate complete pictures. Each activity had a time limit of 3 minutes. Each activity was scores for fluency (number of distinct responses) and originality (response scored as original if not present on a standard list of frequent responses; Goff & Torrance, 2002). The two figural creativity tests were also scored for elaboration, with a point awarded for each non-essential detail of the completed image. For the final test, a flexibility score was also awarded to reflect the number of different ways the triangles were used to make completed images. In addition to raw scores, participants were also assigned a normalised scale score between 11 and 19 for the above metrics (fluency, originality etc.). These were based on a norming sample of 240 adults (Torrance & Goff, 2002).

3.3.2.6 Ideation tasks

Participants were presented with a set of 10 open-ended concept generation tasks, in which they were given up to 6 minutes to generate and sketch up to three concepts in response to a short design brief (e.g. *Chores such as cooking and cleaning may be difficult for wheelchair users due to space and height limitations. Generate concepts for products that may facilitate domestic chores for wheelchair users.*) An example sketch produced for this task is presented in figure 3-1). For a full list of the 10 ideation tasks used see appendix 1.

The 10 tasks were a subset of a larger series of tasks used in an fMRI study by the Imagine-D project (Hay et al., 2019a). This series of tasks were developed using a number of sources, including student design projects within the University of Strathclyde as well as from activities within the wider design community (e.g. design competitions).

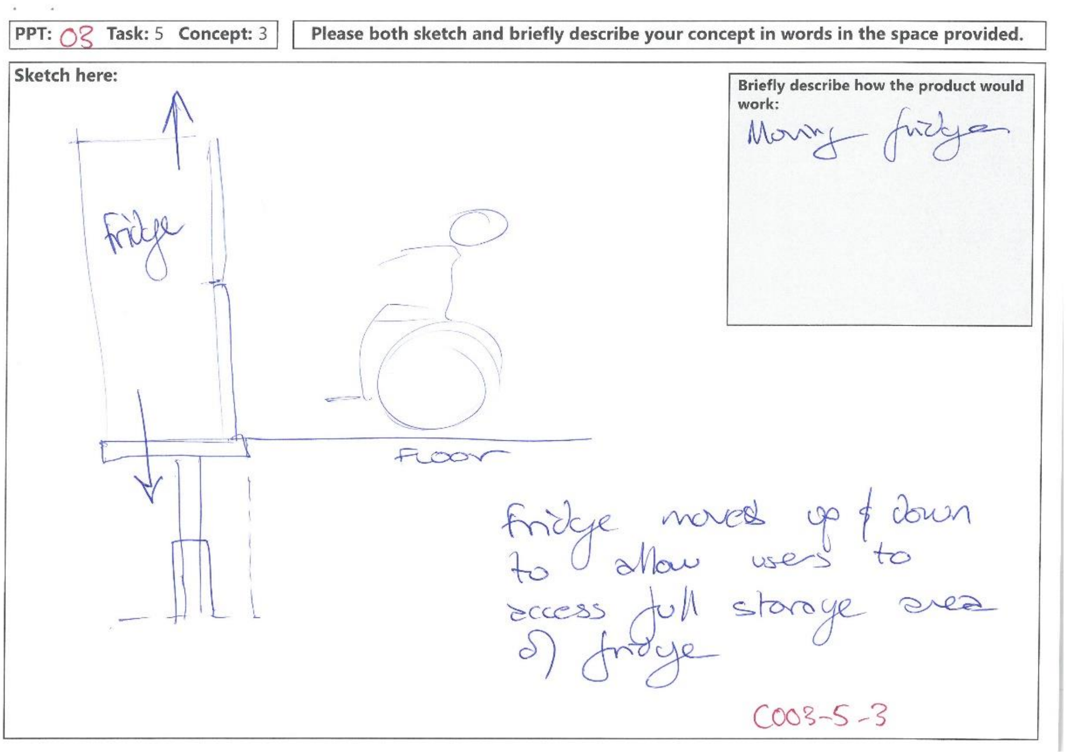


Figure 3-1. Example concept sketch produced by participant in the study

A relatively high number of ideation tasks were used to yield a more robust measurement of participants' ideation performance given that, in general, increasing the number of samples increases the reliability of the data. It was also beneficial in that it gave a reflection of participants' ideation performance across a diverse range of problems, and helped control for variance in domain-knowledge across participants. A 6-minute time limit was set on each ideation task to avoid participants spending a disproportionate amount of time on a given task, as well as to limit the overall duration of the experiment. Finally, the maximum limit of three concepts per task was aimed to ensure the overall number of concepts generated in this study was not too large, given the time and resource intensive nature of the concept assessment procedure (see section 3.3.3).

In five of the tasks, participants were permitted to sketch while they were generating ideas ('sketching combined' condition). In the other five tasks, participants were only permitted to sketch their ideas after mentally generating them ('sketching separate' condition). The latter condition was included as preparation for the aforementioned fMRI study of design ideation which also had participants ideate and sketch separately. Since the goal of the present study was to investigate the cognitive processes involved in design ideation as it naturally occurs, only data from the 'sketching combined' condition were included in the analyses. Data from this condition were deemed to be more ecologically valid since designers typically sketch during ideation. Findings relating to the 'sketching separately' condition will be reported in another publication.

In all tasks, the design brief was presented on a computer screen for 30 seconds or until the participant pressed the space bar. Participants were then required to begin generating a concept in response to the design brief. In both conditions, participants were asked to press 'B' when they had mentally generated a concept, and 'M' when they had completed the sketch. This cycle of generate and complete sketch continued until participants had sketched the maximum limit of 3 concepts, or until the 6-minute time limit had ran out. The order of tasks was randomised across participants, and the order of the separate and combined conditions was counterbalanced across participants.

3.3.3 Novelty assessment of concepts

In order to evaluate the novelty of participants' concepts, a subjective scoring method was used whereby three independent raters (R1, R2 & R3) with design expertise assessed concepts on a scale of 1 (least novel) to 7 (most novel). R1 was educated to masters level (5 years) in PDE, with 5 years experience in postgraduate PDE cognition research. R2 held a bachelors degree in Product Design and Innovation and had 5 years industrial experience in product development engineering. R3 held a bachelors degree in Industrial Design Technology as well as 10 years industrial experience and 26 years teaching experience in product design. R1 assessed the full sample of concepts (n= 937), while R2 and R3 assessed all concepts generated in three of the tasks (n=266; 28.38% of full sample). As a general rule of thumb, a subset of 10% of the full sample is considered sufficiently large for conducting inter-rater reliability analyses (Campbell et al., 2013; Hay et al., 2019b). To assess inter-rater reliability, Cronbach's alpha was calculated, which gives a measure of consistency (i.e. extent to which judges' ratings correlate in an additive manner, Koo & Li, 2016) and can be used with three or more raters (Liao et al., 2010; Multon, 2010). The Cronbach's alpha was .762, indicating a good level of consistency between the raters (Amabile, 1996; Baer et al., 2004).

In several respects, the rating method used for this study was similar to the consensual assessment technique (CAT; Amabile, 1982), a reliable and widely used method of creativity assessment (Baer & McKool, 2009; Carson, 2006; Kaufman et al., 2008a). This approach requires multiple judges to assess participants' responses according to their own subjective definition of the construct being assessed (e.g. creativity, novelty). The judges employed should be "appropriate observers" i.e. "those familiar with the domain in which the product was created or the response articulated" (Amabile, 1982, p.1001). The requirement that judges be experts is important as expert judges tend to show higher agreement ratings compared with non-experts, thus expert ratings are considered more reliable (Kaufman et al., 2008b). A final aspect of the CAT worth noting is that judges are required to rate participants' outputs relative to one another, rather than against some external, standard criteria.

Consistent with this approach, all the judges used in this study had expertise in product design. They were also instructed to use their own subjective definition of novelty, and to use the full scale and rate concepts relative to one another. However, unlike the CAT method, they were also asked to consider products that already exist when making judgements. In addition, the CAT typically involves all judges rating all concepts in the sample. In the present study, this was not feasible due to the large sample size and high volume of concepts produced. While previous studies of design employing the CAT method have had judges rate the full sample of concepts, these studies have typically used sample sizes considerably smaller than the current study (e.g. Christiaans & Venselaar, 2005, n=55; Pektas, 2010, n=46).

3.4 Results

The three main analyses conducted on the data, i.e. correlation, moderation, and multiple regression analysis, are reported in the following sub-sections. Note that the results of the moderation analysis are reported before the main regression analysis because any significant moderation effects were included as predictors in the main multiple regression analysis.

Note that there were a small number of missing values in the data set (n=4) with one participant having not completed the Simon task nor the 3-back task; and two other participants having not completed the Visual Patterns Task. Therefore, any analyses involving these tasks were ran with slightly fewer participants (Simon task = 100; 3-back task = 100, Visual Patterns task = 99).

3.4.1 Correlations

Pearson’s correlations were examined between all measures in the study, and are displayed in table 3-2. This section will focus on the different cognitive processes and their correlations with a) design novelty and with b) divergent thinking. Note that correlations are significant at the $p<.05$ level, and any reference to effect sizes follows Cohen's (1992) conventions i.e. correlations around .1 are weak, those around .3 are moderate, and those around .5 or higher are strong.

Correlations with design novelty

Design novelty was positively and significantly correlated with associative flexibility ($r = 2.49$), Gr ($r=.288$) and Gf ($r=.208$). A significant, positive correlation was also observed between novelty and the Simon effect ($r=.226$). However, since higher Simon effect scores indicate lower inhibition, this correlation actually indicates a negative relationship between novelty and inhibition. All of the above effect sizes were generally in the weak to moderate range. Scatterplots displaying each of the effects are presented in figure 3-2. Note that there was no significant relationship between design novelty and divergent thinking ($r=.052$). Correlations between design novelty and all other measures were also non-significant (all $p<.05$).

Correlations with divergent thinking

Significant, positive correlations were found between divergent thinking and the two measures of semantic association, with a moderate (fluency, $r=.365$) and strong effect size (flexibility, $r=.494$) respectively. The positive correlation between divergent thinking and Gr was significant with weak effect size ($r=.239$). Scatterplots displaying the above effects are presented in figure 3-3. All other correlations with divergent thinking were non-significant (all $p>.05$).

Table 3-2. Descriptive statistics and Pearson's correlations for all measures

	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Design Novelty	3.27	.61	1															
2. Associative fluency	12.21	3.64	.184	1														
3. Associative flexibility	14.02	4.13	.249*	.665**	1													
4. Gr	11.78	3.42	.288**	.327**	.432**	1												
5. Simon effect	23.20	30.71	.226*	-.018	-.069	.040	1											
6. Stroop Effect	88.76	69.54	-.077	.058	.129	-.046	-.104	1										
7. 2-back	.85	.17	-.114	.118	.125	.071	.048	.050	1									
8. 3-back	.77	.14	-.096	.041	.044	.041	-.012	.083	.755**	1								
9. Gf	25.08	5.05	.208*	.094	.046	.249*	.087	-.129	.093	.086	1							
10. Gc	111.35	4.84	.020	.113	.334**	.275**	.091	-.095	.037	.060	.221*	1						
11. VPT	9.99	1.72	.005	-.003	.031	.225*	-.080	0.063	.192	.261**	.357**	.168	1					
12. Corsi blocks	6.43	1..24	-.086	-.081	-.094	-.151	.105	.145	-.094	-.020	.020	.081	.204*	1				
13. PFT	14.92	3.16	-.005	.207*	.209*	.068	.080	.066	.271**	.318**	.332**	.193	.228*	.114	1			
14. MRT	17.26	5.10	-.096	-.051	.119	.206*	-.066	-.063	.073	.163	.319**	.245*	314**.	.136	.352**	1		
15. VVIQ	56.73	9.46	-.043	.042	.030	-.018	-.025	-.002	-.186	-.141	.056	-.138	-.081	-.152	-.255*	-.099	1	
16. ATTA	64.06	7.83	.052	.365**	.494**	.239*	-.189	.170	.017	-.050	-.018	.081	-.050	-.058	.155	-.025	.057	1

VPT, Visual Patterns test; PFT, Paper Folding test; MRT, Mental Rotation Test; VVIQ, Vividness of Visual Imagery Questionnaire; ATTA, Abbreviated Torrance Test for Adults. **, Correlation significant at the .01 level; *, Correlation significant at the .05 level.

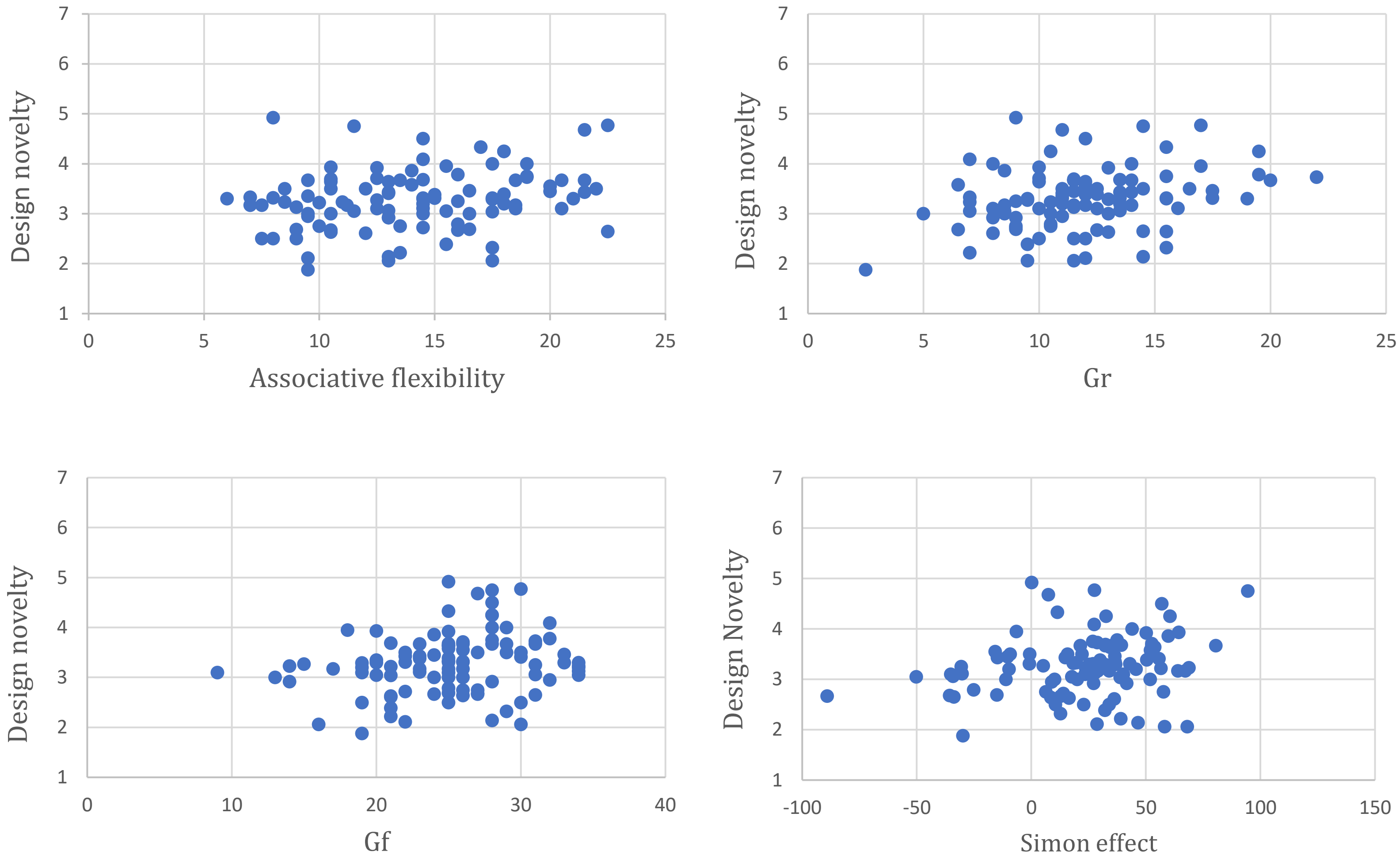


Figure 3-2. Correlations between Design novelty and Associative flexibility, Gr, Gf and Simon effect

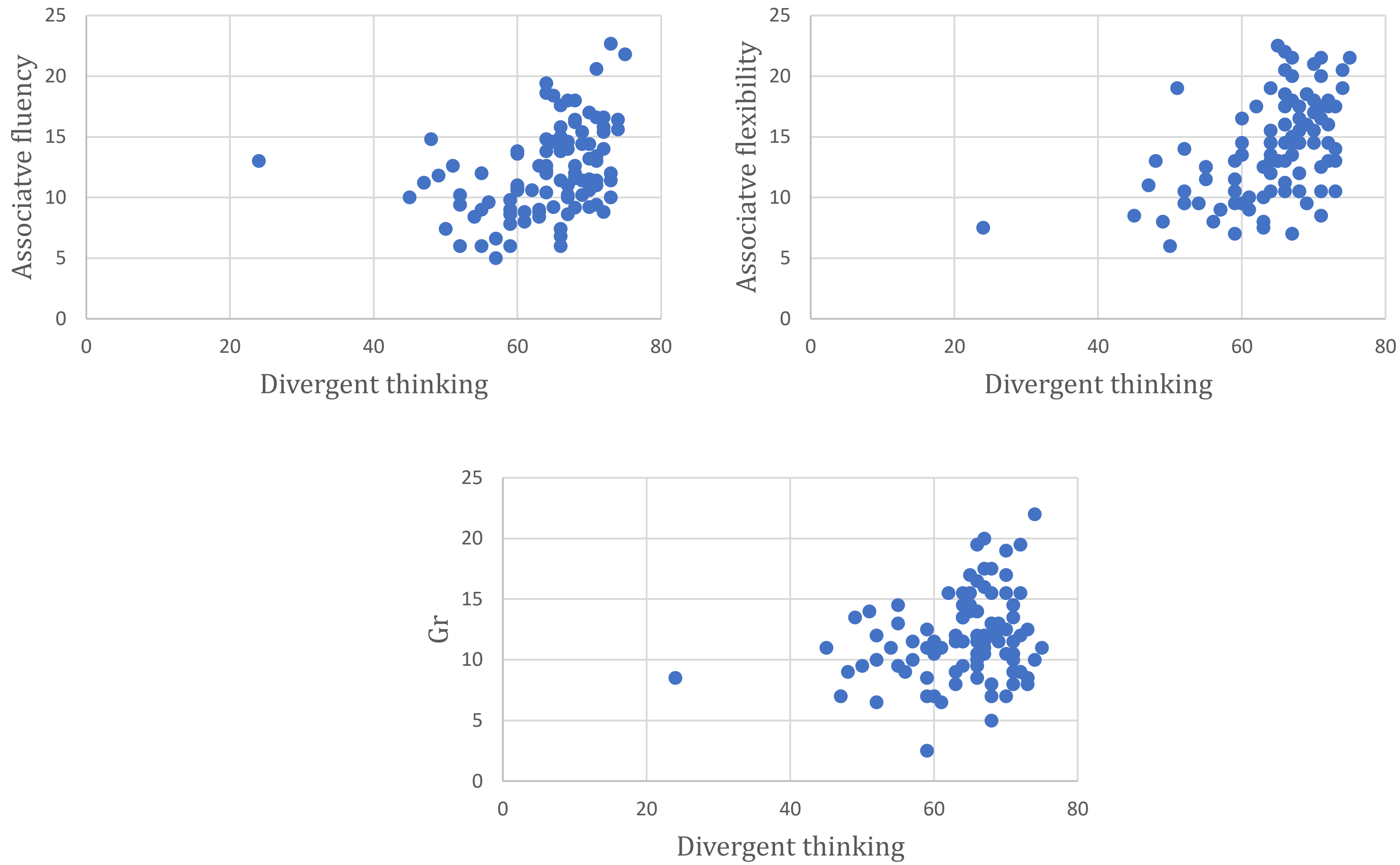


Figure 3-3. Correlations between Divergent thinking and Associative fluency, Associative flexibility and Gr

3.4.2 Moderation analysis

Having examined correlations among each of the cognitive domains, moderation analysis was then explored, with focus firstly on design novelty and then divergent thinking as the dependent variables (DV). This involved use of multiple regression analysis and so it was firstly confirmed that the data met the assumptions for this analysis.

For clarification of terms, note that when reporting the overall significance of regression models, R^2 refers to how much variance in the dependent variable can be accounted for by the regression model (e.g. R^2 =.30 indicates that the model explains 30% of variance in the dependent variable). When reporting the significance of each independent variable (IV; also called predictor) on the model, B, SE_B and β are provided. B values (or unstandardised coefficients) are used to predict scores on the dependent variable based on the predictor variable. Specifically, for every 1 unit increase in the predictor variable, the dependent variable will increase by the value of B (or decrease, where B is negative). Note that B values are unstandardised (i.e. they reflect the original unit of measurement used for that variable) and so cannot be meaningfully compared with other B values). The standard error (SE_B) is a measure of the precision of the coefficients estimate, with smaller SEs indicating higher precision. Finally, β (beta-value) is a standardised version of B, and so can be compared with other β values in order to estimate their relative contribution to variance in the dependent variable.

All tests for moderation were conducted in the same way. Firstly, since moderation can only occur when both the hypothesised independent variable (IV) and moderator variable (M) are significantly associated with the DV, only those processes that were shown to be significantly correlated with the DV were tested for moderation. If the hypothesised IV and hypothesised moderator variable (M) were both significantly correlated with the DV, an initial multiple linear regression analysis was conducted including only the IV and M as predictors. If both predictors were significant, as well as the overall model, a second regression model was generated which included the interaction term between the IV and M as an additional predictor. The interaction term was calculated by multiplying each participants' score on the IV by their score on M. Note that on this second model both the IV and M variables were standardised to reduce high collinearity with the interaction term (Aiken et al., 1991).

The occurrence of moderation was then established by examining if a) the second model with the interaction term explained more variance than the first model (indicated by a significant R^2 change (ΔR2)) and b) if the interaction term was a significant predictor of the DV on the regression model. The presence of both confirmed that significant moderation was occurring, and the effect was then visualised in graph format to facilitate interpretation.

3.4.2.1 Moderation of the relationships between different cognitive processes and novelty

In section 3.2.5, several moderation effects were hypothesised regarding potential moderators of relationships between design novelty as the DV and a number of cognitive processes as IVs. The specific hypotheses are re-stated below and the results of the moderation analyses are reported.

Novelty-Associative flexibility

The correlation analysis revealed that associative flexibility was significantly associated with novelty, as expected. It was hypothesised that working memory may be significant moderator of this relationship. However, since none of the working memory measures were significantly correlated with novelty, the data did not support this hypothesis.

Novelty-Gr

Novelty and Gr were found to be positively correlated. It was proposed that semantic association and/or mental imagery may moderate this relationship. Since none of the mental imagery measures (MRT, PFT, VIVIQ) were significantly correlated with novelty, only the former was examined for moderation.

An initial regression model with Gr and associative flexibility as predictors was significant, R^2 =.084, $F(2,98)=5.56$, $p=.005$. However, the second model with the interaction term included did not result in a significant change in R^2, $\Delta R^2 = .000$, $\Delta F(1, 97)=.002$, $p=.967$. This suggested that inclusion of the interaction term in the model did not account for significantly more variance in novelty score than the first model, i.e. without the interaction term. Thus, the hypothesis that associative flexibility moderates the relationship between novelty and Gr was not supported.

Novelty-Inhibition

The correlation analyses revealed that the inhibition (Simon effect only) was significantly and negatively associated with design novelty. It was proposed that Gf and/or Gc may be potential moderators of a negative relationship between inhibition and novelty. Of these two, only Gf was significantly correlated with novelty and so only this process was tested as a moderator. The initial regression model was significant, R^2 =.084, $F(2,97) = 4.461$, p =.014. However, a further model with the interaction term included did not result in a significant R^2 change, $\Delta R^2 = .023$, $\Delta F(1, 96)$=.2.426, p=.123.Thus, the hypothesis that Gf moderates the relationship between novelty and inhibition was not supported.

Novelty-Gf

Gf was significantly correlated with novelty, as expected. It was hypothesised that this relationship may be moderated by Gr and/or working memory. Working memory was ruled out as a moderator given its lack of significant correlation with novelty. Regarding Gr, the initial regression model with Gf and Gr as predictors was significant, R^2 =.084., $F(2,98)$ =5.599, p =.005, however the second model with the interaction term included did not result in a significant R^2 change and so the hypothesis was not supported, $\Delta R^2 = .013$, $\Delta F(1,97)=1.456$, p=.231.

Novelty-Gc

With regards to Gc, it was proposed that Gc would be positively related to ideation novelty. Moreover, it was hypothesised that Gr, working memory and/or semantic associative processes may moderate this relationship. However, since the correlation between novelty and Gc was non-significant, such hypotheses were not supported.

Moderators of the novelty-mental imagery relationship

It was hypothesised that one or more of the mental imagery measures (PFT, MRT, VVIQ) would be positively associated with design novelty. It was also hypothesised that visual working memory capacity (VPT and/or Corsi) may moderate the relationship between mental imagery processing and novelty. However, since none of the mental imagery processes, nor either of the visual working memory processes, were significantly correlated with novelty, the data did not support these hypotheses.

Novelty-Divergent thinking

It was proposed that divergent thinking may be positively related to design novelty. Moreover, Gf was hypothesised as a potential moderator of this relationship. Since the data indicated no significant correlation between novelty and divergent thinking, these hypotheses were not supported.

3.4.2.2 Moderation of the relationships between different cognitive processes and divergent thinking

Having examined moderation effects with design novelty as the DV, potential moderators were then examined with divergent thinking as the DV. The correlation analyses suggested that only semantic associative processes (both fluency and flexibility) and Gr were significantly associated with Gr. Thus, only these processes were considered for further moderation analyses.

It was originally hypothesised that semantic association may moderate the relationship between design novelty and Gr. While the data did not support this hypothesis, it was examined whether it might hold with regards to divergent thinking, rather than design novelty as the DV. That is, it was examined whether semantic association moderates the relationship between divergent thinking and Gr.

This was firstly tested with Gr and associative fluency. The initial multiple regression model was significant, $R^2 =.132$, $F(2,98) =8.587$, $p =.001$. However, the second model with the inclusion of the interaction term did not result in a significant R^2 change, $\Delta R^2 = .003$, $\Delta F(1, 97)=.390$, $p=.534$.

With respect to Gr and associative flexibility, the initial model was significant, $R^2 =.245$, $F(2,98) =15.910$, $p <.001$. Furthermore, the second model with the interaction term included was also found to result in a significant R^2 change, $\Delta R^2 = .042$, $\Delta F(1, 97)=5.727$, $p = .019$, and the interaction term explained a significant amount of variance in divergent thinking ($B =-.1218$, $SE_B=.051$, $p =.017$). This showed that significant moderation was occurring. The interaction plot (see figure 3-4) suggested that at low levels of associative flexibility, there was a positive relationship between Gr and divergent thinking score. However, at high levels of associated flexibility, there was a negative relationship between Gr and divergent thinking. Thus, associative flexibility had a reverse moderation effect on the relationship between divergent thinking and novelty.

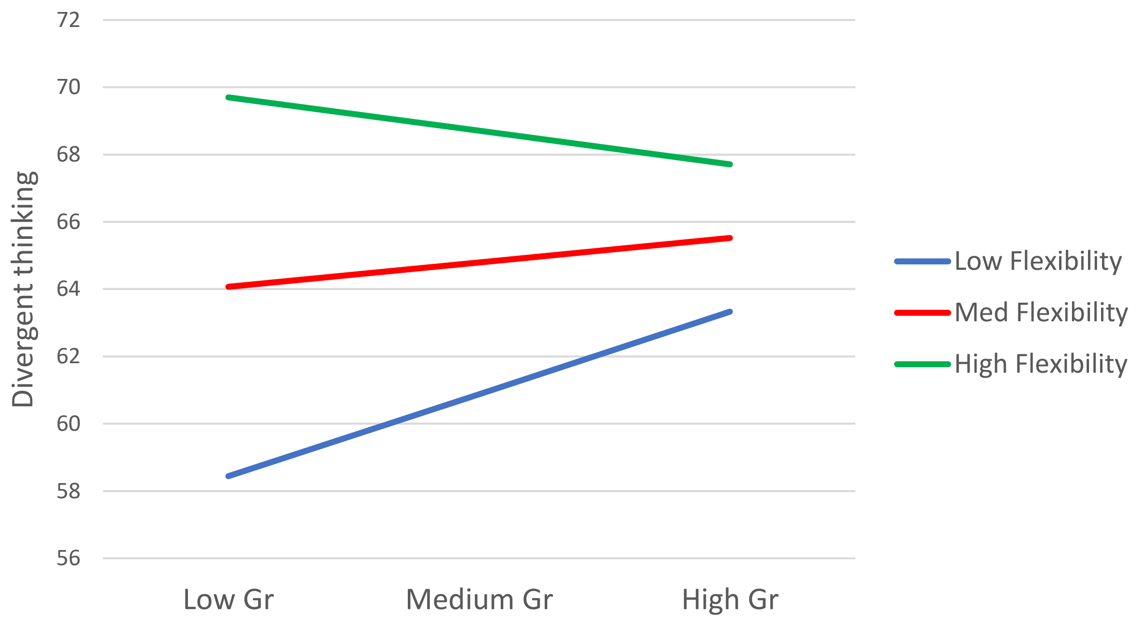


Figure 3-4. The relationship between Divergent thinking and Gr at low, medium, and high levels of Associative Flexibility.

3.4.3 Examination of the variance in novelty scores accounted for by the cognitive processes

Having explored moderation effects, it was then examined how much variance in design novelty could be explained by scores across all of the cognitive measures. To do this, a multiple regression analysis was conducted with design novelty as the DV and all of the cognitive test scores as predictors. However, the 2-back was not included due to its high correlation with 3-back (r=.755), since overly high correlations between independent variables in regression analysis can cause issues with interpreting findings (Johnston et al., 2018).

The overall model was significant, R^2 =.260, F(14, 83) =2.084, p <.021. Results for each predictor, including the unstandardised coefficient (B), standard error of the coefficient (SE_B), standardised coefficient (β) and significance level are presented in table 3-3.

Table 3-3. Unstandardised coefficient (B), Standard error of the coefficient (SEB), Standardised coefficient (β) and significance level for each predictor of design novelty

	B	SE_B	β	p
Associative fluency	-0.014	0.023	-0.085	0.526
Associative flexibility	0.050	0.023	0.342	0.028
Gr	0.040	0.021	0.226	0.058
Simon effect	0.004	0.002	0.213	0.039
Stroop effect	0.000	0.001	-0.037	0.723
Three-back	-0.421	0.468	-0.094	0.370
Visual Patterns Task	0.003	0.040	0.008	0.943
Corsi Blocks	-0.004	0.051	-0.009	0.931
Gf	0.027	0.014	0.221	0.055
Gc	-0.027	0.014	-0.209	0.063
Paper Folding Task	-0.012	0.023	-0.062	0.606
Mental Rotation Task	-0.018	0.013	-0.149	0.194
Vividness of Visual Imagery	-0.009	0.007	-0.139	0.171
Divergent thinking	-0.007	0.009	-0.089	0.437

Design novelty was significantly and positively predicted by associative flexibility (B =.050, SE_B =.023, β=.342, p =.028) and Simon effect (B =.004, SE_B = .002, β=.213, p =.039), again the latter suggesting a negative relationship between inhibition and novelty. The predictors Gr (B =.040, SE_B =.021, β=.226, p =.058) and Gf (B =.027, SE_B

=.014, β=.221, p =.055) were also approaching significance. All other predictors were non-significant (p<.05).

3.4.4 Examination of the variance in divergent thinking accounted for by the cognitive processes

For comparison with the above, it was then examined how much variance the cognitive tests could explain in divergent thinking score, rather than design novelty. A multiple regression analysis was conducted with divergent thinking as the DV and all other measures (except 2-back and Design Novelty) as predictors. The interaction term between Gr and associative flexibility was also included in the model. The model was significant overall, R^2 =.342, F(14, 83) = 3.086, p =.001. Results for each predictor are presented in table 3-4.

Table 3-4. Unstandardised coefficient (B), Standard error of the coefficient (SEB), Standardised coefficient (β) and significance level for each predictor of divergent thinking.

	B	SE_B	Β	p
Associative fluency	-0.051	0.278	-0.023	0.856
Associative flexibility	2.136	0.815	1.121	0.010
Gr	1.905	0.913	0.833	0.040
Associative flexibility X Gr	-0.109	0.061	-1.219	0.075
Simon effect	-0.044	0.024	-0.174	0.068
Stroop effect	0.009	0.011	0.074	0.450
Three-back	-5.683	5.661	-0.098	0.318
Visual Patterns Task	-0.286	0.489	-0.062	0.560
Corsi Blocks	-0.038	0.641	-0.006	0.953
Gf	0.026	0.170	0.017	0.880
Gc	-0.050	0.173	-0.030	0.774
Paper Folding Task	0.358	0.276	0.145	0.198
Mental Rotation Task	-0.168	0.163	-0.110	0.307
Vividness of Visual Imagery	0.064	0.083	0.075	0.442

Associative flexibility (B =2.136, SE_B =.815, β=1.121, p =.010) and Gr (B =1.905, SE_B =.913, β=.833, p =.040) were found to be positive and significant predictors of divergent thinking on the model. All other predictors were non-significant (p<.05). Thus, comparing the above two models suggests that overall, the cognitive tests accounted for a larger portion of the variance in divergent thinking (R^2 =.342) than design novelty (R^2 =.260).

Note, however, that on the design novelty model, ATTA was included as a cognitive predictor, whereas on the divergent thinking model design novelty was not a predictor. For a fairer comparison, a final model was generated with design novelty as the DV without ATTA included as a predictor. This only led to a marginal decrease in the amount of variance explained by the model, R^2 =.255, $F(13,84)$ =2.208, p= .016.

3.5 Discussion

The present study aimed to examine the cognitive processes associated with the generation of novel design concepts. The results revealed that novelty was significantly and positively correlated with associative flexibility, Gr and Gf. The positive correlation between novelty and associative fluency was also approaching significance. In addition, a significant, negative correlation between novelty and inhibition was observed. Notably, there was no significant correlation between novelty and divergent thinking. Thus, while divergent thinking is widely used as a measure of creativity, the results suggest divergent thinking is distinctly different from idea generation in design.

Furthermore, moderation effects were examined, both with design novelty and divergent thinking as the dependent variable. No evidence for moderation effects were found with regards to design novelty. However, the relationship between divergent thinking and Gr was found to be moderated by associative flexibility. Finally, using multiple regression analysis, it was found that 26% of the variance in design novelty could be accounted for by variance in the cognitive test scores. By contrast, a similar model with divergent thinking as the dependent variable suggested that 34.2% of the variance in divergent thinking could be explained by the cognitive predictors. In the following section, the above findings will be discussed in more detail, firstly with focus on each of the cognitive processes assessed and their relationship (or lack of relationship) with design novelty in the current study. Following this, the implications of the findings regarding the influence of mood during incubation will be discussed. Finally, discussion is provided relating to the overall variance accounted for in ideation by the cognitive processes assessed.

3.5.1 Semantic association

Semantic association is one of cognitive processes most commonly associated with creative cognition (Abraham & Bubic, 2015; Beaty et al., 2020; Benedek et al., 2012b). Thus, it is unsurprising that associative flexibility was significantly and positively correlated with novelty, and furthermore, was found to significantly predict novelty scores in the regression model. In addition, the correlation between novelty and associative fluency was also approaching significance ($p=.066$). Finally, both measures of associative processing were significantly and positively correlated with divergent thinking. Note, however, that the hypothesis that the relationship between design novelty and semantic association would be moderated by working memory was not supported by the data.

Overall, the results are consistent with a broad range of findings across the creativity (e.g. Beaty et al., 2014b; Benedek et al., 2012b; Kenett & Faust, 2019) and design literature (e.g. Georgiev & Georgiev, 2018; Jin & Benami, 2010) suggesting that the forming of associations between semantic concepts stored in memory is fundamental to the generation of novel ideas.

3.5.2 Executive functions

The present investigation also examined the relationships between three executive functions (Gr, WM & inhibition) and ideation novelty. Findings relating to each will now be discussed in turn.

Gr

A significant, positive correlation was observed between ideation novelty and broad retrieval ability (Gr), i.e. the controlled retrieval of information stored in long term memory (Carroll, 1993). Gr was also positively associated with divergent thinking, a finding which has been observed in several previous studies (Beaty et al., 2014b; Frith et al., 2019; Gilhooly et al., 2007; Silvia et al., 2013). The hypothesis that the relationship between design novelty and Gr would be moderated by semantic association and mental imagery was not supported. However, associative flexibility was found to moderate the relationship between divergent thinking and Gr, such that at low levels of associative flexibility, Gr was positively related to divergent thinking, but at higher levels of associative flexibility, the relationship between Gr and divergent thinking was negative.

Gr is typically assessed using verbal fluency (as in the current study) and is argued to be a measure of executive functioning in that successful performance requires suppressing interference from previous and/or incorrect responses as well strategic search for sub-categories (which contain relevant items) as well as switching to a new category once the current one has been exhausted (Beaty et al., 2014b; Rosen & Engle, 1997; Silvia et al., 2013; Troyer et al., 1998; Unsworth et al., 2011). Gr is thus held to support creativity through strategic memory search, management of interference from various sources (e.g. inappropriate ideas) as well as switching between strategies (Beaty et al., 2014b; Silvia et al., 2013). While Gr is widely held to be a measure of executive functioning, several theorists maintain that it to some extent involves more automatic semantic spreading activation (Rosen & Engle, 1997; Troyer et al., 1998). For instance, Rosen and Engle, (1997) argue that during verbal fluency tasks, relevant items are accessed via automatic spreading activation in semantic memory (from the cue to related nodes).

However, the moderation analysis suggested a complex relationship between Gr and associative flexibility during creative ideation, at least with respect to divergent thinking (no moderation effects were found for design novelty). Specifically, it was found that at low levels of associative flexibility, Gr facilitated divergent thinking, but at higher levels of associative flexibility, Gr impaired divergent thinking. It is difficult to provide a definitive interpretation of this, but one tentative explanation is that, for individuals who are less capable of generating a high number of associations (i.e. have low associative flexibility), the executive aspects of Gr can compensate for this by allowing concepts to be accessed through strategic search of long term memory and controlled retrieval processes. Conversely, for individuals who are more adept at generating associations between concepts (i.e. have high associative flexibility), the more controlled, strategic aspects of Gr are no longer required and in fact hinder ideation. This can be related to the notion that aspects of executive cognition such as interference management and inhibitory control can, at least under some circumstances, be a hindrance to creativity (see following sub-section on inhibition). However, it is emphasised that this explanation is tentative and that future work is needed to explore the interaction between Gr and associative processing in more depth. Future work should also address why this effect occurs with respect to divergent thinking but not design ideation.

Inhibition

The current study found some evidence to suggest that lower levels of inhibition may be favorable to the generation of novel ideas. This was indicated by the significant positive correlation between Simon effect scores and novelty, as well as the fact that Simon effect scores positively predicted novelty scores in the regression model. Longer Simon effect scores indicate lower levels of inhibitory control, as they show that longer processing times were required to suppress a prepotent response. These findings therefore suggest that lower levels of inhibition may facilitate novel idea generation. However, there was no evidence for the hypothesis that the negative relationship design novelty and inhibition would be moderated by intelligence (i.e. Gf and/or Gc).

The negative novelty-inhibition relationship observed here contrasts with recent accounts emphasizing the important role of inhibition during creative ideation, i.e. in the suppression of inappropriate and/or unoriginal ideas (Benedek et al., 2012a; Benedek et al., 2014b). The findings are more consistent with the view that cognitive disinhibition aids in the generation of novel ideas (Eysenck, 1993; Martindale, 1995). Martindale (1995), for instance, argues that the level of spreading activation across a semantic network depends on an individuals' attentional state. During states of focused attention, only a small number of nodes (which represent concepts) are activated, with other surrounding nodes being inhibited from activating. However, during a state of defocused attention inhibition levels are reduced and activation spreads across nodes in the network. This increased spreading activation caused by disinhibition is assumed to increase the likelihood that novel remote associations will be formed. A similar theory is proposed by Eysenck (1993), however, a key difference between the two theories is that while Eysenck (1993) suggested cognitive disinhibition was a personality trait associated with creativity, Martindale's (1995) account proposes that creative individuals can flexibly switch between states of focused versus unfocused attention in accordance with task demands (Vartanian, 2002).

On the other hand, performance of the Stroop task, which is also a measure of inhibition, did not show any association with novelty scores in the present study. This is likely due to the fact that the Stroop task and Simon task both involve different types of conflict resolution and appear to engage separate inhibitory mechanisms (Egner & Hirsch, 2005; Scerrati et al., 2017; Stürmer et al., 2002). In the case of the Stroop, names of colours are presented on the screen (e.g. 'blue', 'red', 'green'), and participants are required to respond to the font colour in which the words are presented. Participants tend to respond slower on trials in which the word-names are incompatible (e.g. the word 'blue' in red ink) rather than compatible (e.g. the word 'blue' in blue ink). This form of conflict is referred to as stimulus-based conflict (Egner et al., 2007) and reflects an incompatibility between relevant stimuli (i.e. font colour) and irrelevant stimuli (i.e. the colour name). Evidence indicates that successful resolution of this conflict involves a biasing of sensory processing towards task-relevant (as opposed to task-irrelevant) stimuli (Egner et al., 2007; Egner & Hirsch, 2005).

On the Simon task, by contrast, participants are required to respond to the word 'left' using their left hand, and the word 'right' using their right hand (although many variants of the task exist; Luo & Proctor, 2018). Participants tend to respond faster when the stimulus word and spatial location are congruent (e.g. word 'left' presented on the left side) as compared to incongruent (e.g. word 'left' presented on the right side). Thus, conflict stems from incompatibility between an irrelevant stimulus feature (i.e. spatial location) and a relevant response dimension (i.e. location of response button; Scerrati et al., 2017). A common explanation for such 'response-based' conflict (Egner et al., 2007) is that there is a direct pathway of response activation between the irrelevant spatial location and the response set, such that presentation of the stimulus (e.g. on the left side) primes a spatially congruent response (i.e. with the left hand; (De Jong et al., 1994; Egner et al., 2007; Kornblum et al., 1990; Stürmer & Leuthold, 2003). Thus, conflict resolution on the Simon involves suppression of this response in favour of a more indirect route of activation i.e. between the relevant stimulus feature (whether the word is 'left' or 'right') and response set (Egner et al., 2007; Stürmer & Leuthold, 2003).

In short, the Stroop task requires inhibitory control at the sensory-perceptual level, whereas the Simon task requires inhibitory control at the response-making or 'decisional level' (Egner et al., 2007; Scerrati et al., 2017). Therefore, one tentative interpretation of the present findings, which observed a negative relationship only between Simon inhibition and novelty, is that lower inhibitory control at the decisional level is key for the generation of novel design concepts. That is, participants with lower levels of response inhibition (as measured by the Simon task) also generated more novel ideas because they were less inhibited and constrained in their decision-making tendencies, which lead to the exploration of more unconventional and unique perspectives and resulted in more novel outcomes being produced. This interpretation is consistent with the view that creativity is linked with behavioural disinhibition (Eysenck, 1993; Martindale, 1995), as well as evidence suggesting that creative individuals may be higher in impulsivity (Burch et al., 2006; Schuldberg, 2001). However, it is nonetheless speculative and more research is further needed to explore the relationship between disinhibition and novel concept generation.

Working memory

A final aspect of executive cognition that was examined in the present study was working memory. No evidence of a relationship between working memory and ideation novelty was observed here, with neither updating performance nor visuo-spatial working memory capacity showing correlations with novelty. This runs contrary to the general consensus that working memory plays an important role in the creative process. Benedek et al. (2014b), for instance, suggest that higher working memory capacity facilitates associative combination processes in that a higher number of concepts can be held and manipulated during the task. Consistent with this, several studies have found positive associations between divergent thinking and working memory (Benedek et al., 2014b; de Dreu et al., 2012; Oberauer et al., 2008). A number of studies in the design literature have also suggested that working memory plays an important role in the ideation process (Bilda & Gero, 2007; Dumas et al., 2016). For instance, Dumas et al. (2016) observed positive correlations between working memory capacity and both fluency and novelty on a design ideation task.

However, it should be noted that a number of studies have found no evidence for a relationship between working memory and creative ideation (Lee & Therriault, 2013; Takeuchi et al., 2011). In conjunction with the current results, this may suggest that the relationship between working memory and ideation is not straight forward and may be influenced by other variables. For example, one potential reason for the discrepancy between the findings of this study and those of Dumas et al. (2016) relates to differences in task duration between the two studies. In the current study, participants were required to work multiple ideation tasks, each lasting a relatively short duration (6 minutes max), whereas in Dumas et al.'s (2016) study, participants performed one ideation task over a longer duration (50 minutes in total). Therefore, one possible explanation for why Dumas et al. (2016) found that working memory was related to ideation performance is that working memory is more important for longer ideation tasks, since more task-related information accumulates over time and needs to be continuously monitored and processed. This could involve processes such as updating task goals and sub-goals, as well as keeping track of previously generated ideas, all of which could benefit from working memory support. Future work is needed to further explore this possibility as well as to examine other potential moderators of the working memory-ideation relationship.

3.5.3 Intelligence

As discussed in section 3.2.1, theorists tend to distinguish between fluid intelligence (Gf) and crystallised intelligence (Gc). As expected, Gf was found to be significantly and positively correlated with novelty and was also found to significantly predict novelty scores. However, there was no evidence for the hypothesis that this relationship would be moderated by Gr and/or working memory. Finally, regarding Gc, there was no evidence that this was related to design novelty.

Gf refers to the use of logic and abstract reasoning to solve new problems and adapt to novel situations (Jaeggi et al., 2008; Sanginabadi, 2020). Previous studies have observed positive correlations between Gf and divergent thinking (Beaty et al., 2014b; Cho et al., 2010; Frith et al., 2019; Kim, 2005; Nusbaum & Silvia, 2011), suggesting it is important in general creative cognition. Recent reviews focused on aspects of design cognition (Ball & Christensen, 2019; Hay et al., 2017b) have also emphasised that various forms of reasoning, notably inductive and abductive reasoning, play a key role in ideation.

Gf may also assist in the deployment of effective strategies during ideation. Nusbaum and Silvia, (2011) found that on a divergent thinking task, individuals higher in Gf were more likely to successfully use a strategy suggested to them by the researchers before the task commenced. In a design context, Dumas et al. (2016) found that individuals with higher relational reasoning ability more effectively implemented an ideation method (TRIZ) during a design task i.e. such individuals were more likely to generate novel solutions after using the method. Thus, the observed correlation between Gf and novelty in the present study may be due to individuals higher in Gf developing and executing strategies more effectively. However, there may be other mechanisms by which Gf aids ideation novelty and more research is needed to fully explore the relationship between the two.

In contrast to Gf, Gc was not correlated with novelty in the present study. Gc refers to breadth and depth of acquired knowledge (Carroll, 1993; McGrew, 2005). Studies on general creativity tend to find positive associations between Gc and divergent thinking ability (Batey et al., 2009; Beaty & Silvia, 2013; Cho et al., 2010; Frith et al., 2019; Silvia et al., 2013), perhaps because individuals with larger conceptual knowledge have more material to retrieve and combine in order to form novel associations (Batey et al., 2009; Frith et al., 2019). However, Beaty et al. (2014b) found that Gc was less predictive of divergent thinking than Gf, suggesting that fluid intelligence may be more important during ideation.

In the design literature, the concept of Gc has received very little attention, and the present findings suggest that it is not an important ability for the generation of novel concepts. Many researchers have emphasised the importance of a large knowledge base, though this tends to refer to domain-specific knowledge (Ball et al., 2004; Christensen & Ball, 2016; Cross, 2004). For instance, Ball et al. (2004) observed that design experts have a large knowledge base accumulated through years of design experience, and also appear to retrieve and apply design-relevant knowledge more automatically and rapidly as compared with novices. In addition, having design groups in which members have experience and knowledge in different areas of design can positively impact the novelty of ideas generated (Ball & Christensen, 2019; Christensen & Ball, 2016). Such evidence indicates that depth and diversity knowledge is an important factor in design, though it appears to be domain-specific knowledge that is key, rather than the more general knowledge base associated with high crystallised intelligence.

3.5.4 Mental Imagery

The present study found no association between novelty and mental imagery tests (MRT, PFT, VVIQ), which is surprising given that mental imagery is assumed to play a key role in many aspects of creative cognition (Abraham & Windmann, 2007; Finke, 1990; Pidgeon et al., 2016) and design ideation (Athavankar, 1997; Dahl et al., 2001; Hay et al., 2017b). For instance, Dahl et al. (2001) notes that mental imagery "enables the designer to understand the design problem, develop design solutions to the problem, and then evaluate the potential solutions that have been developed" (p6). There is also behavioural (Hay et al., 2017b) and neuroimaging evidence (Campbell et al., In preparation) to support the view that mental imagery is a fundamental part of ideation.

While our results suggest no association between mental imagery and novel idea generation in design, it would be premature to dismiss its importance in the ideation process at this stage in light of the wider literature. It is more likely the case that mental imagery processes are required during ideation tasks, but do not specifically relate to the generation of novel concepts. They may, however, contribute to other design outcomes such as elaboration (i.e. amount of detail in the sketch) or aesthetic value. Thus, there are several avenues of research to explore the potential outcomes that do relate to mental imagery.

3.5.5 Divergent thinking

Finally, the current study found that divergent thinking (assessed by the ATTA; Goff & Torrance, 2002), was not related to novelty scores on the ideation task. Divergent thinking tasks are considered a measure of creative potential, i.e. a person who scores highly on a divergent thinking task is thought to have high potential to produce creative work at some point in their life (Runco & Acar, 2012). Supporting this, there is evidence for the predictive validity of divergent thinking tasks with respect to real life creative achievements (Althuizen et al., 2010; Beaty et al., 2018; Runco, 1986), which may suggest that the cognitive processes involved in divergent thinking are to at least some extent reflective of the cognitive processes involved in domain-specific forms of creativity.

However, only a few studies have examined the predictive validity of divergent thinking tasks in a design context. One study by Casakin et al. (2010) found that the Tel Aviv Creativity Test (TACT; MIlgrim & MIlgrim, 1976) predicted creative problem solving in Architects. Though the TACT is not a widely used measure of divergent thinking in modern creativity research, it does share some key similarities with Torrance Test (participants are encouraged to generate high number of responses, has verbal and figural component). In another study, however, Kwon et al. (2017) found that among scores on the TTCT, RAT and AUT, only the AUT was correlated with performance of an ideation task (generating ideas for bike accessories). While this lead the authors to conclude that only the AUT has predictive validity in the product design field, the fact that participants in this sample were not from a design background limits the conclusions one can draw from this study.

The study reported here found that neither total ATTA scores, nor scores on any individual facets of the ATTA (i.e. originality, flexibility etc.) were related to design novelty. Such a result may be taken as support for critics of divergent thinking as a measure of creativity such as Dietrich (2019), who suggests that the cognitive processes occurring across different domains of creativity are highly diverse and cannot be captured by generic divergent thinking tasks. Other authors have also commented on the fact that divergent thinking tasks fail to take into account the many factors that influence creativity, including education, domain expertise and socio-cultural factors (Baer, 1998; Brown, 1989; Frith et al., 2019; Shah et al., 2012; Silvia et al., 2008).

An interesting question is whether, in light of the present findings, divergent thinking plays any role at all in design ideation. There is some evidence to suggest that designers explore a limited area of the solution space during ideation, selecting one idea early on in the process and refining developing it without consideration of alternatives (Ball et al., 2001; Ball & Christensen, 2019). Such an approach would seem to bear little relationship to the concept of divergent thinking, which places great emphasis in generating a high number of diverse solutions to an open-ended problem (Guilford, 1950).

On the other hand, many design theorists maintain that divergent thinking does play an important part in ideation. Tversky and Chou (2010), for instance, suggest that producing a high number of potential ideas via divergent thinking benefits design ideation in that it increases the likelihood that a novel and practical solution will eventually be realised. Many popular ideation techniques such as brainstorming and 6-3-5 also place emphasis on the free and unconstrained generation of ideas, and likely rely on divergent thinking (Gero et al., 2013). Protocol evidence also suggests that divergent thinking plays an important role in design ideation (Goldschmidt, 2016).

Rather than divergent thinking not playing a role in design ideation, it might rather be the case that the divergent thinking processes that occur in a design domain are different from those that occur in generic divergent thinking tasks, which would explain the lack of relationship observed in this study. This point is discussed by both Frith et al., (2019) and Baer (1998), who suggest that divergent thinking is likely involved in many different forms of creativity, though the nature of such processes may be different across fields; such that, for instance, the divergent thinking processes involved in design are likely to be different from those involved in poetry writing. It might also be the case, however, that other divergent thinking tests such as the alternative uses task, are more predictive of ideation performance than the ATTA. Indeed, this was suggested by the results of Kwon et al. (2017) study as described above. As noted, however, this study did not involve participants with a design background and future work is required to address whether the results can be replicated in a design population.

3.5.6 Implications for the influence of mood during incubation

A key aim of this thesis is to examine the influence of mood during incubation on subsequent design ideation. The present study was a preliminary investigation aimed towards identifying the processes involved in novel idea generation in design and whether these are known to be enhanced, or in any way influenced, by mood. In this section, each of the cognitive processes showing a relationship with novelty will be discussed in terms of how they are influenced by mood. Research examining other, related types of affective state (e.g. emotion) are also included.

Firstly, the findings suggested a role for semantic associative processing during novel ideation, which is noteworthy given that positive moods are widely held to enhance such processes (Ashby et al., 1999; Friedman & Förster, 2010; Rowe et al., 2007). For instance, several theorists contend that moods (both positive and negative) have different signalling functions which affect the individual's mode of cognitive processing (Carver, 2003; Friedman & Förster, 2010; Hao et al., 2015). While negative moods are held to signal danger and restrict attentional scope, allowing the threat to be processed and a solution to be devised, positive moods are held to have the opposite effect, i.e. they broaden attention and facilitate an exploratory and playful mode of processing (Carver, 2003; Friedman & Förster, 2010; Schwarz, 1990, 1994). This broadening of attention is thought to be accompanied by an increase in activation across semantic memory networks, allowing access to a larger range of concepts (Derryberry & Tucker, 1994; Friedman & Förster, 2010). Positive moods have also been linked with unconscious mode of processing, as opposed to negative moods, which are held to promote conscious and analytical thought (see Affective Modulation Framework; Rotteveel & Phaf, 2007). Since unconscious thought is held to be associative in nature (Dijksterhuis & Nordgren, 2006), this further suggests that positive moods facilitate associative processes.

In terms of empirical evidence, one clear indication that positive moods influence associative processing is the observation that positive moods increase semantic priming effects (Corson, 2002; Hänze & Hesse, 1993; Topolinski & Deutsch, 2013). Semantic priming is a well-documented psychological phenomenon whereby exposure to a priming stimulus results in quicker responding to semantically related targets

(Hanze and Hesse, 1993). Semantic priming effects are typically explained in terms of semantic spreading activation, such that activation spreads from the prime to related targets, thereby increasing response times towards to the latter (Neely, 1991; Storbeck & Clore, 2008). In one study, it was found that very brief positive emotion inductions (i.e. a few seconds) increased semantic priming levels compared to negative emotion inductions (Topolinski & Deutsch, 2013). This effect was found to replicate with several emotion induction methods, such as presentation of consonant versus dissonant music chords, and brief exposure to happy versus sad faces. In addition, studies have shown that the RAT creativity task, which is assumed to involve spreading activation, can also be enhanced by both brief positive emotion inductions (Topolinski & Deutsch, 2012), as well as a more a more extended mood induction (Rowe et al., 2007).

Finally, existing theoretical and empirical work on the incubation effect is highly relevant to the role of semantic processes. Specifically, theories of incubation predict that during incubation, unconscious task related processing occurs in the form of associative spreading activation through semantic networks (Dijksterhuis & Nordgren, 2006; Gilhooly, 2016; Seifert et al., 1995). Consistent with this, studies find that incubation tasks that stimulate associative processes tend to be particularly effective in improving subsequent creativity (Baird et al., 2012; Hao et al., 2014; 2015). Notably, the study by Hao et al. (2015) found that brief, positive emotion inductions during incubation improved novelty of responses on the instances task (a divergent thinking task), an effect they suggested was due to positive emotion stimulating spreading activation during incubation.

Overall, the above theoretical and empirical work, in conjunction with the present finding that associative flexibility was associated with design novelty, suggests that inducing positive mood during incubation is likely to stimulate associative processes and increase subsequent novelty scores.

With regards to Gr, which also significantly correlated with novelty in the present study, evidence suggests this too is enhanced by positive mood (Bartolic et al., 1999; Phillips et al., 2002). There is no definitive explanation for why this effect occurs although there are several possibilities. Gr is typically measured using verbal fluency tasks, as in the current study. Bartolic et al. (1999) reasoned that since both positive mood (Davidson, 1979) and verbal fluency tasks (Phelps et al., 1997) have been associated with greater activity in the left hemisphere, the increased cortical activation resulting from positive mood therefore boost verbal fluency performance. In addition, positive moods may improve verbal fluency through enhanced cognitive switching (Ashby et al., 1999). As noted in section 3.2.1, performance of verbal fluency tasks are thought to involve both clustering (retrieving responses from a particular sub-category) and switching (switching to a new-subcategory when the existing one has been exhausted (Troyer et al., 1998). Ashby et al. (1999) suggest that individuals are more adept at flexibly shifting between categories under conditions of positive affect, and thus able to retrieve a higher number of responses on verbal fluency tasks.

Finally, as discussed in section 3.5.2, though widely considered a measure of executive function, verbal fluency is also thought to rely to some extent on semantic associative processes (Rosen & Engle, 1997). As outlined above, it has been consistently demonstrated that positive mood enhances semantic spreading activation, and so it might be the case that positive moods enhance verbal fluency by increasing access to a wider range of semantic associates.

On the basis of the above, it can be predicted that positive mood during incubation will improve subsequent novel ideation through the enhancement of Gr-related processes such as flexible switching between categories when retrieving concepts from long term memory and possibly semantic spreading activation.

The present study also observed that greater interference on the Simon task (i.e. Simon Effect) was associated with higher novelty scores. In other words, it appeared that lower levels of inhibition were associated with higher novelty. Interestingly, there is evidence that positive moods may impair inhibition. For instance Braver et al. (2001) found that performance on the AX-CPT, a measure of inhibitory control, was negatively impacted when participants were briefly exposed to a positive image before each trial. Phillips et al. (2002) also observed that positively induced mood was associated with poorer inhibition performance on the Stroop task, although note that Stroop performance did not appear to be associated with novelty in the present study.

As an explanation for why positive moods impair inhibition, Phillips et al. (2002) pointed towards evidence that positive moods tend to be accompanied by more task-irrelevant thoughts (Seibert & Ellis, 1991) as well as a more diffuse, associative mode of processing (Ashby et al., 1999). While the latter effects may be beneficial on creativity and word association tasks, Phillips et al. (2002) argued, they are likely to disrupt inhibition tasks, which require controlled focus and attention.

In addition to the above, the finding that positive mood broadens the scope of attention is often explained in terms of reduced inhibition (Rowe et al., 2007; Vanlessen et al., 2013; Wang et al., 2011). For instance, Rowe et al. (2007) found that positively induced mood, as compared with negatively induced mood, impaired performance on the Flanker task, which requires participants to focus on a central target while ignoring surrounding distractor stimuli. In the same study, Rowe et al. also observed that positive mood enhanced performance of the RAT, and furthermore, that higher levels of Flanker interference under positively induced mood were correlated with higher RAT performance. On the basis of this finding, the authors suggested that positive mood results in a 'global relaxing of inhibitory control' which serves to widen attentional scope, reduce filtering of information, and facilitate assess to stored, conceptual information in memory. Such a finding would account for why positive mood impairs inhibition but facilitates RAT performance.

The above evidence indicates that a positive mood induction during ideation may lead to lower levels of in inhibition which could in turn result in the generation of more novel design concepts. However, it should be noted that some studies find no relationship between positive affect and inhibition (e.g. Martin & Kerns, 2011), and there is also some evidence to suggest the opposite effect i.e. that positive affect improves inhibition (Aisenberg et al., 2015; Frühholz et al., 2009). Given such inconsistencies in the literature, no definitive hypothesis regarding the relationship between mood and inhibition during incubation can be made.

A final cognitive process found to be positive associated with novelty was Gf, suggesting that logical reasoning may be involved in the generation of novel design concepts. There was some early evidence to indicate that reasoning processes were enhanced by positive mood. Rauscher et al. (1993) found that performance on spatial reasoning tasks was higher after listening to a piece of classical music (Mozart's sonata for two pianos in D Major, K488), as compared with listening to relaxation instructions or silence. While this study did not measure participants' mood, this particular piece is commonly used to induce positive mood (He et al., 2017; Schellenberg et al., 2007), and so the results may be taken as indirect evidence for the view that positive mood improves fluid reasoning.

However, studies more directly investigating this issue have tended to suggest that moods of both positive and negative valence impair reasoning ability (Channon &

Baker, 1994; Jung et al., 2014; Oaksford et al., 1996). For instance, Jung et al. (2014) found that both positive and negatively induced mood resulted in poorer logical reasoning relative to a neutral group, with this effect being most pronounced for negative moods. Several explanations have been put forth to explain why mood interferes with logical reasoning. One possibility is that the mood-relevant thoughts that tend to accompany mood states (whether positive or negative) increase working memory load and therefore leave less resources available for the reasoning task (Baddeley, 2003; Jung et al., 2014). Focusing on the deleterious impact of positive moods, Melton (1995) suggests that individuals experiencing positive moods may wish to maintain this state, and are therefore reluctant to engage in effortful processing of tasks which they may find demanding and unpleasant, such as reasoning tasks. Alternatively, Melton (1995) suggests that people in positive moods may be more impulsive and more likely to stick with their initial answer without further consideration, which was supported by the finding that individuals in positive moods spent less time on reasoning tasks as compared with controls.

Note, however, that in cases where the mood state experienced is highly relevant to the task at hand, the negative effects of mood on reasoning tend to be diminished (Blanchette et al., 2007, 2014; Blanchette & Caparos, 2013; Chang & Wilson, 2004). Explaining why relevance moderates the relationship between mood and reasoning, Blanchette et al. (2014) point towards the finding that emotional or mood-related content (such as those used in typical mood induction procedures) tend to attract attention (Yiend, 2010). Therefore, mood states induced via stimuli that have no relevance to the reasoning task will serve to divert attention away from the task. Conversely, in situations where the mood-related stimuli and the reasoning task are in some way semantically linked, the opposite effect occurs i.e. cognitive resources will be channelled towards the task at hand. In sum, although there is evidence to suggest that moods (positive and negative) can interfere with reasoning processes, this effect may not occur in instances where the mood state experienced and the reasoning task are related.

Overall, the findings suggest that positive mood can enhance some of the key cognitive processes identified as contributing to novel idea generation in this study. There is clear evidence that positive moods improve semantic associative processes as well as Gr. There is also evidence to suggest that positive moods can reduce inhibitory control, which should also be favourable to novel ideation in light of the present findings. However, the relationship between inhibition and mood appears to be inconsistent and so this hypothesis can only be offered tentatively. Finally, regarding Gf, much of the evidence indicates that positive moods impair logical reasoning processes. Although this relationship appears to be complex and dependent on the nature of the task, it is nonetheless possible that positive mood may interfere with Gf-related processes during ideation, which could impact the novelty of ideas produced.

3.5.7 Variance in ideation accounted for by the cognitive processes

Design novelty was the main creativity outcome of interest in the present study. As well as identifying the key cognitive processes associated with design novelty, it is also important to consider the strength of the associations as well as how much variance in design novelty can explained by variance in the cognitive processes. The correlation analyses revealed that among the cognitive processes assessed, only associative flexibility, Gr, Gf and inhibition (negative) were significantly associated with design novelty. Note that the correlations were generally of weak effect size, ranging between $r= .208$ (Gf) and $r=.288$ (Gr) and thereby suggesting only modest associations between these processes and novelty. Furthermore, the multiple regression analysis suggested that together, the cognitive processes accounted for 26% of the variance in novelty. Thus, a considerable portion of the variance was unexplained by the model and it is clear that there are many other factors influencing design novelty which were not examined here. This likely includes factors such as domain-specific knowledge (Shah et al., 2012), personality (Milojevic & Jin, 2019) and motivation (Jeon et al., 2011). A more in-depth discussion on the importance of these factors and their relationship with design cognition is provided in the general discussion section of this thesis (chapter 6).

With regards to divergent thinking, which was also examined as a creativity outcome, only the two semantic association measures and Gr were significantly correlated with divergent thinking. Note, however, that the correlations between divergent thinking and associative processing were in the moderate to strong range (associative fluency, $r=.365$, associative flexibility, $r-.494$). The close relationship between the two, as well as the apparent lack of relationship with other processes (apart from a weak correlation with Gr) may be taken as support for the perspective that semantic association is the fundamental process underlying performance of divergent thinking tasks (Runco, 2004).

It is noteworthy that the correlations between semantic association and design novelty were less strong (with only associative flexibility reaching significance) suggesting that while semantic association may also be involved in design ideation, it plays a less fundamental role here as compared with divergent thinking. It is also interesting that, overall, a broader range of cognitive processes were significantly correlated with design novelty than divergent thinking, which may be due to the more multi-faceted nature of design tasks. As noted in section 3.2.4, performance of design ideation tasks requires consideration of many factors beyond novelty, such as problem constraints

(Jin & Chusilp, 2006), functionality (Shah et al., 2003a) and aesthetics (Chandrasekera et al., 2013).

Regarding the results of the multiple regression analysis with divergent thinking as the DV, this suggested that the cognitive processes (including the interaction between Gr and associative flexibility) accounted for 34.2% of the variance in divergent thinking score. Thus, although the amount of variance accounted for was higher for divergent thinking than design novelty (which was 26%), again the overall variance left unexplained is considerable and suggests an important role for other factors (i.e. personality, motivation). It is also important to consider that certain cognitive processes which have previously been identified as key contributors to divergent thinking (e.g. episodic memory; Beaty & Schacter, 2018) were not examined in the current study, and it is likely that inclusion of such processes would have led to an increase in the variance accounted for by the model.

3.6 Conclusion

The empirical study reported in this chapter aimed to investigate the cognitive processes involved in the generation of novel design concepts. The results showed that design novelty scores were significantly and positively associated with associative flexibility, Gr and Gf, highlighting an important role for these processes during design ideation. Novelty was also found to be negatively correlated with inhibition (as measured by the Simon effect), providing some evidence in favour of the cognitive disinhibition account of creativity (Eysenck, 1993; Martindale, 1995). By contrast, working memory, mental imagery, divergent thinking, and Stroop inhibition were not found to be significantly correlated with novelty. There was no evidence for any moderation effects regarding the relationships between design novelty and the cognitive processes above. However, the relationship between divergent thinking and

Gr was found to be moderated by associative flexibility, such that Gr facilitated Gr at low levels of associative flexibility yet hindered divergent thinking at high levels of associative flexibility. Finally, using multiple regression analysis, this study also found that scores on the cognitive tests were able to explain 26% of the variance in novelty, with associative flexibility and Gf emerging as significant predictors on the model, and the predictors Gr and Gf also approaching significance

Importantly, the results have implications for the impact of positive mood on subsequent design ideation. There is considerable evidence that positive moods enhance semantic associative processes (Topolinski & Deutsch, 2013) and general retrieval ability (Bartolic et al., 1999). Thus, a positive mood induction during the incubation period is likely to stimulate such processes and result in a subsequent improvement in novel idea generation. Furthermore, there is evidence that positive mood impairs inhibition (Phillips et al., 2002), which was negatively associated with novelty in this study (Simon effect only). Therefore, a positive mood induction during incubation may foster a more disinhibited mode of thought that is favourable to the generation of novel ideas. Finally, regarding Gf, which was positively associative with novelty, there is much evidence that positive moods interfere with reasoning processes. While this relationship is not straight-forward and appears to be influenced by a number of factors, such as motivation and mood-task relevance, it is nonetheless a possibility that positive moods may interfere with reasoning processes during design and have a negative impact on the novelty of concepts generated.

Overall, the results suggest that positive moods during incubation could exert a facilitative effect on subsequent idea generation in design and they provide a good basis upon which to formally test this hypothesis in the next chapter.

Chapter 4. The Effect of Mood During Incubation on Subsequent Design Ideation

4.1 Introduction

The findings from the literature review in chapter 3 (section 3.5.6) revealed that certain cognitive processes involved in the generation of novel design concepts are also known to be enhanced by positive mood. This therefore suggests that a positive mood induction during the incubation period, through stimulating these processes, may improve subsequent idea generation. As outlined in chapter 1 (section 1.4), there are several other reasons why mood of the designer may be a key influential factor during incubation. Firstly, there is a wealth of evidence in the psychology literature to suggest that positive moods enhance creativity and cognitive flexibility (Ashby et al., 1999; Baas et al., 2008; Davis, 2009). Secondly, during incubation specifically it has been emphasised that positive moods may induce a more flexible mindset and allow the problem solver to move away from ineffective strategies that set in before the break. This can facilitate the adoption of more novel approaches upon returning to the task (Haager et al., 2014; Morrison et al., 2017). Empirical evidence also suggests that positive moods stimulate unconscious remote associative processes occurring during incubation (Hao et al., 2015).

In sum, there is good reason to propose that a positive mood induction during incubation could be effective in improving subsequent design ideation, but no previous study has examined this. More generally, there is also a lack of understanding regarding the influence of mood on the ideation process. In addition to this, as highlighted by the literature review in chapter 2, relatively few incubation studies have been conducted in a design setting and there is limited understanding on whether incubation facilitates ideation and the factors that may influence this process.

To address this, the present chapter reports an empirical study in which three groups of Product Design Engineering students performed an ideation task with an incubation period during which they received a happy, sad, or neutral mood induction. A fourth group of participants performed the ideation task without any incubation period or mood induction. Ideation performance was compared between the four groups, both in terms of fluency and novelty. This allowed for examination of whether mood during the incubation period has an impact on subsequent design ideation. The study also allowed for a more general assessment of the role of incubation in a design context and whether it is effective in facilitating design ideation.

Before reporting this study, the relevant research literature from a number of key areas will be reviewed. Firstly, an overview of the mood induction procedure is provided, which is commonly used in mood-cognition research and was also employed in the current study. Secondly, theoretical, and empirical research regarding the relationship between creative cognition and mood will be reviewed. This literature, as well as the findings from study 1 (presented in section 3.5.6), gives insight into the potential ways in which a mood induction may influence design ideation during the incubation period. Thirdly, mood research more specifically related to design cognition will be reviewed. While little research has been conducted on this issue to date, some existing bodies of literature give some indication as to how mood may impact subsequent ideation. Finally, studies from the incubation literature that have focused specifically on mood (or related constructs) will be reviewed. For a more general review of incubation studies in creativity and design, the reader is referred to chapter 2 of the thesis.

4.1.1 Exploring the mood-cognition relationship through the mood induction procedure

There are many approaches to the study of the mood-cognition relationship. For instance, clinical studies have focused on common mood disorders (e.g. anxiety and depression) and how they impact various cognitive processes such as attention and memory (see Marvel & Paradiso, 2004; for a review). The application of neuroimaging techniques has also become increasingly popular and has contributed to our revised understanding of how regions traditionally classified as 'affective' (e.g. amygdala) and 'cognitive' (e.g. DL-PFC) are highly integrated and cooperate across a range of tasks (Liu et al., 2009; Pessoa, 2008).

Another common approach, which will be used in the current study, is to induce a particular mood state in participants and then examine the impact of this on subsequent cognitive performance. Many different mood induction procedures have been used by researchers. The Velten method (Velten, 1968) was one of the first mood induction procedures to be used, which involves participants reading a list of positive ('I feel cheerful and lively'), or negative ('People annoy me; I wish I could be by myself') self-referential statements. However, an extensive range of other methods have subsequently been utilised, including listening to music (Clark, 1983; Putkinen et al., 2017), watching videos (Joormann & Siemer, 2004; Rottenberg et al., 2018), recalling autobiographical memories (Mills & D'Mello, 2014; Strack et al., 1985), reading stories (Fartoukh et al., 2014; Watts et al., 2019), as well as manipulation of facial or bodily muscles to mimic the expression of a particular mood state (Fernández-Abascal & Díaz, 2013; Zhang et al., 2014b). It is also common for researchers to use music in combination with another mood induction procedure, e.g. reading Velten statements (Ter Kuile et al., 2010), or engaging in autobiographical recall (Zhang et al., 2014b).

A recent meta-analysis concluded that mood inductions are, in general, effective in inducing the desired mood state (Joseph et al., 2020). Effectiveness is typically established by having participants complete a mood questionnaire before and after the induction and examining whether any change in self-reported mood has taken place.

However, a range of physiological methods have also been used, including heart rate, blood pressure, zygomatic activity, electrodermal activity and respiration rate (Khalfa et al., 2008; Mauss & Robinson, 2009; Ribeiro et al., 2019). For example, Khalfa et al. (2008) found that happy music, relative to sad music, was associated with increased blood pressure, zygomatic activity and electrodermal activity.

Although widely applied and generally observed to be effective, mood induction procedures are not without criticism. In particular, there is controversy around their susceptibility to demand characteristics. The concept of demand characteristics was introduced by Orne (1959) and refers to aspects of the experiment that convey the researcher's aims or hypotheses to the participant, and which may lead the participant to modify their behaviour in line with such aims (McCambridge et al., 2012). Accordingly, it has been argued that, following a particular mood induction, participants only report being in the corresponding mood state because of a sense that the experimenter expects this response (e.g. Buchwald et al., 1981; Westermann et al., 1996). The influence of demand characteristics may be particularly problematic in instances where participants are given overt instructions to 'get into' a particular mood state, which is a common approach in mood research (Joseph et al., 2020).

However, various forms of evidence indicate that mood inductions do indeed result in genuine changes in mood (see Västfjäll, 2001; for an early review). In one study by Kenealy (1988), which explicitly addressed the issue of demand characteristics, participants were given a musical mood induction under one of three conditions: no instructions, demand instructions (i.e. "people generally feel happy/sad listening to this music") and counter-demand instructions, in which they were told people often feel the opposite mood state to the actual one being induced. It was found that in all conditions self-reported mood was consistent with the corresponding mood state (e.g. those listening to happy music reported higher levels of happiness, regardless of instructions). The authors suggested that if experimental demand was a factor of influence, those in the counter demand would be expected to report their mood state as more consistent with the researcher's instructions. Accordingly, it was concluded that "the music procedure is relatively free from explicit demand" (Kenealy, 1988, p.46).

Furthermore, many studies have found mood induction procedures to be effective even when implemented under a 'cover story' in which participants are misled about the true purposes of the procedure. The exact cover story used typically depends on the type of mood induction procedure involved. For instance, several studies using the autobiographical recall method, whereby participants recall and/or write about a happy or sad event from their past, have misinformed participants that the task is aimed to assess their recall ability (Joormann et al., 2012), or that the goal of the study is to create a 'life experiences' inventory (Brand et al., 2007; Schwarz, 1990). A study using music, by contrast, administered the induction under the pretence that it was aimed to block out distracting noises in the environment (Drace, 2013). In some cases, participants may also be told that they are taking part in two separate experiments, e.g. one involving listening to music or watching film clips (mood induction) and the other involving the behavioural measure of interest, which serves to make the connection between the two less obvious (Davis, 2009; Martin et al., 1993; Siemer, 2001). Finally, many studies do not actively deceive participants, but simply avoid giving participants overt instructions to achieve a particular mood state (e.g. Rottenberg et al., 2007). For instance, rather than be asked to 'feel' or 'get into' a particular mood, participants may be simply asked to give their full focus and attention on the presented stimuli. Importantly, Joseph et al.'s (2020) meta-analysis found that mood inductions without explicit instructions still tend to be effective and adding explicit instructions does not necessarily increase effectiveness. Overall, the above evidence suggests that mood induction procedures do result in genuine mood change and contradicts the view that their effects are merely due to demand characteristics.

4.1.2 The relationship between mood and creative cognition

The general consensus is that mood is a highly influential factor on the creative process. For instance, in their meta-analysis of the mood creativity relationship, Baas et al. (2008) stated that mood is "one of the most widely studied and least disputed predictors of creativity" (p.779). Likewise, in a review of the mood-creativity literature, Ashby et al. (1999) stated that "it is now well recognized that positive affect leads to greater cognitive flexibility and facilitates creative problem solving across a broad range of settings" (p.530). Much of the early work in this area was conducted by Isen and colleagues, who over a series of experiments demonstrated that, following a positive mood induction, participants were more likely to generate more unusual responses on a word association task (Isen et al., 1985) and also showed increased flexibility and broader inclusivity on categorisation tasks, tending to group more stimuli together and include more non-prototypical exemplars within a category (Isen & Daubman, 1984). Furthermore, Isen and colleagues found that induced positive mood facilitated performance on a range of creative problem solving tasks, such as Duncker's (1945) candle problem and the Remote Associations Task (RAT; Isen et al., 1987). Since then, evidence has continued to show that positive mood benefits creative performance across a range of tasks and settings, such as in laboratory-based divergent (Campion & Levita, 2014; Fernández-Abascal & Díaz, 2013; Ritter & Ferguson, 2017; Yamada & Nagai, 2015) and convergent (Rowe et al., 2007; Shen et al., 2019) thinking paradigms, as well in organisational and workplace environments (Amabile et al., 2005; Han et al., 2019).

Several theoretical explanations for the link between positive mood and creativity have been put forth. One prominent account, the Dopaminergic Theory of Positive Affect (Ashby et al., 1999; 2002) proposes that positive mood results in an increased dopamine supply to the anterior cingulate cortex, a frontal cognitive control region involved in cognitive set shifting. This in turn is proposed to enhance cognitive flexibility and improve performance on a range of tasks, particularly those which involve creativity. The dopaminergic account has received some empirical support but mainly with respect to the flexibility dimension of creativity (Chermahini & Hommel, 2010; 2012). Moreover, this relationship appears to be non-linear, in that individuals with medium dopamine levels tend to show greater flexibility as compared to those with low or high levels of dopamine (Chermahini & Hommel, 2010; 2012).

Another common explanation for the link between positive mood and creativity focuses on the different signalling functions associated with positive and negative mood. As noted in chapter 3 (section 3.5.6), positive moods are held to signal that the current situation is safe which in turn promotes a more exploratory mode of processing and a broadening of attentional scope (Carver, 2003; Friedman & Förster, 2010; Schwarz & Bless, 1991; Schwarz, 1990). This exploratory approach is also held to be accompanied by increased semantic spreading activation and a broader access to concepts stored in long term memory, allowing for the generation of more novel, unusual associations (Derryberry & Tucker, 1994; Friedman & Förster, 2010). This can be contrasted with negative moods, which signal that the present situation may be dangerous or threatening, thereby fostering a more analytical, constrained mode of processing so that the situation can be assessed (Forgas, 2002; Schwarz, 1990).

There is much evidence that positive moods do indeed increase the breadth of attentional scope as well as facilitate greater access to material stored in long term memory (Ashby et al., 1999; Derryberry & Tucker, 1994; Fredrickson, 2001; Rowe et al., 2007). In a creativity context, Rowe et al. (2007) found that positively induced mood enhanced performance of the RAT creativity task but impaired performance on a visual selective attention task, the latter effect suggesting a broader attentional scope with reduced filtering of stimuli. Moreover, analysis of individual differences in performance under positive induced mood revealed that success rate on the RAT task was positively correlated with levels of impaired selective attention, suggesting that the two effects were caused by a common underlying mechanism. The authors proposed that the finding reflected a general reduction in inhibitory control under positive mood resulting in both a more global attentional scope as well as broader access to conceptual information stored in long term memory.

Despite the wealth of evidence to indicate that positive mood enhances creativity, there is some controversy in this area in that several studies have observed that positive mood impairs creativity (George & Zhou, 2002; Kaufmann & Vosburg, 2002) and negative mood facilitates it (Adaman & Blaney, 1995; da Costa et al., 2020; George & Zhou, 2002; Kaufmann & Vosburg, 2002; Montani et al., 2018; Shen et al., 2019). Furthermore, other studies have found that neither positive (Clapham, 2001; Göritz & Moser, 2003) nor negative (Göritz & Moser, 2003; St-Louis & Vallerand, 2015; Verhaeghen et al., 2005) mood states have any relationship with creative performance. Thus, although the mood-creativity link has received much empirical attention, the relationship is by no means straightforward and many inconsistencies in the literature remain.

A key moderating factor, which may in part explain the inconsistencies in the literature, appears to be the type of creativity task being performed (Baas et al., 2008; Davis, 2009; Friedman et al., 2007; Martin, 2001). As discussed above, positive moods are held to facilitate exploration, play, and the adoption of multiple perspectives, whereas negative moods are argued to foster a more detail-orientated, analytical approach, and engender motivation to rectify an unfavourable situation (Forgas, 2002; Friedman & Förster, 2010; Schwarz, 1990). As a result, it has been proposed that positive moods may be most beneficial on 'fun' tasks which promote enjoyment and 'blue-sky thinking', with negative moods being more conducive to creativity during relatively serious problems, or in situations where there may be strict performance criteria (Baas et al., 2008; Friedman et al., 2007).

Another perspective is offered by Davis (2009) who suggests that while positive moods may reliably increase performance on relatively simplistic divergent thinking tasks, they may have more limited benefits on more domain-specific creativity tasks of the kind typically performed by creative professionals in applied circumstances (i.e. where there is typically a requirement for both novel and feasible solutions). In such cases, Davis (2009) proposes that positive moods exert counter-active effects on ideation because while they facilitate associative processing and cognitive flexibility, they also foster complacency and reduce critical thinking. With regards to negative moods, the opposite effect is assumed to occur (i.e. an increase in more constrained, evaluative cognition but with impaired associative, divergent thought). Thus, the counteractive effects of both positive and negative moods mean that neither results in any overall performance benefit.

The findings of Davis' (2009) meta-analysis provide some support for this perspective. Firstly, Davis (2009) made a distinction between "ideation tasks" and "creative problem-solving tasks". The former comprised tasks which were argued to place emphasis on generating novel responses (e.g. divergent thinking tasks; categorisation tasks) with less need for evaluation. By contrast "creative problem-solving tasks" included tasks which were argued to require both a degree of novel thought but also an ability to generate workable solutions (e.g. Dunker Candle task). With regards to “ideation tasks”, positive moods significantly enhanced performance, yet no effect was observed for negative moods. By contrast, on “creative problem-solving tasks”, neither positive nor negative moods benefited performance, which could potentially indicate counter-active, or incompatible effects of these respective mood states, as discussed. Secondly, Davis (2009) observed that meta-analytical effect sizes derived from non-experimental studies were considerably weaker as compared those based on laboratory studies, thus indicating a less robust mood-creativity relationship in more domain-specific settings. Accordingly, Davis (2009) concluded that “creativity in organizations entails identifying real problems, devising novel and useful solutions, and exerting considerable effort to achieve those solutions. In part then, the robust effects for positive mood in experimental research point to a preponderance of single component ideation tasks used in those studies, whereas comparatively weaker effects of mood in non-experimental settings probably reflect creative tasks involving multiple rather than single components of creativity.” (p. 33).

This has important implications for the relationship between mood and design ideation, since design ideation is a domain-specific form of creativity in which the problems encountered are typically complex and multi-dimensional, and where there is a requirement for solutions that are not only novel, but that also address a specific problem and are capable of being practically implemented. It is possible that, in line with Davis’ (2009) perspective, positive moods could exert counter-active effects on design ideation, enhancing diffuse, associative processes but also impairing analytical, evaluative cognition; in which case there would be no overall impact of mood on design outcomes.

On the other hand, it should be recognised that several studies using more domain-specific tasks have nonetheless observed enhancing effects of positive mood (Amabile et al., 2005; Watts et al., 2019; Yefet & Glicksohn, 2020). For example, Watts et al. (2019) found that low-activating positive moods significantly improved performance on a business-related brainstorming task, which required participants to generate creative ideas to prevent a failing business from going into administration. Another recent study by Yefet and Glicksohn (2020) found that positively induced moods benefited subsequent artistic creativity. These results demonstrate that the enhancing effects of mood can still be observed in more domain-specific settings and highlight that the influence of mood on design ideation is still very much an open question.

4.1.3 The relationship between mood and design ideation

It is also important to examine the existing research on the relationship between mood and design ideation. As noted in the introduction, this is a topic that has received very little attention in the literature. Nonetheless, there are a few lines of research within the literature which may give at least a partial insight into the potential effects of a mood induction during incubation on subsequent design ideation.

The influence of mood on the ideation process has been explored to some extent by researchers investigating creative flow during ideation. The concept of flow, first introduced by Csikszentmihalyi (1975), is defined as “an intense, optimal state of consciousness (also known as being in the zone) resulting from highly focused attention on a task in which perceived skills and challenges are balanced” (Cseh et al., 2015, p. 281). Notably, it is associated with both positive affect (Engeser & Schiepe-Tiska, 2012), as well as increased productivity during ideation (Dorta et al., 2008). Using various self-report methods, a number of studies have attempted to examine fluctuations in various mental states (including flow) throughout the ideation process

(Dorta et al., 2008; 2011; Safin et al., 2016). Such studies have typically found that the early stage of ideation is associated with anxiety, possibly due to the large size of the problem space and lack of certainty regarding potential solutions. However, as the designer begins to generate concepts and approaches the discovery of a candidate solution, they typically enter a state of flow followed by a sense of control and relaxation as a satisfactory solution emerges (Dorta et al., 2008; 2011).

Since flow is associated with the experience of positive affect (Engeser & Schiepe-Tiska, 2012), one possible explanation of these results is that positive affect during flow aids the designer in the discovery of the solution. This interpretation would be consistent with the research reviewed in section 4.1.2 showing a link between positive mood and creativity. However, it is also possible that causality occurs in the opposite direction, i.e. approaching the discovery of a solution leads one to enter a more positive, flow state (Cseh et al., 2015). Indeed, there is evidence to show that the generation of creative ideas causes an increase in positive mood (Amabile et al., 2005; Shaw, 1999) suggesting that the mood-creativity link is bi-directional. The question of whether flow-related positive mood leads to, or alternatively, is caused by the approaching of a solution currently remains unexplored. In addition, no attempts have been made to explore how flow-related positive mood may influence specific performance outcome measures; thus it is not known whether, for instance, experiencing positive mood during flow is associated with the generation of more novel ideas. Overall, findings from design flow research are useful in that they suggest mood and design ideation are closely related and may influence each other, though it is not clear from this literature alone whether a positive mood induction would be likely to enhance ideation novelty.

Another relevant body of research has focused on the relationship between design ideation and humour. Several theorists have proposed that humour production and design creativity are similar processes. For instance, both are held to involve an element of spontaneity and surprise, and involve making connections between seemingly unrelated ideas (Gero, 1996; Hatcher et al., 2016; Yi et al., 2013). Though humour and positive mood are not synonymous, there is some relation between the two constructs. For instance, inducing a humorous atmosphere has been associated with improved mood and enhanced creativity (McGee, 1989). In addition, researchers often use humorous videos as a means of inducing positive mood (Joormann & Siemer, 2004; Rottenberg et al., 2018), highlighting the close relationship between the two. Finally, referring specifically to brainstorming during design ideation, Wodehouse et al. (2014) proposed that a humorous atmosphere is key because it serves to elevate mood and create a more positive group dynamic, encouraging less self-censoring and fear of criticism, and allowing ideas to be more freely generated (see also Stroebe et al., 2010).

There have been some attempts to use humour as a means of improving ideation, either by incorporating aspects of humour production into the design process or attempting to induce a humorous atmosphere using stimuli (e.g. videos). In one study, Kudrowitz (2010) found that engaging in comedy improvisation games resulted in higher fluency on a subsequent brainstorming exercise. Hatcher et al. (2016) also found that improv-based ideation, whereby techniques used in improvisational comedy were incorporated into a group ideation session, improved ideation outcomes relative to classic brainstorming. In another key study, Wodehouse et al. (2014) had participants carry out a group brainstorming session under three conditions: a) classic brainstorming; b) brainstorming modelled on a humour production method and c) video-enhanced brainstorming, whereby participants were exposed to a humorous video before and during brainstorming. Notably, the authors highlighted that the latter condition was designed to induce a fun and humorous mood. The results suggested that structured brainstorming (condition b) was the most effective of all three, resulting in more fluency and originality than the other two groups. By contrast, the video-enhanced intervention appeared to be the least successful. Thus, only partial support for the view that humour could improve ideation was observed.

The lack of effectiveness of the 'video-enhanced brainstorming' condition may argue against using induced mood as a means of improving ideation outcomes. However, the authors highlight that some caution should be taken when interpreting the results due to some limitations with the induction procedure. For instance, they point out that not all participants appeared to be engaged with or react to the video, potentially creating isolation and divisions within the group. This could conceivably have influenced both the effectiveness of the induction, as well as the overall success of the brainstorming session, which relies on a positive group dynamic. The authors also noted that all groups performed video-stimulated brainstorming last, and so fatigue effects may have influenced the results. Overall, while Wodehouse et al. (2014) did not observe a positive effect of humorous stimuli exposure on brainstorming, the majority of studies in this area have suggested that incorporating humour into the design process can improve ideation. Since humour and positive mood are related constructs, such findings may give an indication that a positive mood induction could result in enhanced idea generation.

A final body of research that is relevant focuses on the relationship between mood and creativity in the workplace. Though studies in this area are not typically focused on design creativity per se, they are often conducted with organisations where creating and developing products are key aspects of the work carried out. For instance, in a study by Amabile et al. (2005) participants were employees involved in a variety of projects which included "developing new products" as well as "creating new processes" and "solving complex client problems" (p. 376). Using a combination of self and peer ratings, this study found evidence of a clear, positive relationship between positive mood and creative performance within the organisation. Importantly, the study also found evidence of a mood-related incubation effect, such that positive mood on one day tended to be associated with creativity on the following day, and in some cases, up to 2 days later. Amabile et al. (2005) therefore argued that positive mood increases the breadth of available semantic associations, which then incubate for several days before resulting in the generation of a creative idea. These findings may indicate that mood and incubation are related factors in the design process, although an important point to note is that Amabile et al.'s (2005) findings highlight the importance of mood before the incubation period takes place, rather than the role of mood during the incubation period, which is the focus of this thesis.

A similar study by George and Zhou (2002) was carried out with a helicopter manufacturing organisation, specifically in a department "charged with developing creative designs and manufacturing techniques" (p. 691). In this study, employees reported their mood (in the past week), and their clarity of feelings (i.e. awareness of one's affective state), as well perceived rewards for creativity in the workplace. Creative performance was measured via supervisor ratings. Interestingly, the relationship between mood and creativity was found to be moderated by both clarity of feelings and perceived rewards. For instance, when both clarity of feelings and perceived rewards were high, negative moods were positively related to employee creativity. This suggested that in situations where creativity is a rewarding outcome, negative mood may signal that the current situation is unsatisfactory and encourage the generation of novel solutions which can improve the status quo and bring about reward. This, of course, can only occur when participants are aware that they are experiencing negative mood. Conversely, when perceived rewards were high and recognition was low, positive moods rather than negative moods were linked with higher creativity. The authors suggested that when creativity is a key goal, but one is not clear on their current mood state, positive moods may nonetheless enhance creativity by influencing relevant cognitive processes (i.e. cognitive flexibility, associative spreading etc.; Ashby et al., 1999).

Overall, findings from the above research suggest that both positive and negative moods may, at least under certain circumstances, influence design cognition. The results from Amabile et al.'s (2005) research may also point towards an important relationship between positive mood and incubation in the ideation process. However, it does have to be emphasised that both studies included individuals from a variety of professions, and also used a broad measurement of creativity which was not focused specifically on the generation or development of novel design concepts. Thus, only a limited insight into the relationship between mood and design ideation may be obtained from this research.

4.1.4 The role of mood during the incubation period

Having looked at the general literature on mood and creativity, as well as mood and design creativity, it is also important to look at existing literature concerning the influence of mood specifically during incubation. Interestingly, several anecdotal accounts from highly creative individuals, which have been a source of inspiration for much of the incubation research conducted, may indicate a role for positive mood during the incubation period. For instance, Amabile et al. (2005) note the cases of Poincaré, who reported that most of his major breakthroughs occurred when relaxing on vacation, and Mozart, who similarly reported that his creative ideas came most abundantly when performing enjoyable recreational activities unrelated to his profession, such as walking and travelling.

In terms of contemporary theoretical perspectives, there have been some suggestions that positive mood during incubation may relieve fixation on a creative problem (Haager et al., 2014; Morrison et al., 2017). For instance, Morrison et al. (2017) argue that in the initial stage of problem solving, participants may become frustrated due to fixation and inability to make progress on the problem, resulting in negative mood. They suggest that the distraction from fixation provided by incubation may cause a shift from negative to more positive mood, which in turn favours subsequent creativity because it broadens attention and engenders a more flexible mind set.

There is also some empirical evidence to suggest that positive moods during incubation may help overcome fixation on a learned mental set (Haager et al., 2014). In this study, participants first worked on a series of number reduction problems, which could only be solved by the application of a given rule. Following this, participants were then given an ostensibly unrelated task which was actually designed to induce positive or negative mood. Following the induction task, participants then worked on a new set of number reduction problems which, unknown to the participants, could be solved either by the application of the previously learned rule or by a new, quicker method. The results revealed that, as compared with the negative mood condition, participants who received the positive mood induction were significantly more likely to abandon the old rule in favour of the newer, simpler strategy. In other words, the positive mood group showed a less fixated mindset following the induction. Haager et al. (2014) suggested this effect was due to the fact that positive mood broadens attention and increases cognitive flexibility, allowing more novel strategies to be adopted even in instances where workable and well learned methods are already established.

A key point, noted by Haager et al. (2014), is that the findings may point towards an important role for mood during the incubation period, since their study design was somewhat similar to an incubation paradigm, i.e. consisted of two problem solving phases separated by a break during which an unrelated task was performed. As acknowledged by the authors, the study was not strictly an incubation paradigm, since a different set of problems were presented before and after the mood induction and each set could be solved using different strategies. Nonetheless, the findings may give some indication that positive moods induced during incubation could reduce fixation on a previously learned mental set. Importantly, this may have implications for design ideation, where fixation has been noted as a pervasive obstacle to creativity (Crilly & Cardoso, 2017; Vasconcelos & Crilly, 2016). It may be that positive moods during incubation could help overcome design fixation by increasing cognitive flexibility and facilitating the adoption of more novel perspectives and strategies.

Aside from fixation, other research focusing on the effects of reward on creativity may also give some insight into the role of mood during incubation. In a recent study by Zhang et al. (2019), three groups of participants carried out a Chinese version of the RAT as the main task, with an incubation period in which a spatial rotation task was performed. One group were given a reward notification at the end of the first task phase (i.e. immediately before incubation), stipulating that if a certain success rate was achieved on the RAT task a monetary reward would be given. The second group received the same notification, but at the end of the incubation period (i.e. immediately before returning to the main task). A third group did not receive any reward notification. The results found that only the group who received the notification before incubation period showed a significant increase in RAT performance post-incubation. There are several explanations for this finding. One explanation is that individuals receiving the notification before incubation may have been motivated to consciously work on unsolved RAT problems during the incubation task. However, the fact that there were no significant differences in performance of the incubation task across groups suggests that this was not the case. The authors also consider the possibility that monetary reward may have a detrimental impact on creativity (e.g. due to excessive levels of extrinsic motivation), and so the incubation period provided time for such influences to fade, relative to the group who received the notification immediately before returning to the RAT task. One possibility that is not fully considered by the authors, however, is that the reward notification before incubation may have induced positive affect, which stimulated unconscious, remote associative processes during incubation. Indeed, the presentation of reward is a common method for inducing positive affect (Nusbaum et al., 2018) and has been shown to enhance creativity (Isen et al., 1987). While this explanation is plausible, it can only be speculative since participants' affect levels were not measured in the study.

Finally, only one study to date has directly examined whether manipulating affect during the incubation period can influence subsequent creativity (Hao et al., 2015). In this study, Hao et al., (2015) assessed the influence of various mood inductions (positive, negative, neutral) during a short incubation period (30 seconds). The divergent thinking task used was the instances task (Wallach & Kogan, 1965), whereby participants are required to generate exemplars from a given category (e.g. list as many things as possible that are round). Overall, performance was higher in the three incubation conditions as compared to a control condition (i.e. no incubation), showing a general incubation effect. However, the positive incubation condition was found to be most effective in enhancing subsequent response novelty. The authors interpreted this finding within the Unconscious Work theory of incubation, arguing that positive emotions increase the breadth of semantic spreading activation during the incubation period, thereby facilitating remote associative processes and long-term memory retrieval. While this evidence suggests that positive affect is an important factor during incubation, the findings cannot be assumed to generalise to the domain of design ideation, which as previously discussed, has several differences with general divergent thinking.

4.1.5 Literature review conclusion

The evidence reviewed here, in conjunction with the findings from study 1 (reported in section 3.5.6), overall suggests that a positive mood induction during incubation could have a beneficial impact on subsequent design ideation. Evidence from the general mood creativity literature suggests that positive moods can improve cognitive flexibility and novel thinking. In the design literature, while there is a lack of evidence directly investigating this issue, some of the existing research does indicate that positive moods may enhance design ideation. Finally, with regards to the incubation literature specifically, there is both direct (Hao et al., 2015) and indirect (Haager et al., 2014; Zhang et al., 2019), evidence to suggest that positive mood during incubation improves subsequent creative cognition.

It is important to also consider the potential importance of negative moods during the incubation period. Negative mood states tend to foster an analytical, detail-orientated approach which can aid in identifying and solving problems (Forgas, 2002; Schwarz, 1990). They have also been linked with evaluation and critical thought (George & Zhou, 2002). Thus, it is plausible that negative moods could also have a beneficial impact on subsequent ideation performance.

However, it has to be emphasised that there are considerable inconsistencies in the mood-creativity literature, with some studies showing that neither positive (Clapham, 2001; Göritz & Moser, 2003) nor negative moods (Göritz & Moser, 2003; St-Louis & Vallerand, 2015; Verhaeghen et al., 2005) have any relationship with creative performance. Moreover, Davis (2009) notes that in the case of domain-specific creativity tasks (particularly those which require practical solutions), both positive and negative moods may have counter-active effects on ideation. Specifically, positive moods may facilitate associative processing and cognitive flexibility, but impair evaluation and critical thinking. With regards to negative moods, the opposite effect may occur (enhanced evaluation but impaired divergent thinking and flexible thought etc.). Therefore, there is the possibility that neither positive nor negative moods will have a beneficial impact on subsequent ideation.

Finally, aside from mood, an important aim of this study is simply to examine whether incubation *per se* has a beneficial impact on subsequent design ideation. As highlighted by the literature review in chapter two of this thesis, incubation has received much empirical support but most of this is from studies using generic creativity tasks and general problem-solving tasks. Therefore, there is a lack of knowledge regarding how effective incubation is in a design context, where the problems involved are typically complex, sophisticated, and multi-dimensional. Among the few design incubation studies that have been conducted, mixed results have been observed, with some finding that incubation improves ideation outcomes (Al-Shorachi et al., 2015; Starkey et al., 2020) and others showing limited or no incubation effects (Cardoso & Badke-Schaub, 2009; Tsenn et al., 2014). More generally, it also needs to be acknowledged that several studies in the creativity literature have reported no incubation effects (e.g. Carruthers, 2016; Dorfman, 1990; Torrance-Perks, 1997) or have only observed them under specific conditions (e.g. Beck, 1979; Vul & Pashler, 2007), further highlighting that incubation is by no means effective in all circumstances. The above highlights the need to investigate whether incubation in general has a beneficial impact on subsequent ideation.

4.1.6 Present study

To address the above, in the following empirical study four groups of designers generated ideas in response to an ideation task. Three of the groups were given an incubation period halfway through the ideation task, during which they were administered either a happy, sad, or neutral mood induction. The fourth group (control) continuously worked on the ideation task and were not given an incubation period nor a mood induction.

During the happy and sad mood inductions, participants received a combination of the Velten and music mood induction procedures. Thus, participants read a series of happy or sad self-referential statements while listening to mood-appropriate music. In the neutral condition, participants read a series of sentences and listened to music which previous research has found not to significantly influence mood. For simplicity, this procedure is referred to as 'neutral mood induction' (as is common in the literature), though it should be clarified that there was no attempt to induce any particular mood state (e.g. 'neutral mood') in this condition. The Velten and music procedure was deemed to be a suitable for the current study given that in real life designers may engage in similar activities during the incubation period, such as listening to music or reading text. In addition, previous studies investigating the mood-creativity link have found music to be effective in terms of stimulating subsequent to creativity (Adaman & Blaney, 1995; He et al., 2017; Ritter & Ferguson, 2017).

Broadly, the study had two aims: to investigate the general impact of incubation on design ideation, as well as to assess the influence of mood during the incubation period on subsequent ideation performance. To investigate any general incubation effects, ideation performance (assessed by fluency and novelty) was firstly compared between the control group who worked on the task continuously and the neutral incubation group. In line with the wider literature on incubation and creative problem solving, it was hypothesised that following the incubation period, the neutral incubation group would show higher fluency and novelty than the control group. To assess any additional influence of mood on incubation, ideation performance between the three incubation groups was then compared. On the basis of the results of study 1 (presented in section 3.5.6), as well as the literature reviewed it in the current chapter, it was hypothesised that the happy induction group would have higher performance than the other two groups following the incubation period. In the following sections, the methods and results of this empirical study are reported. Following this, a discussion of the findings is provided.

4.2 Methods

4.2.1 Participants

A total of 73 participants took part in the study (46 males, 28 females; mean age = 21.47, SD =3.19, range = 19 – 41 years). One participant's data were removed from the final analysis due to non-compliance with the ideation task instructions. Participants were undergraduate (2nd year or above) or postgraduate students of Product Design Engineering (PDE), or individuals who had already graduated from a PDE course. Most participants were students from Strathclyde University or Glasgow School of Art. Participants were recruited as part of a larger study investigating various aspects of design cognition. Ethical approval was granted by the Department of Design, Manufacturing and Engineering Management Ethics Committee. All participants were reimbursed £17 for their participation in the overall study.

4.2.2 Ideation Task

The ideation task used across conditions involved participants generating and sketching as many concepts as possible in response to the following design brief: "Working while travelling may be noisy; full of distractions; and physically uncomfortable. Generate concepts for products that may reduce the difficulties associated with on the go working". As with study one, the task was taken from an fMRI study of design cognition conducted by the Imagine-D project (Hay et al., 2019a).

Participants were required to sketch each concept on a sheet of A4 paper, as well to provide a brief description of the concept alongside the sketch. Consistent with study 1 (combined sketching condition), participants were permitted to sketch during ideation. Participants were asked not to spend more time sketching than was necessary, and to only provide a level of detail in the sketch/description that was sufficient for the concept to be clearly interpreted by another individual.

4.2.3 Mood Induction

For the mood induction procedure (MIP), a combination of the musical MIP and Velten's (1968) self-referential statements was used. Previous studies have found this combination to be effective in inducing the intended mood state (Joseph et al., 2020; Richell & Anderson, 2004; Ter Kuile et al., 2010). Based on the procedure of Clapham (2001), the self-referential statements were taken from Velten's (1968) original study with the exception that neutral statements were replaced with excerpts from a word processing manual (Convergent Technologies, 1983). This approach was deemed necessary because previous research has shown that the original neutral statements, which cover a range of topics and contain diverse information, can enhance subsequent creative performance. Word processing instructions, by contrast, do not appear to influence affect or creativity (Clapham, 2001), and so were deemed more appropriate for the current experiment. Example sentences from each of the three induction procedures are presented in table 4-1. For a full list of all sentences used, see appendix 2.

Table 4-1. Example sentences used in the mood induction

Mood induction	Example Sentence
Positive	“If your attitude is good, then things are good and my attitude is good”
Negative	“I feel terribly tired and indifferent to things today”
Neutral	“The installation guide describes the procedure for powering up a system.”

Regarding the musical excerpts used for the mood induction, participants in the happy condition listened to Symphony 6 in F Major, Op. 68 “Pastoral” by Beethoven, and those in the sad condition listened to Adagio in G Minor by Albinoni. Previous studies have found these pieces to be effective in inducing the desired mood state (Jefferies et al., 2008; Ribeiro et al., 2019; Västfjäll, 2001). In the neutral condition, participants listened to “La Mer: From Dawn until Noon on the Sea” by Debussy, since previous research has found that it does not have any significant effect on mood (Martin & Metha, 1997). Before the mood induction procedure, participants were told that they would be required to read a series of sentences presented on the computer screen, and that they would also listen to some music during this time. To reduce potential effects of demand characteristics, participants were not explicitly instructed to attain a particular mood state. A meta-analysis of mood induction studies has also suggested that adding explicit instructions does not necessarily increase the effectiveness of the induction (Joseph et al., 2020). During the induction, participants were presented with 45 sentences (Velten statements or neutral statements) on a computer screen at a rate of 10 seconds each and were asked to read each statement carefully as it was presented. Participants also listened to the mood-appropriate music via headphones during this time. After all 45 sentences had been presented, participants continued to listen to the music for an additional 30 seconds. Thus, the mood induction lasted for a total of 8 minutes. Previous studies have shown that this is sufficient time for the mood induction procedure to be effective (Gendolla & Krüsken, 2001; Marcusson-Clavertz et al., 2019; van der Zwaag et al., 2012). Initial piloting of the mood induction procedure using this duration also suggested that it had the desired effect on participants' mood (see section 4.2.5 below for mood assessment details).

4.2.4 Procedure

All participants gave informed consent and provided demographic information including age, gender and current year of academic study (or total years of PDE study if they had already graduated). They were then assigned to one of four conditions: a) incubation with happy mood induction, b) incubation with sad mood induction, c) incubation with neutral mood induction or d) control condition with no incubation period. Assignment to conditions was pseudo-randomised such that PDE education levels were balanced across conditions.

Participants in the three incubation conditions firstly performed the ideation task for 8 minutes. Following this, they were asked to stop performance of the ideation task and to complete the mood assessment questionnaire. To prevent participants consciously thinking about the task during the incubation period, at this point they were not told that they would return to the ideation task after the break. Previous incubation studies have taken this approach, both in general creativity (Ellwood et al., 2009; Snyder et al., 2004) and in design (Al-Shorachi et al., 2015; Tsenn et al., 2014). Following completion of the mood questionnaire, which took approximately 1 minute to complete, participants then undertook the relevant mood induction procedure (i.e. happy, sad, neutral).

After completion of the mood induction, participants filled out the mood questionnaire once more. Thus, the incubation period lasted for approximately 10 minutes (including 8 min induction and pre-/post- questionnaire). Finally, participants returned to the ideation task for a further 8 minutes. They were asked not to repeat any concepts they had generated in the first phase.

In the control group, participants simply performed the ideation task continuously for 16 minutes. Concepts generated in the first 8 minutes and last 8 minutes of the task were time stamped as such by the researcher, so as to allow for comparison with participants' pre- and post- incubation performance in the other groups.

4.2.5 Mood assessment

The Scale for Mood Assessment (EVEA; Sanz, 2001) was used to assess participants' mood before and after the mood induction. This scale was developed specifically for use in mood induction experiments (Sanz, 2001) and numerous studies have shown that it is sensitive to changes across a variety of mood states (Pereira & Vargas, 2005; Sanchez Lopez, 2011; Sanchez et al., 2013). The scale includes 16 items, each composed of a self-referential statement relating to one of four mood states, including happiness (e.g. "I feel optimistic), sadness-depression (e.g. "I feel depressed"), anger-hostility (e.g. "I feel irritated") and anxiety (e.g. "I feel nervous). Each statement is accompanied by an 11-point Likert scale ranging from 0 ("not at all") to 10 ("very much"). There are four items per each mood state assessed. The full questionnaire is provided in appendix 3.

In the current study, only participants' scores on the happiness and sadness-depression scale were included in the analyses, since the mood induction procedures were specially focused on these two mood states. In addition, previous studies attempting to induce happiness and sadness have tended not to measure changes along other mood dimensions such as anger and anxiety (Greenberg & Meiran, 2014; Hervas & López-Gómez, 2016; Hills et al., 2001; Misalidi & Bonoti, 2014; Roisman et al., 2006).

4.2.6 Ideation performance assessment

The ideation task was scored in terms of fluency (number of ideas generated) and novelty. Two independent raters were recruited to carry out the novelty assessment (Rater 1 and 2 from study 1). The raters followed the same procedure as that used in study 1, which may be considered a variant of the consensual assessment technique (CAT; Amabile, 1982). Both raters assessed all of the concepts produced from the task on a scale of 1 (least novel) to 7 (most novel). Consistent with the CAT method, raters were instructed to use their own subjective definition of novelty, and to rate concepts against one another. However, they were also asked to consider products that already exist in the world, which is not generally required in the CAT method.

Since only two raters were recruited, rather than three (as in the previous study), inter-rater reliability was assessed using an intra-class correlation (ICC). As in study 1, the focus was on consistency between the two raters rather than absolute agreement. There are several forms of ICC analysis and the one that is applied depends on a number of factors (Koo & Li, 2016; McGraw & Wong, 1996). In this case, a two-way random effects model was applied, which is used when raters are selected from a larger sample of raters with similar characteristics (in this case, individuals with design expertise), and when the ratings are expected to generalise to this larger sample. The ‘multiple raters’ form of this model was used, which applies to situations where judges scores will be averaged together, e.g. to yield a single score for each item being rated (as was the case in this study).

With regards to interpretation of the ICC, several guidelines have been proposed for this. Cicchetti and Sparrow (1981) suggest that values below .4 indicate poor reliability, values between .40-.60 indicate moderate reliability, values between .60 and .75 indicate good reliability, and values above .75 indicate excellent reliability. More recent guidelines by Koo and Li (2016) suggest that values below .50 indicate poor reliability, values between .50-.75 indicate moderate reliability, values between .75 and .90 indicate good reliability, and values above .90 indicate excellent reliability. Since the ICC figure is only a statistical estimate of the true ICC value, it is also recommended that 95% confidence intervals are taken into consideration (Koo & Li, 2016). These indicate an upper and lower bound between which there is a 95% chance the true ICC value lies.

In the current study, the ICC (with 95% confidence intervals) between the two judges' ratings was .531 (.417 - .622). Within Cicchetti and Sparrow's (1981) guidelines this indicates moderate to good interrater reliability, whereas within Koo and Li's (2016) guidelines this suggests poor to moderate interrater reliability. Taking both sets of guidelines into account, the ICC estimate (with confidence intervals) for the current study was therefore taken to indicate moderate interrater reliability.

After establishing inter-rater reliability, each judge's ratings were then averaged together to give an aggregate novelty score for each concept. For participants in the incubation group, a pre- and post- incubation novelty score was then calculated for each participant, which reflected their average novelty score in the pre- and post-incubation phase, respectively. For participants in the control group, an average novelty score for was calculated separately for concepts generated in the first and last 8 minutes of the task.

4.3 Results

4.3.1 Mood induction effectiveness

Participants' mean happiness and sadness scores before and after the mood induction for the three experimental groups are presented in table 4-2. In addition, participants' change scores (pre- and post- induction) for happiness and sadness levels are presented in figure 4-1.

Table 4-2. EVEA happy and sadness scores before and after the mood induction for the three experimental groups. Each scale ranged from 0-10.

	Happy induction		Sad induction		Neutral induction	
	Pre	Post	Pre	Post	Pre	Post
Happiness	5.65 (1.53)	6.18 (1.58)	5.75 (2.27)	4.17 (2.80)	5.49 (1.48)	5.10 (1.57)
Sadness	1.01 (.96)	.60 (.79)	1.23 (1.65)	2.79 (2.21)	.60 (.80)	.68 (.82)

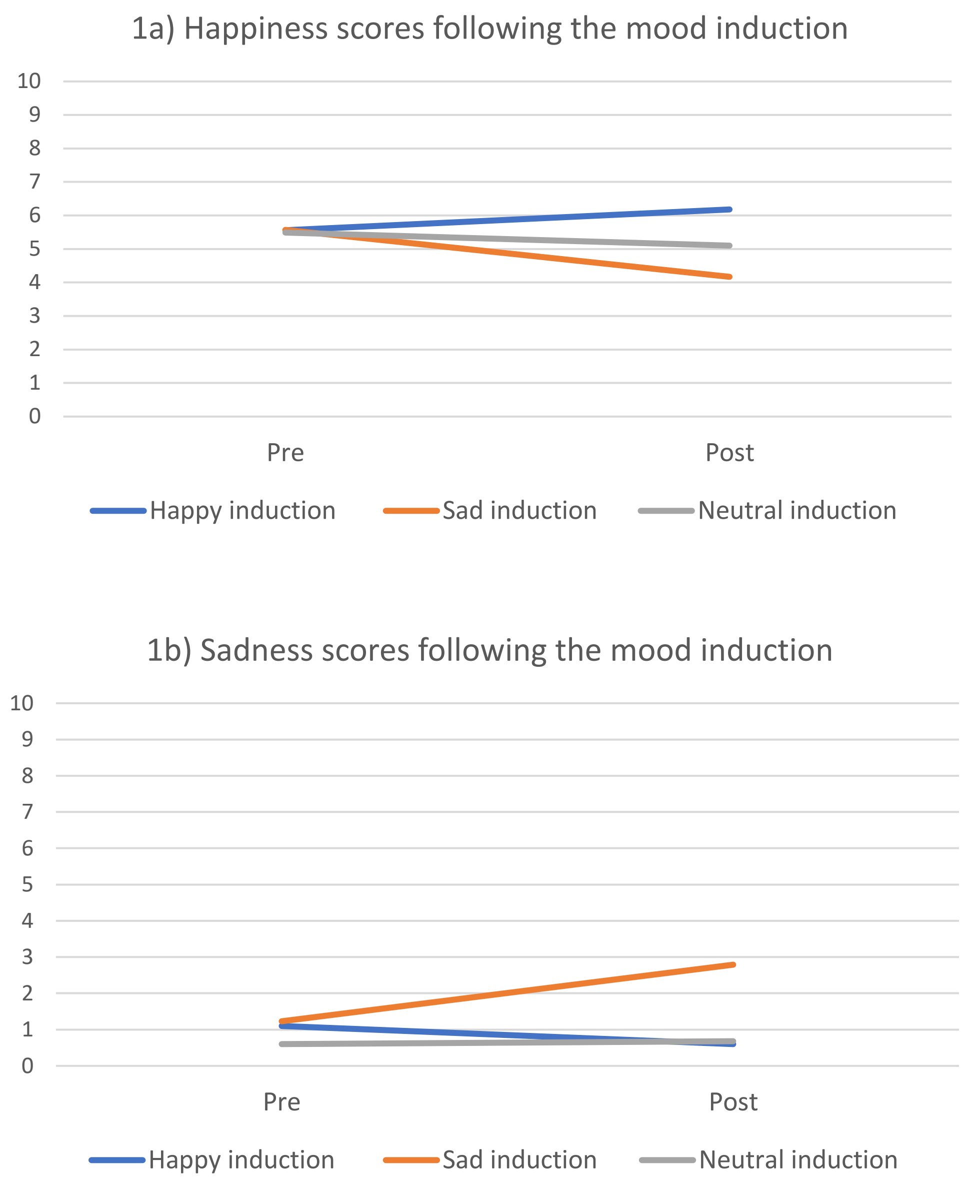


Figure 4-1. Participants' happiness (1a) and sadness (1b) scores on the EVEA mood scale before and after the mood induction.

4.3.1.1 Manipulation checks

Manipulation checks were carried out separately for the happy and sad mood induction in order to examine their impact on participants' mood. In both cases, mood scores reported by the neutral group were used as a control.

Happy mood induction

To examine the effectiveness of the happy induction, a two-way mixed ANOVA was conducted with time as the within-subjects factor (pre- and post- mood induction) and mood induction type (happy, neutral) as the between-subjects factor. The dependent variable was participants' happiness scores on the EVEA. A significant interaction between time and induction condition was hypothesised such that before the mood induction there would be no significant differences between the two groups' happiness scores, whereas following the mood induction, the happy mood induction group would have significantly higher happiness scores than the neutral induction group. It was also hypothesised that the happy induction group would report significantly higher levels of happiness after, as compared to before, the mood induction.

As hypothesised, the two-way mixed ANOVA revealed a significant interaction between time and induction condition, $F(1, 34)=4.760$, $p=.036$, $\eta^2p=.123$. Planned comparisons using t-tests revealed that, following the mood induction, the happy induction group ($M=6.18$, $SD=1.58$) reported significantly higher levels of happiness than the neutral induction group ($M=5.10$, $SD=1.57$, $p=.046$). The comparison between the happy induction group's scores before ($M=5.56$, $SD=1.53$) and after ($M=6.18$, $SD=1.58$) the mood induction showed a trend in the direction expected but did not reach significance ($p=.058$). This could be due to the fact that participants in the happy group (as with all groups) reported moderately high levels of happiness before the mood induction.

Sad mood induction

To examine the effectiveness of the sad induction a similar approach was used to the above. However, participants' pre- and post- sadness scores both had a skewness level in excess of 1 (pre=2.651; post=1.772) indicating that the data were positively skewed. Thus, the data for both measures were transformed to render the data more suitable for parametric analysis. The data were transformed using the square root method (which involved calculating the square root of the original score), since this method can be used with positively skewed data that includes zero values.

Following data transformation, a two-way mixed ANOVA, was conducted, with time as the within-subjects factor (pre- and post- mood induction) and mood induction type (sad, neutral) as the between-subjects factor. The dependent variable was participants' sadness scores on the EVEA. A significant interaction between time and induction condition was hypothesised such that before the mood induction there would be no significant differences between the two groups' sadness scores, whereas following the mood induction, the sad mood induction group would have significantly higher sadness scores than the neutral induction group. It was also hypothesised that the sad induction group would report significantly higher levels of sadness after, as compared to before, the mood induction.

As hypothesised, the two-way mixed ANOVA revealed a significant interaction between time and induction condition, $F(1, 34)=9.003$, $p=.021$, $\eta^2p=.147$. Planned comparisons using t-tests revealed that, following the mood Induction, the sad induction group ($M=2.79$, $SD=2.21$) reported significantly higher levels of sadness than the neutral induction group ($M=.68$, $SD=.82$, $p=.001$). In addition, the sad induction group reported significantly higher levels of sadness after ($M=2.79$, $SD=2.21$) as compared to before ($M=1.23$, $SD=1.65$) the mood induction.

Overall, the manipulation checks revealed that the happy and sad mood induction were effective in inducing the intended mood state. The one exception to this was that the comparison between the happy induction group's pre- and post- induction score showed a trend in the direction expected but did not reach significance. As highlighted, this could be due to the fact that participants in this group reported moderately high levels of happiness at baseline.

4.3.2 Ideation performance before and after the incubation period

A total of 340 concepts were generated in the study. Of these, 11 (3.23%) were removed because they did not meet the requirements of the design brief or did not provide enough information to be interpreted by the raters. In the following sections, differences between the four groups' ideation performance in terms of fluency and novelty are assessed, both before and after the incubation period.

For both fluency and novelty, it was established whether or not a general incubation effect (i.e. non-mood related) had occurred by firstly comparing the control condition with the neutral incubation condition. For both performance metrics, a significant interaction effect (assessed via a 2-way ANOVA) was hypothesised such that within the first 8 minutes of the ideation task there would be no significant differences between the two groups, whereas in the last 8 minutes the neutral group incubation would have significantly higher fluency and novelty scores than the control condition. Following this, it was then examined whether there were any differences in ideation performance between the three incubation groups (i.e. happy, sad, and neutral). Based on the findings from study 1, as well as existing literature on the relationship between creative cognition and mood, it was hypothesised that the happy incubation group would outperform the other two groups following the incubation period. Accordingly, an interaction effect was hypothesised such that there would be no significant differences between the groups before the incubation period, whereas the happy incubation group would show significantly higher fluency and novelty than the other two groups following the incubation period.

Fluency

Differences in ideation performance between the groups were examined firstly for fluency. Participants' average fluency scores across the four groups are presented in table 4-3. Note that for the experimental groups (happy, sad, neutral induction), the first and last 8 minutes correspond to the pre-incubation and post-incubation phase, respectively.

Table 4-3. Mean number of concepts generated in the first and last 8 minutes of the ideation task

	Condition	Mean	SD	Range
First 8 minutes	Control (n=18)	2.44	.86	1 - 5
	Happy (n=18)	2.28	1.07	1 - 5
	Sad (n=18)	2.17	.62	1 - 3
	Neutral (n=18)	2.28	.75	1 - 4
Last 8 minutes	Control (n=18)	2.22	1.1	1 - 4
	Happy (n=18)	2.33	1.13	1 - 5
	Sad (n=18)	2.33	1.03	1 - 5
	Neutral (n=18)	2.06	.80	1 - 3

Before carrying out the relevant statistical analysis, participants' pre- and post-incubation scores fluency were checked for outliers. For the pre-incubation fluency measure, two outliers were identified (both > 3 standard deviations above the mean). No outliers were identified on the post-incubation fluency measure. Note that for all statistical analyses reported below, outliers are included as their exclusion was not found to impact the results. Finally, in terms of data distribution, both the pre- and post- incubation fluency scores had a skewness level of < 1, thus the data were deemed suitable for parametric analysis.

To examine whether a general incubation effect had occurred, differences in fluency between the control group and the neutral group were assessed using a 2-way mixed ANOVA, with time as the within-groups factor (pre- and post- incubation), and incubation condition (neutral incubation or control) as the between-groups factor. The interaction between time and incubation condition was non-significant, suggesting no incubation effect had occurred, $F(1, 34)<.01$, $p=1.000$, $\eta^2p =.000$. In addition, the main effects for time, $F(1, 34)=2.00$, $p=.166$, $\eta^2p =.056$ and incubation condition, $F(1, 34)=.44$, $p=.514$, $\eta^2p =.013$, were non-significant.

Following this, differences among the three incubation groups were examined in order to assess whether there were any differences between incubation with and without a mood induction. A 2-way mixed ANOVA was conducted with time as the within-groups factor (pre- and post- incubation), and incubation condition (happy, sad and neutral) as the between-groups factor. The interaction between time and incubation condition was non-significant, $F(1, 51)=.70$, $p=.501$, $\eta^2p =.027$, therefore the hypothesis that the happy incubation group would show significantly higher fluency than the other two groups following the incubation period was not supported. In addition, the main effects for time, $F(1, 51)<.01$, $p=1.000$, $\eta^2p =.000$ and incubation condition, $F(1, 51)=.15$, $p=.862$, $\eta^2p =.006$, were non-significant. Overall, there did not appear to be any significant differences between the incubation groups in terms of fluency.

Novelty

Differences in ideation performance between the groups were then examined in terms of novelty of ideas generated. The mean novelty score of all four groups in the first and last 8 minutes of the ideation task are presented in table 4-4. Again, the first and last 8 minutes of the task corresponds to pre-incubation and post-incubation for experimental groups.

Table 4-4. Mean novelty score for concepts generated in the first and last 8 minutes of the ideation task

	Condition	Mean	SD	Range
First 8 minutes	Control (n=18)	2.71	.89	1.00 - 5.25
	Happy (n=18)	2.85	.60	1.75 - 3.60
	Sad (n=18)	2.71	.47	1.75 - 3.50
	Neutral (n=18)	2.71	.79	1.75 - 4.75
Last 8 minutes	Control (n=18)	2.91	1.16	1.50 - 5.50
	Happy (n=18)	3.03	.68	1.75 - 4.13
	Sad (n=18)	2.73	.88	1.63 - 5.13
	Neutral (n=18)	3.20	.61	2.50 - 4.38

Before conducting the appropriate statistical analyses, the data were firstly checked for outliers. This revealed one for the pre-incubation novelty measure (> 3 standard deviations from the mean). No outliers were found for the post-incubation novelty measure. Again, outliers were included in the analyses reported below as their exclusion was not found to impact the results. In terms of data distribution, scores for both pre-incubation and post-incubation novelty had a skewness level of < 1, thus the data were deemed suitable for parametric analysis.

Firstly, as above, differences between the neutral and control group were examined in order to establish whether incubation in general had any influence on ideation performance. To assess this, a 2-way mixed ANOVA, with time as the within-groups factor (pre- and post- incubation), and incubation condition (neutral incubation or control) as the between-groups factor. The interaction between time and incubation condition was non-significant, suggesting no incubation effect had occurred, $F(1, 34)=.57$, $p=.456$, $\eta^2p=.016$. In addition, the main effects for time, $F(1, 34)=3.41$, $p=.073$, $\eta^2p=.091$ and incubation condition, $F(1, 34)=.41$, $p=.525$, $\eta^2p =.012$, were non-significant. Thus, there was no evidence that a general incubation effect had occurred.

It was then examined whether there were any differences between the incubation groups with and without a mood induction. A 2-way ANOVA was conducted, with time as the within-groups factor (pre- and post- incubation), and incubation condition (happy, sad and neutral) as the between-groups factor. The interaction between time and incubation condition was non-significant, $F(1, 51)=1.49$, $p=.234$, $\eta^2p=.055$, therefore the hypothesis that the happy incubation group would show significantly higher novelty than the other two groups following the incubation period was not supported. In addition, there was no significant main effect of condition, $F(1, 51)=1.00$, $p=.375$, $\eta^2p=.038$. There was, however, a significant main effect of time, $F(1, 51)=.4.22$, $p=.045$, $\eta^2p=.076$, such that novelty scores across groups were found to be higher following the incubation period ($M=2.99$, $SD=.74$) as compared to before the incubation period ($M=2.76$, $SD=.63$). While this might be interpreted as an incubation effect, it should be noted that there was a trend towards a main effect of time when comparing the neutral incubation group with the non-incubation control ($p=.073$, reported above). Therefore, the results may suggest that there was a tendency for participants to generate more novel ideas with increasing time on task (regardless of whether or not an incubation period was given).

4.4 Discussion

The present study examined the influence of a happy, sad and neutral mood induction during the incubation period on subsequent design ideation. The results revealed that firstly, there was no evidence of a general i.e. non-mood related incubation effect in that there were no significant differences in ideation performance (fluency and novelty) between the neutral incubation group and the control group. Moreover, there were no significant differences in ideation performance between the three incubation groups, showing no support for the hypothesis that positive mood during incubation would have a particularly beneficial effect on subsequent ideation. While there was no evidence for an incubation effect in the current study, the results did reveal a tendency for all participants to generate more novel ideas in the latter half of the task. This is a robust phenomenon in the creativity literature known as the serial order effect. This finding is relevant to both the current study and study 3, and is therefore included in a more general discussion provided chapter 6 (section 6.5.1). The remainder of this chapter will focus on potential reasons for the lack of incubation effects in the current study, both in general and in relation to mood.

4.4.1 Absence of general incubation effect

The current study found no evidence that incubation facilitates design ideation, neither in terms of the fluency or novelty of ideas generated. This finding is inconsistent with the wider literature suggesting that incubation has a positive impact on subsequent creativity. For instance, a meta-analysis of 117 incubation studies suggested that incubation has an overall positive effect on subsequent creative problem solving (Sio & Ormerod, 2009). In addition, subsequent reviews of the incubation literature have generally assumed that the effect is robust and have instead focused on the potential mechanisms that may underlie it, such as unconscious processing (Gilhooly, 2016; Ritter & Dijksterhuis, 2014) or the forgetting of misleading memory contents (Dodds et al., 2004; Smith & Blankenship, 1991). An important caveat with the existing evidence for incubation, however, is that the majority of this comes from studies using generic creativity tasks (e.g. AUT, RAT) or problem solving tasks (e.g. 9-dot problem), with comparatively less focus on domain-specific tasks. Thus, a broad explanation for the current results is that incubation is simply less effective in more domain-specific, applied creativity settings.

Indeed, as highlighted by the literature review chapter in chapter 2 of this thesis, the evidence for the benefits of incubation in a design context has been somewhat inconsistent. For example, Tsenn et al. (2014) found that incubation successfully reduced design fixation, in that designers exposed to fixating stimuli were found to borrow significantly less features from these examples after, as compared to before, the incubation period. However, Tsenn et al. (2014) also compared the performance of the incubation group with a non-incubation control group and found incubation actually impaired performance in terms of novelty and quality. Moreover, the notion that incubation helps overcome design fixation has not been reliably supported. For instance, Cardoso and Badke-Schaub (2009) found that incubation did not relieve example-induced fixation in a sample of industrial design students. Overall, these findings align with the results of the current study and suggest that incubation is not an effective way of improving design ideation.

In contrast to the current findings, however, some studies have found more favourable evidence for the utility of incubation in a design context (Al-Shorachi et al., 2015; Starkey et al., 2020; Vargas-Hernandez et al., 2010). For instance, Vargas-Hernandez et al. (2010) examined the effects of an incubation period on subsequent design ideation in a sample of mechanical engineering students. Findings showed that incubation was effective in improving ideation across a number of performance metrics including novelty, quality and variety. Interestingly, in the same study Vargas-Hernandez et al. (2010) also examined the effects of incubation on a divergent thinking task in a sample of psychology students. Again, the benefits of incubation were observed across a number of measures on this task. Accordingly, the authors concluded that there is a high degree of alignment (i.e. generalisability) between the effects of incubation in these two domains. However, it should be noted that the nature of the incubation activity (and duration) across these two experiments was different in several respects. In the design study, participants were given a three-day, unsupervised incubation period, whereas in the divergent thinking study, participants were given a 10-minute incubation period during which they were given a maze completion task. Thus, there were potentially a range of different factors separately influencing subsequent performance in both cases. For instance, given the duration of the incubation period in the design study, participants may have had greater opportunity to consciously thinking about the problem and/or encounter inspirational stimuli in the environment. For a clearer comparison of the effects of incubation across these two domains of creativity, future research may wish to use the same incubation task in both settings.

Overall, while the majority of studies using generic creativity tasks have found support for the efficacy of incubation, results within the design literature have been more inconsistent. Some design studies have found incubation effects whereas others have not, and in some cases the incubation has been found to have a negative influence on performance (Tsenn et al., 2014). Therefore, the lack of any incubation effect in the current study is not wholly surprising and may reflect the fact that incubation is simply less effective when applied to more domain-specific forms of creativity such as design ideation. While it is difficult to provide a definitive explanation for why this would be the case, there are a number of possibilities. One explanation is that incubation disrupts creative flow, a concept introduced by Csikszentmihalyi (1975) which refers to a state of full immersion in an activity or 'being in the zone' (Cseh et al., 2015; Rogatko, 2009). The importance of this state of mind across various fields of domain-specific creativity has been noted. For instance, MacDonald et al. (2006) found that the achievement of a state of flow was related to increased creativity during musical composition. Importantly, the experience of flow also tends to precede the discovery of a solution in design ideation (Dorta et al., 2008; 2011). Given the important role of flow in design ideation, it is certainly conceivable that any interruption to this process (such as incubation) would have detrimental effects on creative performance. Consistent with this notion, Tsenn et al. (2014; described above) suggested that a potential reason why the control group in their study outperformed the incubation group across a number of measures was due to incubation causing a break in concentration. In the current study, however, it does have to be recognised that no differences in performance were observed between the control conditions and incubation conditions, whereas if flow interruption was a significant factor, a performance decrement in the incubation groups would be expected here. Nonetheless, the potentially disruptive effects of incubation on flow state could be one explanation why incubation has received less favourable support in the design literature as compared to more generic creativity tasks.

Another potential explanation, which is related to the above, concerns individual preference. Designers likely have an established routine which they follow when carrying out concept generation for actual projects in their professional life, or as part of their educational curriculum in the case of design students. For some individuals, this may involve some form of incubation period which they utilise in order to increase their creative output; though for others, this may involve a prolonged period of continuous work on the problem. For those in the latter group, incubation may have limited utility and in fact could actively disrupt performance. If this is the case, it could explain why incubation has had mixed support in the design literature and would at least partially account for why no incubation effect was observed in the current study.

This can be contrasted with more generic creativity tasks, where participants are very unlikely to have established routines and preferences related to how they perform these. In such cases, incubation would be less likely to disrupt performance or remove participants from a routine that they are used to. From this perspective, it can be predicted that the incubation paradigm utilised in the current study would be more effective in improving performance on a standard creativity task. This issue is addressed in study 3 of the thesis (Chapter 5), which examined the influence of the current incubation procedure on subsequent visual creativity within a sample of participants who were from a non-design background.

4.4.2 The role of mood during incubation period

The above discussion relates to some of the possible factors that may explain why incubation in general was not effective in improving design ideation. However, it is also important to explore why there did not appear to be any mood-related incubation effects, contrary to the hypothesis that positive moods during incubation would have a particularly beneficial impact on subsequent performance. In the following section, some potential explanations for why this hypothesised effect did not occur are discussed.

4.4.2.1 Counteractive effects of mood on design cognition

One possibility is that the positive mood induction enhanced some of the cognitive processes contributing to design ideation, while having a negative impact on others. The results of study one suggested that associative flexibility, general retrieval (Gr), fluid intelligence (Gf) and lowered inhibition are key cognitive processes involved in the generation of novel design concepts. With regards to associative flexibility and Gr, studies tend to reliably show that positive mood has a beneficial impact on these processes (Ashby et al., 1999; Bartolic et al., 1999; Phillips et al., 2002), and so it is expected that these would have been enhanced by the happy mood induction administered in the current study.

For reduced inhibition and Gf the evidence is less clear cut. Several studies suggest that positive mood reduces inhibitory control (Braver et al., 2001; Phillips et al., 2002) and facilitates access to a wider range of semantic associates (Rowe et al., 2007). In this way, a positive mood induction would be expected to enhance design ideation by impairing inhibition. However, there appears to be some inconsistency in the literature regarding the relationship between inhibition and positive mood. A number of studies have suggested that positive mood may actually improve inhibition (Aisenberg et al., 2015; Frühholz et al., 2009) whereas other research has simply found no relationship between the two (Martin & Kerns, 2011). It is therefore possible that the happy mood induction in the current study either served to increase inhibition or simply had no influence on this cognitive process. Either of these scenarios could have potentially limited the effectiveness of the mood induction on subsequent ideation, since reduced inhibition appears to be key for the generation of novel ideas.

Finally, in relation to Gf, most of the evidence suggests that this cognitive process is impaired by both positively and negatively valanced moods (Channon & Baker, 1994; Jung et al., 2014; Oaksford et al., 1996). A common explanation for such findings is that the mood related thoughts that tend to accompany mood states tax working memory resources, leaving less processing capacity available for logical reasoning to be performed (Baddeley, 2003; Jung et al., 2014). It has also been proposed that people experiencing positive moods wish to maintain this pleasurable state, and so may be reluctant to engage in effortful, cognitively demanding tasks such as logical reasoning (Melton, 1995). Irrespective of the underlying mechanism, it is clearly a possibility that the happy mood induction in the current study impaired logical reasoning and this consequentially hindered subsequent ideation.

Overall, the notion that the positive mood induction enhanced some key cognitive processes (e.g. associated flexibility; Gr) but impaired others (e.g. Gf) may be linked to the broader perspective put forth by Davis (2009) which argues that positive moods may exert counter-active effects on various aspects of creative cognition, facilitating cognitive flexibility and the adoption of multiple perspectives, but also impairing the more analytical aspects of creative cognition (e.g. evaluation, critical thinking). As such, the overall benefits of positive mood on ideation may be considerably reduced in more applied, domain-specific creativity tasks such as design ideation, which require both divergent, associative processes (in order to generate novel ideas) but also more constrained, evaluative thought (to ensure ideas are feasible and adequately address the problem). While divergent thinking tasks are also thought to involve evaluation, this may be required to a lesser extent given that divergent thinking tasks generally do not specify a particular problem that needs to be addressed, nor do they require consideration of functional and technical factors when devising solutions (Hay et al., 2019a; Shah et al., 2003a, 2012). Thus, the current results may be due to the fact that positive moods are simply less beneficial on more complex, multi-dimensional creativity tasks such as design ideation.

4.4.2.2 Comparisons with existing incubation literature

It is also important to compare the current findings with existing research investigating the role of mood during incubation. A number of perspectives emphasise the facilitative effects of positive mood during incubation, for instance, in terms of stimulating cognitive flexibility and reducing fixation on ineffective strategies that set in before the break (Haager et al., 2014; Morrison et al., 2017). However, to date only one study (aside from the current one) has explicitly manipulated mood during the incubation period. In this study, Hao et al. (2015) found that positive emotions during the incubation period were particularly effective in enhancing subsequent design ideation.

The discrepancy between the current findings and Hao et al.'s (2015) likely relates to the fact that the latter used a divergent thinking task, which as discussed above may be more likely to benefit from positive mood than design ideation tasks. Moreover, the specific divergent thinking task (instances task; Wallach & Kogan, 1965) employed by

Hao et al. (2015) may be particularly susceptible to the effects of a positive mood induction. In this task, participants are simply required to retrieve instances within a given category (e.g. List as many "things that can fly"; "things that can hurt people"). This task may thus be considered highly similar to a standard general retrieval (Gr) task, relying to a large extent on semantic memory retrieval as well as spreading activation, processes which are reliably enhanced by positive mood. Overall, the current findings may suggest that while mood has previously been identified as a factor of influence during incubation, this does not generalise to more complex, domain-specific creativity problems.

4.4.2.3 Comparisons with existing design literature

It is finally important to consider the results in relation to existing work carried out within the design literature. The current study may be considered one of the first in the literature to directly investigate the impact of a positive mood induction on design ideation. However, several bodies of research have examined the influence of constructs which are closely related to mood. For instance, much research has been conducted regarding the relationship between humour and design, which is noteworthy given that humorous content is often used as a means of inducing positive mood.

Although several studies have found that incorporating humour into the ideation process can enhance ideation (Hatcher et al., 2016; Kudrowitz, 2010) it is interesting to note that a study by Wodehouse et al. (2014) found that exposure to a video aimed to induce a humorous mood/atmosphere did not have a beneficial impact on ideation performance. Although there are several key differences between Wodehouse et al.'s (2014) study and the current one (perhaps the most salient being that the former used groups rather than individual ideation) the two studies do converge to suggest that mood-induction procedures may have limited efficacy in a design context.

Some caution should be exercised when drawing conclusions here, however, as Wodehouse et al. (2014) acknowledged that their induction procedure may not have worked as effectively as intended. For example, they note that while many participants exhibited the expected reaction to the video (i.e. laughter) some participants appeared to be unaffected by the procedure, and/or did not pay any attention to it. Likewise, the mood induction procedure employed in the current study had its own limitations (discussed in section 6.3.2). In light of this, perhaps an appropriate conclusion to draw here would be that researchers should continue to examine the utility of mood inductions and build on the limitations of previous studies, while also exploring the use of other methods to probe the potential mood-design link. For instance, experience sampling methods could be used to examine how the mood-ideation link may unfold over time (e.g. days, weeks) within organisations. As discussed in section 4.1.3 some work of this nature has already been carried out (Amabile et al., 2005; George & Zhou, 2002) but such studies did not focus specifically on ideation, and participant samples included a range of professions beyond product design.

4.5 Conclusion

The current study found no evidence to support the hypothesis that incubation facilitates design ideation, nor was there any support for the notion that positive moods during incubation exert a particularly beneficial impact on subsequent incubation. In general, incubation may disrupt creative flow and could also interfere with established routines and preferences for some designers. With regards to positive mood during incubation, it is possible that this had counteractive effects on cognition, enhancing some key cognitive processes (e.g. associative flexibility, Gr) but impairing others (i.e.

Gf). This explanation also aligns with the view that domain-specific tasks (which typically require the generation of feasible solutions) benefit less from positive mood because while this affective state enhances novel thinking and cognitive flexibility, it also impairs analytical thought and critical thinking (Davis, 2009). As such, positive moods are not likely to exert any overall influence on tasks such as design ideation, which require both novel thinking but also an ability to generate practical solutions.

Broadly, then, the results may imply that factors such as incubation and mood simply have reduced influence in a design context due to both population and task-related factors. This notion can be further explored by examining the impact of incubation on creative ideation within a sample of participants with a non-design background, using the same paradigm employed in the current study. If a general incubation effect is observed here, it would lend support to the argument that incubation is simply less effective when applied to more domain-specific tasks such as design ideation. Likewise, if positive mood during incubation is found to be particularly beneficial for subsequent performance, this would support the view that the relationship between mood and creative cognition is simply weaker in more applied, domain-specific settings as opposed to more domain-general creativity tasks. Overall, such a scenario could point to a disconnect between creativity as it is most commonly study in cognitive psychology, and creativity as it is actually applied in more professional, domain-specific circumstances such as design ideation. Alternatively, if, as in the present study, no incubation effects are observed in study 3 (either general or mood-specific), this could suggest that the current findings reflect more specific methodological factors associated with the incubation paradigm (e.g. length of preparation period; type of incubation task; see chapter 6 section 6.2.2 for more discussion of these issues).

To address this, in study three (reported in chapter 5), it was examined whether the current incubation procedure could enhance visual creativity in a sample of participants from a non-design background. As highlighted earlier in this chapter, previous work has already compared the utility of incubation in a design setting versus more general creative cognition as part of a larger project aiming to assess the degree of alignment between insights derived from design experiments and those stemming from cognitive psychology (Shah et al., 2003b; Vargas-Hernandez, 2007; Vargas-Hernandez et al., 2010). Vargas-Hernandez et al. (2010) found that, in general, incubation had a facilitative effect on both types of creativity, suggesting a good degree of alignment between the two domains on this issue. However, it has to be recognised that this study used different incubation activities and durations across the two settings, which limits making a direct comparison. Moreover, the fact that no incubation effect was observed in the current study further suggests that Vargas-Hernandez et al.'s (2010) conclusions may be somewhat premature. Overall, it remains a possibility that there are fundamental differences regarding the influence of incubation in a design context as compared with domain-general creativity.

Chapter 5. The Effect of Mood during Incubation on Subsequent Visual Creativity

5.1 Introduction

Contrary to expectation, the results of study 2 found no evidence that incubation facilitates design ideation. A possible explanation of this is that incubation may be simply less effective on domain-specific creativity tasks as compared with more generic creativity/problem-solving tasks. Similarly, the lack of any mood-related incubation effects in study 2 could also point towards a weaker mood ideation relationship in more domain specific circumstances, as has been suggested by previous work. These ideas can be investigated further by examining the effects of the mood-based incubation paradigm in a more domain-general creativity setting. If incubation was found to enhance ideation under such circumstances (either in general or in relation to mood), it would lend support to the notion that phenomena such as mood and incubation tend to be more effective in relatively simplistic, domain-general creativity tasks, with diminished influence in more specialised, applied settings such as design ideation. If, however, again no incubation effects are observed here, this could suggest that the findings are due to specific methodological factors such as the nature of the incubation task or limitations with the mood induction procedure.

To address this, empirical study 3 examined whether the mood-based incubation paradigm would be effective in enhancing visual creativity within a sample of participant from a non-design background (mainly psychology students). The creativity task used was the mental synthesis task, which requires participants to manipulate and combine raw visual forms in order to produce recognisable patterns/configurations. The task had been widely employed as a measure of visual creativity, and has also been used in the design literature e.g. to investigate the relationship between sketching and mental imagery manipulation (Kokotovich & Purcell, 2000). Before reporting the results of empirical study 3, some relevant research literature focused on the role of incubation and mood specifically in visual creativity is reviewed.

5.1.1 The role of incubation and mood in visual creativity

Although visual creativity has received less attention in the literature, nonetheless, a number of studies have demonstrated the benefits of incubation in this domain. For instance, there is much evidence that incubation can facilitate performance of visual insight tasks (Browne & Cruse, 1988; Henok et al., 2020; Sio & Ormerod, 2009), i.e. visual-based problem-solving tasks that have only one, often counter-intuitive, solution. An example of this is the 9-dot problem, which requires solvers to connect a 3x3 array of dots using no more than four straight lines and without lifting the pencil from paper (or tracing over previously drawn lines). Participants typically fail to realise (at least initially) that the problem can only be solved by extending lines outside of the array boundaries.

Evidence for the utility of incubation has also been observed in more open-ended visual tasks. Pallier and Tiliopoulos (2011) examined the effect of incubation on both verbal and visual divergent thinking. In this study, participants were initially required to work on the creativity task (verbal or visual) until the they could no longer produce any new responses, after which they were informed that the task was finished and asked to carry out an unrelated activity. Following the incubation period, participants were given an unexpected return to the creativity task. In both cases, participants received a burst of new ideas following incubation and in the case of visual creativity, participants were able to generate more ideas in the second phase of the task than in the first. Given that participants were unaware they would return to the main task, the authors suggested the findings indicate a role for unconscious processing during incubation.

In addition, Gilhooly et al. (2015) found that the creative mental synthesis task was facilitated by a 5-minute incubation period during which a cognitively dissimilar task (solving anagrams) was performed. Interestingly, when a similar task was carried out during the interval (spatial rotation), no incubation effects were observed. This phenomenon, often referred to as the 'similarity effect', has been taken as support for the unconscious work hypothesis (since cognitively similar incubation tasks presumably interfere with unconscious processing of the main task and lead to weaker incubation effects; Gilhooly et al., 2015; Gilhooly, 2016).

Overall, the existing evidence indicates that visual creativity can be facilitated by a period of incubation. However, the influence of mood on the incubation effect in this domain remains to be investigated. There is good reason to propose that positive moods during the interval could exert a particularly beneficial effect on subsequent performance. Incubation is held to facilitate visual insight because it provides an opportunity for mental set-shifting, allowing one to shake off misleading assumptions and to replace ineffective strategies with more fruitful ones (Henok et al., 2020; MacGregor et al., 2001). Experiencing positive mood during incubation could be particularly effective in this regard given that they are associated with cognitive flexibility and breaking away from rigid thought patterns (Haager et al., 2014). Although set-shifting accounts of incubation have mainly been applied to convergent thinking tasks, they may also have relevance to more open-ended problems such as the mental synthesis task. Indeed, Finke (1996) has likened the process of visual discovery on the synthesis task to the 'aha' experience often reported on visual insight tasks, suggesting that the two could rely on similar processes. Therefore, the more flexible, exploratory approach associated with positive moods could be beneficial during incubation on both constrained and open-ended visual problems.

In addition, as discussed, the findings of Pallier and Tiliopoulos (2011) and Gilhooly et al. (2015) support a role for unconscious incubation effects in visual creativity. Unconscious work theories of incubation generally assume that unconscious activity takes the form of diffuse, associative processes such as semantic spreading activation (Dijksterhuis & Nordgren, 2006; Gilhooly, 2016; Ritter & Dijksterhuis, 2014). Applying this to the mental synthesis task, it may be the case that early attempts at the problem lead to the generation of relatively obvious, non-creative responses (e.g. adjoining a rectangle with the triangle to make a flag). However, spreading activation during incubation could lead to the broadening of conceptual boundaries and access to more remote associates, which may then inspire a more creative discovery (e.g. activation spreads from 'flag' to 'golf hole', which can then be achieved by adjoining a circle to the bottom of the flag configuration). As previously discussed, positive moods have been suggested to stimulate unconscious, remote associative processes during incubation in verbal divergent thinking (Hao et al., 2015), and it is possible that similar effects could occur with respect to the mental synthesis task.

5.1.2 Present study

The influence of mood during incubation on subsequent visual creativity was directly examined in the following empirical study, using the same incubation paradigm as employed in study two. In light of the literature reviewed above, a general, non-mood related incubation effect was hypothesised i.e. the mood neutral group were expected to outperform the control group. Furthermore, it was hypothesised that positive moods would be particularly beneficial during incubation period i.e. the positive mood incubation group would have higher performance following the interval than the other two incubation groups.

5.2 Methods

5.2.1 Participants

A total of 80 participants took part in the study (28 males, 52 females; mean age = 23.53, SD = 8.34, range =17-63). Most participants were psychology students recruited from the University of Strathclyde participant pool, and they were rewarded with one research credit for taking part in the study. The remainder of participants were recruited from the general population and their participation was voluntary. Ethical approval for the study was granted by the University of Strathclyde's School of Psychological Sciences and Health ethics committee.

5.2.2 Creativity task

The creativity task used in the study was Gilhooly et al.'s (2015) adapted version of the creative mental synthesis task (Finke & Slayton, 1988). Participants were given a sheet of paper with five shapes (circle, rectangle, square, triangle, letter C) and were required to use different combinations of the shapes to produce multiple recognisable patterns (see figure 5-1). Participants were asked to draw their responses on a sheet of paper along with a brief title for each response.

Participants were given written instructions making them aware of the requirements and rules of the task. The instructions stipulated that each pattern should clearly correspond to its title and be easily recognisable by another person. It was emphasised that participants "could vary the size, position, or orientation of any part, but they could not bend or otherwise alter the shapes of the individual parts" (Finke & Slayton, 1988; p.253). They were also informed that they could not use the same shape twice in the one pattern.

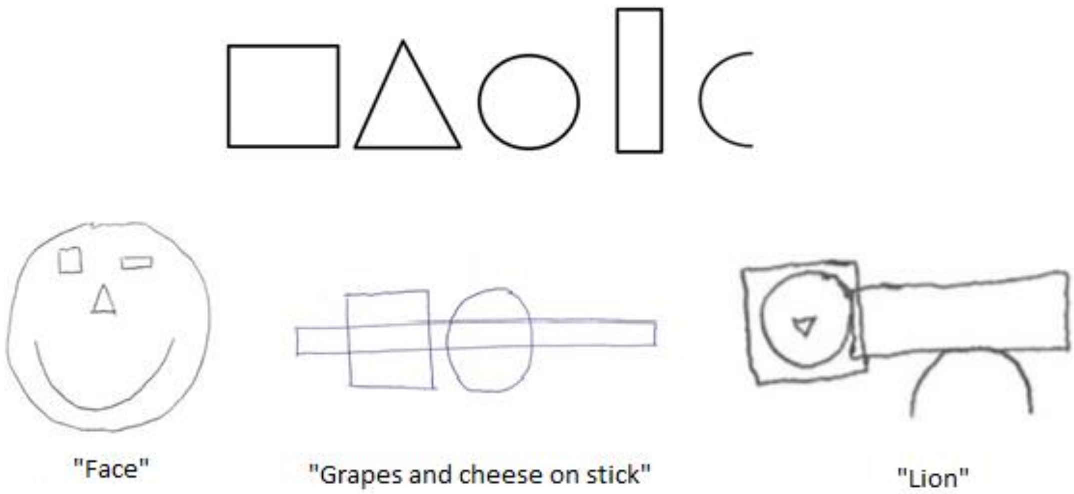


Figure 5-1. Mental synthesis shapes and example responses from study

Note that this version differs from Finke and Slayton's (1988) original task in that in the original participants were given three shapes and required to produce one pattern (rather than multiple patterns). In addition, the original study required participants to memorise shapes and combine them from memory, whereas in the current adapted version participants were provided with the stimuli on a sheet of paper which remain visible throughout the synthesis task (Gilhooly et al., 2015).

5.2.3 Mood induction

The mood induction in the current study was the same in all respects as the induction procedure employed in study 2. For full details relating to this procedure, the reader is referred to section 4.2.3.

5.2.4 Procedure

Participants gave informed consent at the outset of the experiment and also provided demographic information including age and gender. The experimental procedure was highly similar to study 2 (see figure 5-2 for summary), with the exception that the creativity task was the mental synthesis task. Note also that ideation phases of 5 minutes were used rather than 8 minutes, as in study 2. This shorter duration was deemed appropriate given participants would require less time for sketching responses on the synthesis task as compared to the design ideation task. This duration was also consistent with a previous incubation study using the mental synthesis task (Gilhooly et al., 2015).

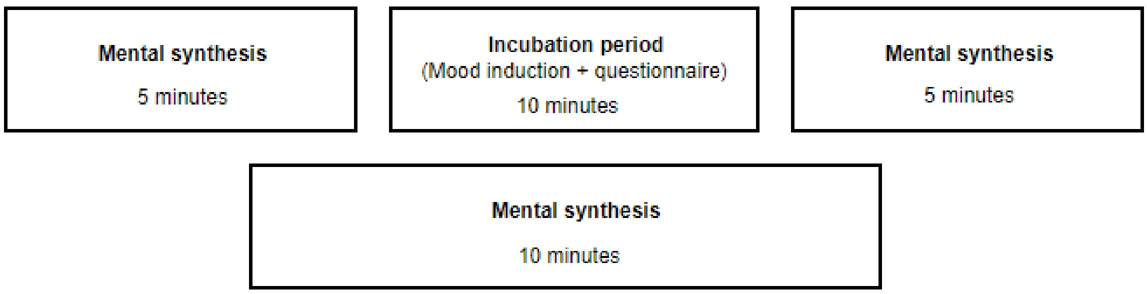


Figure 5-2. Experimental procedure

5.2.5 Mood assessment

The Scale for Mood Assessment (EVEA; Sanz, 2001) was used to assess mood before and after the mood induction. As in study 2, only participants' scores on the happiness and sadness-depression scale were used in the analyses.

5.2.6 Ideation performance assessment

Performance of the mental synthesis task was assessed in terms of fluency and novelty. Novelty was subjectively assessed by three independent raters. Where appropriate, the rating method was kept consistent with the previous two studies: the raters were required to assess novelty on a scale of 1 (least novel) to 7 (most novel), and were asked to rate participants' responses relative to one another. However, the procedure was different in that raters were selected randomly and were not chosen for their expertise in a particular area (given the domain-general nature of the creativity task). In addition, there was no requirement for participants to consider any external standard or reference point relating to novelty (in study 1 and 2, judges were required to consider existing products when making evaluations). Since more than two raters were used, inter-rater reliability was assessed using Cronbach's alpha. This revealed good consistency between the three raters (α =.87).

Following inter-rater reliability analysis, each response was given an average score based on the ratings of the three judges. From this, participants' average pre- and post-incubation novelty score was calculated (or first and last 5 minutes for participants in the control group).

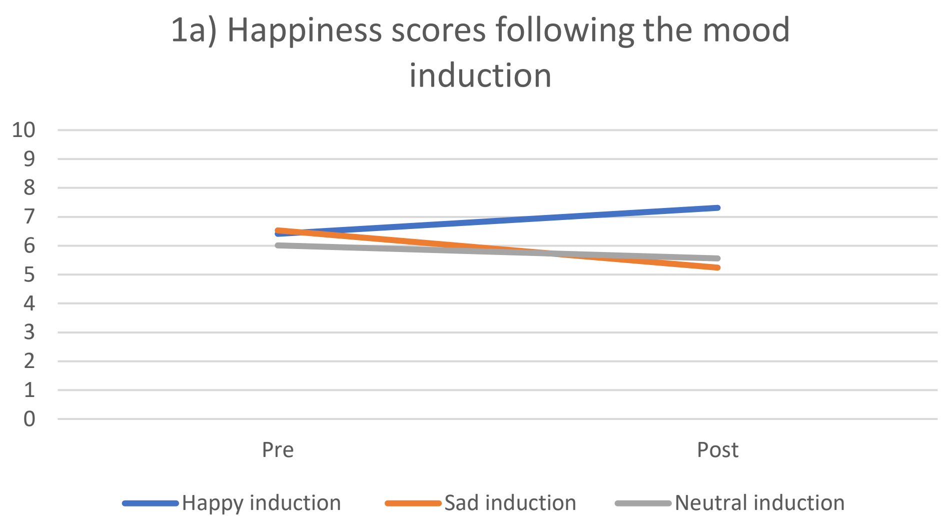
5.3 Results

5.3.1 Mood induction effectiveness

Mean happiness and sadness scores for the three induction groups are presented in table 5-1. In addition, participants' pre-post change scores for happiness and sadness levels are presented in figure 5-3.

Table 5-1. EVEA happy and sadness scores before and after the mood induction for the three experimental groups. Each scale ranged from 0-10.

	Happy induction		Sad induction		Neutral induction	
	Pre	Post	Pre	Post	Pre	Post
Happiness	6.41 (1.34)	7.31 (1.40)	6.53 (1.97)	5.24 (1.95)	6.01 (1.57)	5.56 (1.53)
Sadness	.79 (1.02)	.61 (.81)	1.40 (.35)	2.31 (1.39)	1.68 (1.62)	1.39 (1.13)



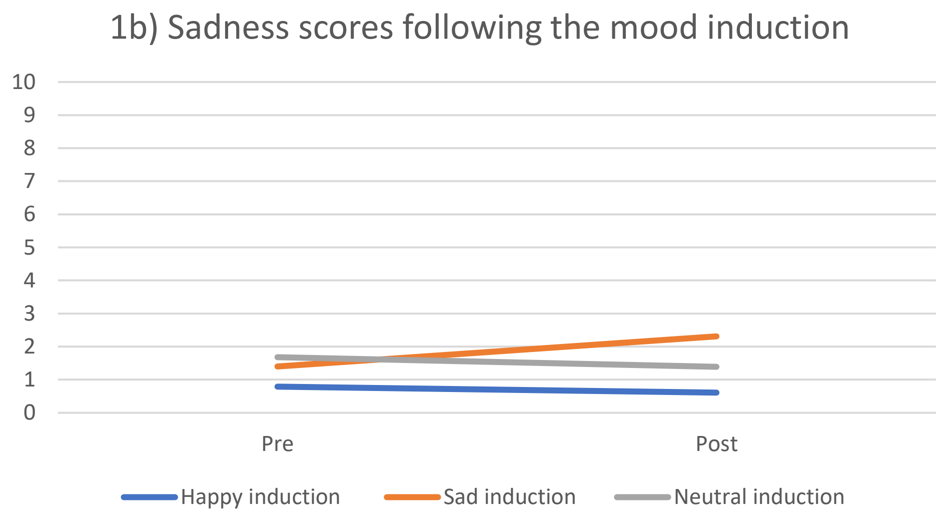


Figure 5-3. Participants' happiness (1a) and sadness (1b) scores on the EVEA mood scale before and after the mood induction.

5.3.1.1 Manipulation checks

The effects of the happy and sad mood induction on reported mood levels were examined separately. In both cases, mood levels reported by the neutral group were used as a control.

Happy mood induction

The effectiveness of the happy induction was assessed using a two-way mixed ANOVA, with time as the within-subjects factor (pre- and post- mood induction) and mood induction type (happy, neutral) as the between-subjects factor. The dependent variable was participants' happiness scores on the EVEA. The ANOVA revealed a significant interaction between time and induction condition, $F(1,38)=18.29$, $p<.001$, $\eta^2p=.325$. Planned comparisons with t-tests found that the happy induction group ($M=7.31$, $SD=1.40$) reported significantly higher levels of happiness than the neutral induction group ($M=5.56$, $SD=1.53$, $p=.001$) following the mood induction. In addition, the happy induction group reported significantly higher levels of happiness after ($M=7.31$, $SD=1.40$), as compared to before ($M=6.41$, $SD=1.34$, $p=.001$), the mood induction.

Sad mood induction

Manipulation checks for the sad mood induction were carried out as above. However, since participants' pre-induction sadness scores were positively skewed (skewness >1), the data were transformed using the square root method (i.e. taking square root of the original score).

Following this, a two-way mixed ANOVA was performed with time as the within-subjects factor (pre- and post- mood induction) and mood induction type (sad, neutral) as the between-subjects factor. The dependent variable was participants' sadness scores on the EVEA. The ANOVA showed a significant interaction between time and induction condition, $F(1,38)= 11.30$, $p=.002$, $\eta^2p=.229$. Planned comparisons using t-tests revealed that, following the mood Induction, the sad induction group ($M=2.31$, $SD=1.39$) had significantly higher sadness scores than the neutral induction group ($M=1.39$, $SD=1.13$, $p=.026$). In addition, the sad induction group showed a significant pre- ($M=1.40$, $SD=.35$) to post- induction ($M=2.31$, $SD=1.39$, $p=.004$) increase in sadness levels, as expected.

Overall, both mood inductions appeared to be successful in inducing the intended mood state.

5.3.2 Mental synthesis performance before and after the incubation period

A total of 642 responses were generated in the study. A small number of these (n=4) were removed because they did not conform to the rules of the task.

Performance on the mental synthesis task was assessed separately for fluency and novelty. All analyses were carried out using a 2-way mixed ANOVA. For both metrics, performance was firstly compared between the control group and the neutral incubation condition, in order to establish whether a general incubation effect had occurred. A significant two-way interaction was expected for both measures, such that the two groups would not show significant differences the first 5 minutes, whereas in the last 5 minutes, the neutral incubation would outperform the control group. In order to examine the influence of mood during incubation, mental synthesis performance then compared between the three incubation groups. An interaction effect was predicted whereby the three groups would not significantly differ during the pre-incubation phase, whereas following incubation, the happy group would have superior performance.

Fluency

Mean fluency scores (number of responses) across the four conditions are presented in table 5-2. Note that for the three induction groups, the first and last 5 minutes corresponds to pre- and post- incubation, respectively.

Table 5-2. Mean number of responses generated in the first and last 5 minutes of the mental synthesis task

	Condition	Mean	SD	Range
First 5 minutes	Control (n=20)	4.80	1.06	3 – 6
	Happy (n=20)	4.40	1.23	3 - 6
	Sad (n=20)	4.30	1.42	3 - 7
	Neutral (n=20)	4.30	1.22	2 - 6
Last 5 minutes	Control (n=20)	3.40	1.31	1 - 6
	Happy (n=20)	4.05	1.40	1 - 6
	Sad (n=20)	3.90	2.07	1 - 8
	Neutral (n=20)	3.75	1.45	1 - 6

To test for a general incubation effect differences in fluency between the control group and the neutral group were examined using a 2-way mixed ANOVA with time as the within-groups factor (pre- and post- incubation), and incubation condition (neutral incubation or control) as the between-groups factor. There was a significant main effect for time, $F(1,38)=20.14$, $p<.001$, $\eta^2p=.346$, but not for incubation condition $F(1,38)=.05$, $p=.825$, $\eta^2p=.001$. The main effect for time showed that participants produced less ideas in the last 5 minutes (M=3.58, SD=1.38), as compared to the first 5 minutes (M=4.56, SD=1.15). The interaction between time and incubation condition was approaching significance, $F(1,38)=3.83$, $p=.058$, $\eta^2p=.091$. This suggested that while both groups' fluency decreased in the latter half of the task, this effect was less pronounced for the incubation group (see figure 5-4).

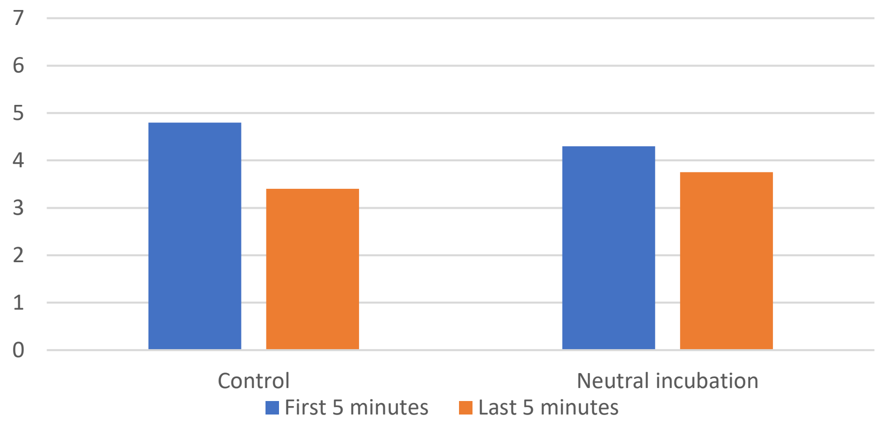


Figure 5-4. Mean fluency scores for neutral incubation and control group in first and last 5 minutes

Following this, performance was then compared between the three incubation groups to assess for any additional influence of mood on incubation. A 2-way mixed ANOVA revealed a significant main effect of time, $F(1,57)=4.51$, $p=.038$, $\eta^2p=.073$, again showing that participants had lower fluency in the second half of the task ($M=3.90$, $SD=1.64$) as compared with the first ($M=4.33$, $SD=1.27$). However, the main effect of mood condition was non-significant, $F(2,57)=.13$, $p=.881$, $\eta^2p=.004$, as was the hypothesised time x mood condition interaction $F(2,57)=.09$, $p=.917$, $\eta^2p=.003$. Therefore, there was no evidence for the hypothesis that the happy incubation group would have superior performance to the other incubation groups following the break.

Novelty

Average novelty scores across the four conditions are presented in table 5-3.

Table 5-3. Mean novelty scores in the first and last 5 minutes of the mental synthesis task

	Condition	Mean	SD	Range
First 5 minutes	Control (n=20)	2.32	.54	1.44 – 3.33
	Happy (n=20)	2.46	.53	1.75 – 3.33
	Sad (n=20)	2.71	.49	1.67 – 3.67
	Neutral (n=20)	2.34	.65	1.33 – 3.89
Last 5 minutes	Control (n=20)	3.03	.81	1.78 – 4.83
	Happy (n=20)	2.88	.67	2.00 – 4.17
	Sad (n=20)	2.80	.85	1.44 – 4.67
	Neutral (n=20)	3.07	.96	1.58 – 4.44

To assess for a general incubation effect, a 2-way mixed ANOVA was conducted with time as the within-groups factor (pre- and post- incubation), and incubation condition (neutral incubation or control) as the between-groups factor. The main effect of time was significant, $F(1,38)=30.62$, $p<.001$, $\eta^2p=.446$, with participants generating more novel responses in the last 5 minutes ($M=3.05$, $SD=.87$) as compared to the first ($M=2.33$, $SD=.59$). However, the main effect of condition was non-significant, $F(1,38)=.02$, $p=.880$, $\eta^2p=.001$, as was the hypothesised time x condition interaction, $F(1,38)=.01$, $p=.929$, $\eta^2p<.001$. There was, therefore, no evidence for a general incubation effect in terms of novelty.

Differences in novelty were then examined between the three incubation groups. Again, there was a significant main effect of time, $F(1,57)= 12.75$, $p=.001$, $\eta^2p=.183$, but not for incubation condition, $F(2,57)=.12$, $p=.884$, $\eta^2p=.004$. The main effect for time again showed that participants had higher novelty in the latter half of the task (pre-incubation: $M=2.50$, $SD=.56$; post incubation: $M=2.91$, $SD=.83$). There was also a trend towards a significant time x condition interaction, $F(2,57)=2.56$, $p=.083$, $\eta^2p=.083$. This appeared to be driven by the fact that while happy and neutral group showed an increase in novelty following the incubation period, performance in the sad group remained relatively unchanged (see figure 5-5).

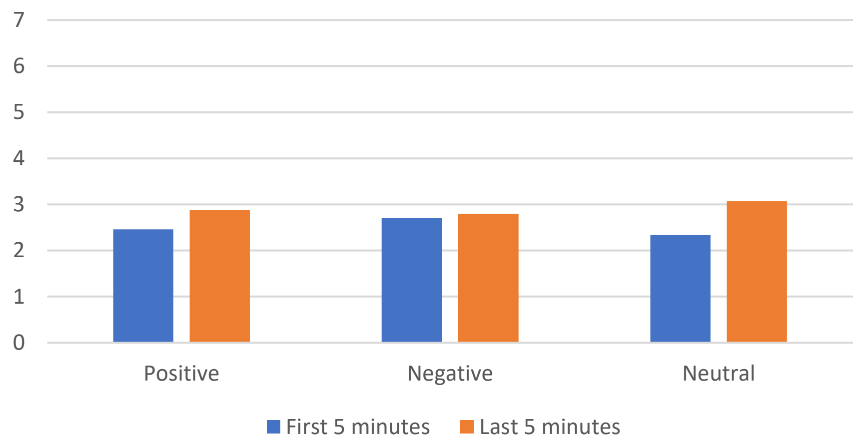


Figure 5.5 Incubation groups' mean novelty scores in first and last 5 minutes

5.4 Discussion

Overall, the general influence of incubation on performance was limited in this study. For fluency, there was a trend to suggest that while the control group and the neutral group showed decreased fluency in the latter half of the task, this decline was less marked in the incubation group. However, incubation was not found to have any impact on the novelty of ideas generated. In terms of mood during incubation, there was no evidence to support the hypothesis that positive moods would have a particularly beneficial impact on subsequent performance. There was, however, a trend relating to sad mood, such that while the control, happy, and neutral group displayed increased novelty in the latter half of the task (i.e. serial order effect), novelty scores in the sad group remained relatively unchanged. It has to be noted that both of the above effects did not reach statistical significance, thus may only be considered preliminary.

5.4.1 The influence of incubation in general

The study suggested incubation had a marginally beneficial impact on fluency, since the decline in fluency was less marked in the neutral group (as compared to the control group). A number of other studies have suggested that incubation benefits fluency on visual creativity, although the benefits of incubation have typically been more pronounced in such cases (Gilhooly et al., 2015; Pallier & Tiliopoulos, 2011). For instance, Pallier and Tiliopoulos (2011) found a clear incubation effect such that individuals generated significantly more ideas after, as compared to before, an incubation period. No such improvement following incubation was observed in the current study.

The current study used a "surprise return" paradigm which aims to prevent participants consciously working on the task during incubation. Studies observing an incubation effect under such circumstances have tended to interpret the results within the Unconscious Work theory of incubation (e.g. Ellwood et al., 2009; Pallier & Tiliopoulos, 2011; Snyder et al., 2004;). However, given that the benefits of incubation on fluency were quite marginal here, it is questionable whether unconscious work explains the results. In addition, the Unconscious Work theory would predict an incubation effect for novelty, as well as stronger incubation effects following a positive mood induction – neither of which were observed here.

As such, it is important to consider explanations other than unconscious work. An alternative explanation for the effect is that in the initial phase of the task participants became committed to a particular strategy for combining/manipulating shapes, or a specific semantic category of responses, which may have eventually led to the slowing of response rate (if the approach no longer fostered new responses). It may be that incubation marginally facilitated breaking away from ineffective approaches and the adoption of new ones, which would explain the less steep decline response rate observed in this group. Such an explanation would be in line with the Forgetting Fixation theory of incubation (Dodds et al., 2004; Smith & Blankenship, 1991).

The results could also be explained by the more straightforward Fatigue Reduction account of incubation, which proposes that incubation simply serves to reduce task related fatigue, allowing the solver to return to the problem re-energised and capable of devoting more attention to the task (Posner, 1973). This account has received limited attention in light of increasing evidence that the incubation effect is sensitive to many factors (e.g. length of incubation period, type of incubation task etc.), as this generally implies the involvement of more complex mechanisms. However, this does not suggest that the account should be ruled out across all situations, and it remains a possible explanation for why a less steep decline in response rate was observed following incubation here.

5.4.2 The influence of mood during incubation period

Contrary to expectation, there was no evidence that positive mood during incubation was particularly beneficial for subsequent creativity. In the introduction, some potential ways in which positive moods could be instrumental during incubation were outlined. For instance, it was proposed that positive moods could aid and the adoption of a more flexible, exploratory approach following an incubation period; allowing weak and ineffective strategies to be replaced by more novel ones. In addition, previous work has implied a role for unconscious spreading activation during incubation in mental synthesis (Gilhooly et al., 2015). It was suggested that positive moods could therefore stimulate such processes during incubation and lead to higher novelty, as has been reported in verbal divergent thinking (Hao et al., 2015). However, no such effects were observed. Therefore, over the course of two studies this thesis has found no evidence for a relationship between positive mood and creativity, which stands in contrast to the wider literature. This issue and its implications will be returned to in the general discussion (see section 6.3).

Note finally that there was a trend to suggest that negative moods during incubation had a disruptive influence on creative performance. Specifically, while the control, happy, and neutral group had higher novelty in the latter half of the task, no such improvement was observed in the negative group. The existing literature on the relationship between negative moods and creativity is rather inconsistent. Similar to the current study, previous research has found that negative mood interferes with creative cognition (Han et al., 2019; Vosburg, 1998). However, other studies have found null effects (Göritz & Moser, 2003; St-Louis & Vallerand, 2015; Verhaeghen et al., 2005), or even facilitative effects for negative mood (Adaman & Blaney, 1995; da Costa et al., 2020; George & Zhou, 2002; Montani et al., 2018). As discussed in section 4.1.2, a critical factor here may be the type of creativity task under examination (Baas et al., 2008; Davis, 2009; Friedman et al., 2007; Martin, 2001). Negative moods have been associated with constrained, analytical thought, which could be beneficial on serious tasks that require critical thinking and feasible solutions (Baas et al., 2008; Friedman et al., 2007). Conversely, this mode of processing could disrupt more 'fun', relatively non-constrained creativity tasks, which might include the mental synthesis task. A caveat to this explanation is that if the current task was perceived as fun, enhanced performance following positive mood would be expected, as has been observed on previous tasks of this nature (Friedman et al., 2007). However, no such effects were observed which casts doubt on this perspective.

There is another explanation which relates to the fact that the mental imagery processes involved in the synthesis task have been found to rely on visuo-spatial working memory resources. Using a dual-task paradigm, Pearson et al. (1999) found that performance on the mental synthesis task was significantly disrupted when carried out in conjunction with a secondary visuo-spatial task (spatial tapping), suggesting the tasks were competing for the same working memory resources. Notably, a number of studies have found that negative moods disrupt visuo-spatial working memory (Figueira et al., 2017; Lavric et al., 2003) possibly due to interference from mood-related intrusive thoughts which leave less capacity available for task-relevant content. It is therefore possible that the negative mood induction in the current study impaired participants' ability to hold and manipulate images in working memory during mental synthesis, leading to a performance decrement in this group.

5.5 Conclusion

While the current study did reveal some benefits of incubation in terms of fluency, this was rather limited and the effect did not reach significance. Importantly, the findings have some key commonalities with the results of study two: neither study found any evidence that incubation improves the novelty of ideas generated, nor was there any support for the view that positive moods exert a particularly beneficial influence during incubation. This suggests that the initial explanation for the results of study two - i.e. that factors such as incubation and mood are simply less effective in domain specific, applied settings such as design ideation – does not appear to offer a full and satisfactory account of the findings. In the following general discussion chapter, reflection will be given on specific methodological factors associated with the current incubation paradigm and how they might help explain the results.

Chapter 6. General Discussion

6.1 Overview of key findings

This thesis aimed to investigate whether incubation in general facilitates design ideation. Theoretically, there is good reason to suppose that incubation exerts a beneficial impact on ideation. However, the issue has received limited attention empirically and there is a lack of knowledge in this area. A second aim of the thesis was to explore the notion that positive moods during incubation have a particularly beneficial impact on subsequent design ideation. In the general creativity literature, positive mood is widely regarded as a key predictor of creative performance, and there is also evidence that positive mood during incubation stimulates unconscious, associative processes, thereby enhancing subsequent divergent thinking. However, no previous research has examined whether similar effects occur in design ideation.

Study 1 (Chapter 3) of the thesis was a preliminary study examining the cognitive processes associated with the generation of novel design concepts. The study found that associative flexibility, general retrieval (Gr), disinhibition and fluid reasoning (Gf) were significantly and positively correlated with concept novelty in design ideation. Importantly, most of these processes (with the exception of Gf) have been shown to be enhanced by positive mood. This, in conjunction with existing theoretical and empirical work, gave further indication that positive moods during incubation could facilitate subsequent design ideation.

Study 2 (Chapter 4) directly examined the influence of mood during incubation on subsequent ideation performance. Contrary to expectation, there was no evidence for the utility of incubation in general, nor was there any support for the view that positive moods during incubation would be particularly effective in enhancing ideation. An initial explanation for these findings was that factors such as incubation and mood may have more limited influence in applied creativity tasks. This notion was explored further in study 3 (Chapter 5), which examined the effects of the mood-based incubation procedure on a more domain-general creativity task. While there was some evidence that incubation exerted different effects across the two studies (e.g. in terms of fluency), in most key respects the results were consistent: neither study found evidence that incubation improved novelty, nor was there any evidence for a positive mood-related incubation effect.

In sum, the findings suggest that incubation does not facilitate design ideation, and that positive mood during incubation does not exert a particularly influential effect during ideation. However, given that similar results were observed in a more domain-general creativity setting (where incubation and mood have been observed to be influential), the findings may be due to methodological factors relating to the current paradigm, including issues such as the nature of the incubation activity, the 'surprise return approach', and the influence of sketching during ideation.

In the following sections, the findings will be discussed in more detail, with focus firstly on the influence of incubation on ideation - both in general and in relation to mood. Secondly, the issue of generalisability of incubation effects across design ideation and more general creativity will be addressed in relation to previous work on this issue (Shah et al., 2003b; Hernandez et al., 2007; 2010). Thirdly, reflection is given on a number of key findings which are not directly related to incubation but that merit discussion (e.g. serial order effect). Fourthly, the implications of the findings with respect to design practice are discussed. Finally, some limitations with the current empirical studies are outlined, followed by suggestions for future research.

6.2 Incubation in general

The general influence of incubation on ideation will be discussed separately with respect to fluency and novelty as there was evidence to suggest that these measures were differentially affected across the two studies.

6.2.1 The effects of incubation on fluency

In study 2, there was no evidence to suggest that incubation benefited fluency on the design ideation task, whereas in study 3 there was some evidence that incubation facilitated this aspect of creativity. Specifically, while both the neutral incubation and control group showed a decline in fluency in the latter half of the task, this decline was less steep in the incubation group. A possible explanation for the discrepancy in findings relates to differences in task difficulty across the two studies. On average, fewer ideas were generated in the design task (pre-incubation: 2.29; post-incubation: 2.24) than on the synthesis task (pre-incubation: 4.45; post-incubation: 3.78). Note that this is despite participants being a given longer time to generate ideas in the design task (2 x 8 minutes) than the synthesis task (2 x 5 minutes). This could suggest that the design ideation task was more difficult than the synthesis task.

Importantly, in an early review of the incubation literature by Kaplan and Davidson (1989), it was proposed that “more difficult problems will need more preparation time prior to incubation time in order for sufficient mental contents to be generated for an incubation period to have a positive effect” (p.32). Mental contents may refer to initial ideas, as well as more generally a representation of problem constraints/requirements and the development of strategies and mental sets. This account assumes that if such mental contents are not fully formed, incubation will have little or no influence on subsequent performance, which is similar to subsequent theories of incubation (e.g. Forgetting Fixation theory; Opportunistic Assimilation theory).

Importantly, the relatively low number of ideas generated in the pre-incubation phase in study 2 (mean= 2.29) may suggest that sufficient time was not given for participants to carry out initial work on the task, thus the benefits of incubation were minimised in this case. This would explain why the facilitative effects on fluency were only observed on study 3, which appears to have been easier and would thus require less preparation time (as suggested by Kaplan & Davidson, 1989).

While this explanation is plausible, it cannot be offered conclusively for several reasons. Firstly, it is inferred that the design ideation task was more difficult than the mental synthesis task based on the differing response rate, although more direct measures would be needed to confirm this (i.e. post-task questionnaire). It is possible that the differences in fluency alternatively reflect the additional time required for sketching concepts on the design ideation task, as compared to the relatively simple configurations produced in the synthesis task. Secondly, the notion that a significant period of initial work is required for incubation to take effect has been questioned both by theoretical perspectives on incubation (e.g. Unconscious Work theory; Gilhooly, 2016), as well as a number of empirical findings (e.g. Dijksterhuis & Meurs, 2006; Gilhooly et al., 2012). Thirdly, although task-difficulty has been proposed as a moderating factor of the incubation effect (e.g. by Kaplan & Davidson, 1989), the question has received limited attention empirically.

6.2.2 The effects of incubation on novelty

With regards to novelty, neither study 2 nor study 3 found any evidence to suggest that incubation enhances this aspect of creativity. This stands in contrast to the substantial body of theoretical and empirical literature on incubation, although the current findings are by no means without precedent. A significant minority of other studies have not observed incubation effects (Carruthers, 2016; Dorfman, 1990; Nam & Lee, 2015; Torrance-Perks, 1997), and several reviews of the incubation literature have also highlighted that simply giving participants a break is by no means guaranteed to facilitate performance (Kaplan & Davidson, 1989; Sio & Ormerod, 2009). Such reviews have tended to emphasise that specific methodological factors often play a key role in determining whether or not incubation effects occur. In the following section, some potential factors are discussed that may account for the current findings.

6.2.2.1 Incubation activity

It is important to discuss how the current incubation activity (separate from the issue of mood) may have impacted the results. During incubation, participants performed a low-demand activity involving reading text and listening to classical music. In general, low-demand activities are thought to be more effective than high-demand tasks because they are more conducive to diffuse, associative cognition (Sio & Ormerod, 2009). However, few studies have examined the effects of music during incubation, and it is possible that the genre of classical music has certain limitations in this context. For instance, Olton and Johnson (1976) found that an incubation period in which participants were encouraged to relax and listen to classical music did not benefit subsequent problem solving. Kaplan and Davidson (1989) subsequently suggested that this may have been due to participants being too relaxed following music exposure, thereby experiencing demotivation upon returning to the main task. It may be that music had similar effects in the current studies, consequentially hindering participants' desire to generate novel responses. Indeed, motivation is often regarded as highly important for creative performance (Sternberg, 2006): participants have to genuinely desire to generate novel and unique responses in order to actually do so. Demotivation to perform creatively following music exposure could therefore explain why novelty in particular seems to have been impervious to the effects of incubation, even when fluency showed some signs of being positively influenced by incubation (i.e. in study 3).

On the other hand, there are a number of counter arguments here. Firstly, in Olton and Johnson's (1976) study, participants were explicitly encouraged to relax while listening to the music, which likely contributed to the potential effects of demotivation. Moreover, if music exposure did demotivate participants in the current study, a performance decrement in the incubation groups relative to the control group would be expected. However, there was no evidence for such an effect – the incubation groups (like the control groups) generally showed an improvement in novelty over time. Finally, it is worth noting that many studies have found that classical music benefits subsequent creativity (Adaman & Blaney, 1995; He et al., 2017; Ritter & Ferguson, 2017) further arguing against the influence of demotivation.

Overall, there does not appear to be any compelling evidence that classical music actively disrupted performance here. There may be other genres/styles of music that work more effectively during incubation. It is also finally worth highlighting that individual preference is likely a key determinant of how effective music works in an incubation context, which may be an argument for giving participants more freedom to choose the music they listen to (see section 6.3.2 for discussion of this in relation to the mood induction procedure).

6.2.2.2 The 'surprise return' approach

In order to prevent conscious work during incubation, participants in both studies were not informed that following the break there would be a return to the main task. Note that there are other ways to prevent conscious work – e.g. inform participants they will return to the main task, but use a highly demanding incubation task to prevent participants' attention being diverted. However, this would have been incompatible with the mood induction procedure used in this research, which was by necessity of low cognitive demand.

Incubation studies (both in the design and creativity literature) do not always explicitly report whether or not participants were made aware of a task return, and there is no consensus on whether this can influence the incubation effect. Among studies using a surprise return paradigm, the majority have observed an incubation effect of some kind (Al-Shorachi et al., 2015; Ellwood et al., 2009; Snyder et al., 2004; Tsenn et al., 2014). In addition, an early review of the incubation literature also concluded that participants' awareness (or lack of awareness) of a return to the main task following the interval did not appear to be a factor of influence on the incubation effect (Kaplan & Davidson, 1989).

However, Gilhooly et al. (2012) argues that where possible participants should be informed of a return because, firstly, it is more ecologically valid in that in real life people are generally aware they will return to a suspended task. Secondly, it has been suggested that unconscious processes during incubation are enhanced by active goals, and so their effects are optimal when a task return is anticipated (Bos et al., 2008; Gilhooly et al., 2015). Some evidence for this perspective has been observed with respect to the fluency dimension of creativity i.e. participants generated more ideas following incubation when they were aware of a return (Gallate et al., 2012). It is not clear, however, whether such an effect generalises to novelty.

Overall, the existing evidence on this issue does not reveal a clear picture but it remains a possibility that participants' lack of knowledge of the task return helps explain why no incubation effects for novelty were observed here. As discussed, informing participants would have been unfeasible given the low-demand nature of the mood induction procedure. Future research could explore the possibility of using more cognitively demanding mood induction procedures (e.g. cognitive task with positive/negative performance feedback), which may be more compatible with an 'informed task return' approach.

6.3 Mood during incubation

The reported research found no evidence to support the view that positive moods during incubation are particularly influential in stimulating subsequent ideation, neither in a design context nor in a more general creativity context. While negative mood was not a key focus of the research, study 3 did find evidence to suggest that negative moods during incubation may disrupt subsequent mental synthesis.

The initial, overarching explanation given for the results of study 2 was that the mood-creativity link is weaker in design ideation than it is in domain-general creativity tasks. Note that this explanation should not be discounted completely. Previous research on humour and ideation has also suggested that induction procedures may have limited impact on subsequent performance (Wodehouse et al., 2014) and in general, much is still unknown about the mood-design ideation relationship. It does have to be acknowledged, however, that the fact similar results were observed across study 2 and 3 makes this explanation seem less likely. As such, in the following sub-sections some specific methodological factors are discussed which may explain the lack of positive mood-related effects across both studies. Following this, the observed differences in the impact of negative mood across the two studies will be addressed.

6.3.1 Experimental design

To date, only one other study has explicitly manipulated affect during incubation. In this study, Hao et al. (2015) examined the effects of brief emotion inductions (positive, negative, neutral) during incubation on subsequent divergent thinking. Relative to a control condition, incubation effects were observed for novelty across all conditions but with particularly enhanced effects following the positive induction. It is possible that the discrepancy in findings between Hao et al.'s (2015) study and the current research is due to differences in experimental design, rather than the fact that Hao et al. (2015) used a domain-general task (as was originally argued chapter 4).

Firstly, Hao et al.'s (2015) study utilised a within-participants design in which participants performed the main task under all of the experimental conditions (i.e. positive, neutral, negative incubation; control). In addition, participants performed multiple short trials (10 x 95 seconds) for each condition. This contrasts with the studies reported in this thesis, where participants were assigned to only one condition (between-groups design), which involved the completion of a single ideation task (or mental synthesis task) over a longer period of time. The inclusion of multiple trials per condition in Hao et al.'s (2015) would have increased statistical power, thus would have been more likely than the current study to detect any incubation or mood-related effects. In addition, within-participant designs are less susceptible to the influence of individual variability. Note however that the adoption of this approach in a design context would have limited ecological validity since designers typically work on one problem for an extended period of time rather than a high number of different design problems over short periods of time (each separated by short breaks).

In addition, the method of response used in Hao et al.'s (2015) study is different to the one employed in the present research. In Hao et al.'s (2015) study, participants were simply required to mentally generate ideas before (10 seconds) and after (20 seconds) the incubation period and were then given additional time to report all ideas verbally at the end of the trial. This contrasts with the current studies in which participants were required to both generate and sketch/draw ideas during the pre-/post- incubation ideation phases. Therefore, while Hao et al.'s (2015) study arguably involved a more 'rapid fire' form of idea generation, the current study required participants to devote a greater amount of time to each individual response. This may be particularly the case in the design study, given that participants had to both conceive of an idea in enough detail to provide a sketch, as well as to spend additional time completing the sketch before moving onto another idea.

One possibility then, is that positive mood inductions are more beneficial for rapid, uninterrupted idea generation, where a high volume of ideas can be generated in a short period of time. Indeed, this would be expected to be the case if the principal mechanism by which positive mood influences ideation is spreading activation, which could conceivably benefit from a more continuous flow or "stream" of ideation, as opposed to ideation interposed with periods of sketching.

6.3.2 Mood induction procedure and related issues

Given that no effects for positive mood were found, and only a hint of an effect related to negative mood in study 3 (discussed below), it is important to consider how effective the mood induction procedures actually were in inducing the intended mood states, as well as to explore alternative approaches that could have been used here.

Overall, the manipulation checks carried out did suggest that the mood induction procedures had the intended effect in both studies. With respect to the happy mood induction, participants who received this reported significantly higher levels of happiness than the neutral group following the induction procedure. In addition, participants reported higher happiness levels after the induction as compared to before; but note that in the case of study 2, this change did not reach significance ($p=.058$). While this could indicate potential weaknesses with the induction procedure, it should be noted that this group (as with all the groups across both studies) reported moderately high levels of happiness at baseline, a robust phenomenon in the mood literature known as the positive mood offset (Diener et al., 2015; Joseph et al., 2020). Given that participants did not report a decrease in happy mood, and in fact displayed an almost significant increase, it is fair to argue that participants were experiencing happy mood during the incubation period in study 2, as intended. Nonetheless, it is worth considering whether alternative approaches could have resulted in a more enhanced mood change, thereby increasing the likelihood of observing a positive mood-related incubation effect (see below for suggestions).

For the negative mood induction, in all cases participants reported significantly higher sadness levels than the neutral group, as well as significant pre- to post- increases in sadness levels. Yet it does have to be noted that in both studies participants' post-induction sadness levels were still at the lower end of the 0-10 point EVEA mood scale (study 2: 2.79; study 3: 2.31). Therefore, while participants may have experienced a significant increase in sadness, this is not to suggest that they were fully induced into a sad mood state. Again, this is consistent with the broader mood induction literature which finds that negative mood states are difficult to induce, which likely relates to the positive mood offset effect as discussed above i.e. people are generally in a positive mood and it is challenging for the mood induction procedure to overcome this (Joseph et al., 2020).

Thus overall, the mood inductions used in the current study appear to have been effective, especially when taking into account the influence of the positive mood offset phenomenon. Nonetheless, there are a number of alternative approaches which might have resulted in an even more effective mood induction. One possibility would be to have participants choose their own music rather than have them listen to pre-selected music, as there is some evidence to suggest that this results in a more intense mood induction (Carter et al., 1995; Völker, 2019). This finding has been interpreted as evidence for the “spreading activation” effects of music on cognition (Schubert et al., 2014), whereby “personal music may facilitate congruent emotions and thoughts because of its integration within the network, giving rise to more complex and sophisticated affective experiences” (Völker, 2019; p.8). Despite its apparent advantage, however, Västfjäll (2001) argues that personalised music may introduce a number of experimental confounds, such as the retrieval of particular memories associated with the music, which could potentially obscure interpretation of the results. In a design context, variation in lyrical content across participants may also introduce a confound in that certain types of verbal stimuli can enhance ideation (Goldschmidt & Sever, 2011). Therefore, while having participants select their own music may increase the effectiveness of the induction, and could also increase ecological validity (e.g. since it would better reflect how designers utilise music in their own design projects), researchers should also be cognizant of the limitations of this approach.

6.3.3 Disruptive effects of negative mood in study 3

It is finally worth exploring the fact that negative mood during incubation appeared to have a disruptive effect on the mental synthesis task, an effect which was not observed in the design incubation study. An explanation for the effects of negative mood on the synthesis task was proposed in chapter 5, which was that negative mood interfered specifically with visual working memory processes required for the maintenance and manipulation of the visual forms. Given the importance of visuo-spatial working memory on this task (Pearson et al., 1999) as well as the fact that negative mood appears to reliably disrupt visual working memory capacity (Figueira et al., 2017; Lavric et al., 2003), this is a plausible explanation for the results. The fact that such an effect was absent in study 2 may reflect the fact that while visual working memory is held to be involved in design ideation (Bilda et al., 2006; Bilda & Gero, 2007) it is likely less fundamental to successful performance of the task. In addition, the results of study 1 suggested that visual working memory is not associated with the generation of novel design concepts since neither of the two visual working memory measures showed any relationship with novelty. As such, any disruption of visual working memory processes would have been unlikely to have a major impact on novelty on the design ideation task.

6.4 Issue of generalisability across creativity domains

The current research is not the first to compare the influence of incubation on design ideation versus more general creative ideation. This issue has previously been explored by Shah and colleagues as part of a larger project investigating the extent to which ideation-related phenomena (incubation, inspirational stimuli, fixation etc.) exert similar effects across these two domains of creativity (Shah et al., 2003b; Hernandez et al., 2007; 2010). Broadly, the aim of this project was to develop a unified theory of the cognitive mechanisms involved in design ideation based on empirical data collected at a number of levels, from highly controlled lab experiments conducted with simple tasks, to more realistic and ecologically valid studies involving professional designers.

In their account of the final results, Vargas-Hernandez et al. (2010) reported that incubation was found to facilitate creative performance (assessed by fluency, variety, novelty and quality) on both a design ideation task (performed by mechanical engineering students) and a domain-general creativity task (performed by psychology students). An interesting exception was novelty, which was not shown to improve in the domain-general study. Overall, however, the authors concluded that incubation effects were generally 'in alignment' across the two domains, and that incubation can be an effective way to facilitate creativity in both cases.

As discussed, it is important to acknowledge that the incubation activity used was different across the two settings. In the design study, participants were given a three-day incubation period whereas in a general creativity study, participants were given a 10-minute maze completion task. Thus, the considerable benefits of incubation observed on the design study could be due to a number of factors including engaging in episodes of conscious work on the problem, as well as encounters with inspirational stimuli. It remains open to question whether similar incubation effects would have been observed using the more controlled and much shorter 10-minute incubation period.

In the current research, which used the same incubation activity across the two settings, a rather different conclusion emerges: findings across the two domains are in alignment only in the sense that incubation appears to have had rather limited effects in both cases, particularly with respect to novelty. Where incubation did appear to influence performance (either in general or in relation to mood), the effects were marginal and were only observed on the visual creativity task. Overall, the findings suggest that, in several respects the conclusions of Vargas-Hernandez et al. (2010) may be premature, and that researchers should be cautious both about the overall benefits of incubation, as well as about making generalisations regarding incubation effects across these two domains of creativity.

6.5 Other key findings

In this thesis, some key findings emerged which are not directly related to incubation but have important implications for design cognition more generally. The first was the observed serial order effect in study 2 and 3; and the second relates to the relatively low level of variance in design novelty accounted for by the cognitive processes assessed in study 1.

6.5.1 Serial order effect

Across study 2 and 3, all participants, including those in the control condition, showed a tendency to generate more novel ideas with increasing time on task. This phenomenon has been referred to as the 'serial order effect' and it has been observed across many different tasks and populations (Beaty & Silvia, 2012; Christensen et al., 1957; Parnes, 1961; Wang et al., 2017). The most well-established explanation of the serial order effect is derived from Mednick's (1962) associative account of creativity, whereby it is assumed that activation is initially restricted to close associates but over time spreads more distantly, allowing more novel associates to be retrieved.

However, a more executive account is offered by Beaty and Silvia (2012), who argue that the effect is in part due to individuals deploying a series of top-down executive processes with increasing effectiveness over the course of the task. For example, on a standard divergent thinking task (e.g. generate alternative uses for a paperclip), participants may use 'executive switching' to search for more distant semantic categories (e.g. cosmetics) after the more obvious ones have been exhausted (e.g. stationary). They may also engage in interference management later on in the task in order to reduce the influence of unoriginal ideas and earlier responses. As evidence of this, Beaty and Silvia (2012) found that fluid intelligence, argued to be a measure of executive ability, moderated the serial order effect such that it was diminished for individuals higher in intelligence. In other words, individuals higher in fluid intelligence appeared to be less influenced by time on task, presumably because they were able to deploy executive processes more effectively from the outset.

It should be highlighted that the above account pertains mainly to the AUT and it cannot be definitively concluded whether the serial order effect observed here also reflects an interplay of associative and executive processes. However, with respect to design ideation at least it should be noted that this account is consistent with the findings of study 1, which found that novelty was associated with both diffuse, associative processes (associate of flexibility, lowered inhibition) as well as more top-down executive-related processes (Gr, Gf). Thus, it is certainly conceivable that a significant increase in novelty over time reflects an underlying change in several of these processes, including associative spreading across increasingly remote semantic networks (associative flexibility), coupled with more controlled semantic memory retrieval and category switching (Gr) as well as more effective deployment of strategies across time (Gf).

Note that while the observed serial order effect is interesting, some caution is merited when drawing conclusions. Firstly, it is not clear whether the serial order effect is as robust and replicable in design settings as it is with respect to more generic creativity tasks. Indeed, a previous design study by Tsenn et al. (2014) found some evidence to contradict the serial order effect, suggesting that design engineering students with extended time on task did not generate significantly more novel ideas than students given a shorter ideation session. Secondly, there is reason to suppose that the serial order effect may be less prominent among expert designers. For instance, Parnes (1961) suggested that training may eliminate the serial order effect, such that more experienced individuals may learn to generate more creative ideas from the outset without the need for extended time on task. Therefore, it might be the case that in expert samples, rather than student samples (as used here), the serial order effect is diminished. A final point to highlight is that in study 1 of the thesis it was suggested that individuals who generate more novel ideas tend to also be higher in Gf. As discussed above, the serial order effect is less marked among individuals higher in this ability (Beaty & Silvia, 2012). Therefore, it could be proposed that among the most creative designers, where Gf levels may be particularly high, the serial order effect is less prominent as such individuals can deploy Gf-related processes from the outset of the task. All of the above suggests that while the serial order effect observed here is interesting, further investigation is needed in order to examine how robust this phenomenon is in design ideation and whether it is influenced by other variables.

A final point to be made here is that the serial-order effect observed across the two studies highlights the importance of including a 'no incubation' control group. While inclusion of a control group is common, a number of studies have nonetheless omitted this (Gallate et al., 2012; Starkey et al., 2020; Yamaoka, 2020; Zhang et al., 2019), instead focusing on the impact of a particular variable across incubation conditions (e.g. incubation activity performed). The underlying assumption of this approach is that the incubation effect is robust, and that the key focus should be on establishing under which conditions it is optimal. In the current studies, however, without a control group it would have not been clear whether the significant increase in novelty reflected an incubation effect or a serial order effect - it was only the fact that this trend was apparent in the control groups that confirmed the latter is the more likely explanation.

6.5.2 Factors affecting design novelty: beyond cognitive processes

Another salient factor that merits discussion is the relatively low portion of variance in design novelty (26%) accounted for by the cognitive processes assessed in study 1, as revealed by the regression analysis. This suggests that there is a wide range of other factors influencing novelty that were not explored in this study. While an exhaustive account of potential factors cannot be provided, some candidates are outlined and discussed below.

6.5.2.1 Cognitive processes not assessed in study 1

Due to time limitations, study 1 was not able to assess the full range of cognitive processes that have in some way been theoretically linked with design ideation (or creativity more generally). One key process that was not examined was episodic memory. Episodic memory has been argued to be involved in 'case-based reasoning' i.e. the retrieval of information relating to previous design problems (Ball et al., 2004; Hay et al., 2017b). Regions implicated in episodic memory (e.g. parahippocampal gyrus) have also shown activation in a previous fMRI study on design ideation (Campbell et al., In preparation). Thus, inclusion of a measure of episodic memory processing would have potentially led to an increase in the portion of novelty explained by the regression model.

Another potentially relevant process is set-shifting, which refers to "the capacity to shift between different tasks, operations or mental sets" (Chiu et al., 2018, p. 1100). Previous research has suggested this process is not involved in general creativity (Benedek et al., 2014b), though it could still play a role in a design context. For instance, one of the key causes of fixation is the continued application of a mental set that is no longer appropriate (Smith, 2011). Thus, designers high in mental set shifting may be less likely to become fixated, which could aid in the generation of novel concepts.

6.5.2.2 Domain-knowledge

It is important to consider the role of domain-knowledge as a factor influencing variance in novelty. In a design context, domain-knowledge includes a broad range of factors such as technical knowledge about physical structures and mechanisms (Shah et al., 2012) as well as knowledge of design approaches and techniques. Given that domain-knowledge is a key predictor of creative performance (Baer, 2015), it is reasonable to propose that designers with a larger domain-knowledge would be more adept at generating novel design concepts. Note also that domain-knowledge is likely to be positively related to experience. In study 1, the majority of participants were PDE students between 2nd and 5th year of study. In general, participants at the more advanced levels of their PDE course (4th/5th year) would be expected to have higher domain-knowledge than those from lower year groups. This difference in experience between participants may also have contributed to novelty variance within the sample.

Another key aspect of domain-knowledge is the level of familiarity with the specific context in which a problem is presented. The problems that product design engineers typically deal with vary widely in context, including domestic and workplace environments as well as more large-scale settings e.g. concerning factors such as transport and infrastructure. It is reasonable to assume that designers vary in their levels of familiarity with a particular context, and that this influences their ability to generate novel concepts (i.e. more familiarity = higher novelty). Note however that in study 1, participants were presented with a broad range of tasks which varied considerably in terms of context. Since participants' novelty score was averaged across these tasks, it is unlikely that context familiarity played a key role here in influencing the variance in novelty scores.

6.5.2.3 Personality

Of the five personality traits that make up McCrae and Costa's (1999) 'big 5' model of personality (extroversion, agreeableness, openness, conscientiousness, and neuroticism), openness (i.e. the tendency to explore new experiences and ideas) is widely regarded as the most important with respect to creativity (Kaufman et al., 2016; Silvia et al., 2009).

While the role of personality in design ideation has received little attention, it is interesting to note that in the existing research, conscientiousness rather than openness has emerged as the key factor in existing research. For instance, conscientiousness has been associated with higher novelty during ideation (Milojevic & Jin, 2019), as well as a tendency to select more novel ideas for further development (Toh & Miller, 2016). The prominence of conscientiousness in this early research is noteworthy given that in the general creativity literature this trait has been linked with lower creativity (Batey & Furnham, 2006). This indicates the interesting possibility that the relationship between personality and design ideation may differ in comparison to other forms of creativity.

6.5.2.4 Motivation

A final likely determinant of ideation novelty is motivation. Motivation is widely regarded as a key predictor of creative performance (Amabile, 1983; An & Runco, 2016) and is also included as a key component on various models of creativity (e.g. Amabile & Pratt, 2016; Runco & Chand, 1995). A distinction is made in the literature between state versus trait motivation (Amabile, 1996; Jeon et al., 2011), both of which may contribute to design novelty in different ways. State motivation refers to an immediate interest in the task-at-hand as well as a willingness to engage in it and remain focused, which is generally thought to be essential for the production of creative work (Sternberg, 2006). By contrast, trait motivation refers to a more stable, enduring willingness to engage with a particular discipline (Jeon et al., 2011). There is some evidence that trait motivation influences creative performance indirectly through domain knowledge (An et al., 2016). That is, individuals with higher trait motivation likely have increased domain-specific knowledge due to their willingness to learn, which then aids performance on creativity tasks. Both motivational factors likely influence novelty in the current research, though further work is needed that specifically addresses this topic. There are a variety of ways to assess motivation in empirical research (e.g. questionnaire, duration of time on task) as well several methods for manipulating motivation levels that could be used here (e.g. stipulating a reward for creative performance).

6.5.2.5 Design ideation as an independent cognitive process

A final explanation for the findings pertains to how design ideation as a cognitive process ought to be conceptualised. The research in this thesis has adopted the widely held view that design ideation is the result of multiple, interacting cognitive processes. This is also the predominant view of creativity more generally (Dietrich & Kanso, 2010; Khalil et al., 2019). However, it should not be discounted that design ideation is in fact a cognitive process in its own right and which is largely independent from other cognitive processes. This would explain why the predictive power of the model was relatively low, and also why the strength of correlations between novelty and the various cognitive processes were largely of weak effect size (even when statistically significant). While this notion departs from the theoretical consensus on ideation, the current findings suggest that it merits further consideration.

6.6 Implications for design practice

It is important to reflect on the practical implications of the present results. At the beginning of the thesis, it was proposed that a mood-based incubation procedure could potentially be utilised by practicing designers as a short-term intervention for enhancing ideation. Such an approach is appealing given that mood can be induced over relatively short time periods, and using accessible stimuli (e.g., music, text, images) that can easily be incorporated into a designers' natural environment. However, the current results to not support the efficacy of this approach, and they also undermine the utility of incubation in general as an intervention for improving creativity in design practice.

Note that since no negative effects of incubation were observed here, there is no recommendation that designers actively avoid incubation periods during an ideation session. However, for designers that regularly incorporate incubation into their ideation routines as a means of enhancing performance, they may wish to reflect on the merits of this approach and the extent to which it actually influences their creativity. It is of course possible that individual preference for incubation is a key moderating factor of the effect i.e., designers that regularly utilise incubation periods are in fact more likely to benefit from it, but this possibility requires further investigation (see section 6.8 for further discussion). It is finally worth commenting that the observed serial order effect has implications for design practice in that it highlights that designers should strive to spend increasing time on task, since later ideas will have a higher chance of being novel. This advice is offered tentatively, however, in that as discussed in section 6.5.1, it is not known how robust this effect is in a design context and whether it diminishes with expertise.

6.7 Limitations

There are some general limitations with the reported research that require discussion. These include shortcomings regarding the method of creativity assessment, the issue of statistical power, as well limitations associated with predominantly recruiting psychology students (as in study 3).

6.7.1 Method of creativity assessment

The assessment method used for the design studies was largely based on the Consensual Assessment Technique (CAT; Amabile, 1982; see section 3.3.3 for overview) with the main exception that raters were required to rate concepts relative to one another (as in the original) but also to consider existing products when making judgements. A key issue in creativity assessment concerns inter-rater reliability i.e. the level of agreement or consistency in ratings between the judges. In the current research, there was some variation in the level of consistency observed across the design studies: in study 1, the Cronbach's alpha calculation (deemed appropriate for studies with more than two raters; Liao et al., 2010; Multon, 2010) was .762, suggesting a good level of consistency between the judges (Baer et al., 2004). In study 2, which involved two raters (R1 and R2 from study 1), an intra-class correlation was calculated which revealed moderate reliability (r=.531). Moderate reliability is lower than ideal, and highlights that the current rating procedure may have some limitations. The decrease in reliability between study 1 and 2 likely reflects the fact that only two judges were used in the latter, since it is widely accepted that a lower number of judges decreases statistical power and leads to lower reliability estimates. Furthermore, the overall volume of concepts was higher for study 2 and was not split across several design tasks as in study 1. The requirement to rate such a high volume of concepts against one another for a single task could have conceivably led to cognitive overload as well as fatigue effects, all of which could negatively impact consistency levels between the judges (Cseh & Jeffries, 2019).

Future design research aiming to use a similar approach to novelty measurement may wish to consider the above factors and whether appropriate adjustments can be made in order to improve reliability e.g. by using more judges and reducing the number of concepts per task where possible. In addition to these considerations, Reiter-Palmon (2020) also outline a number of measures that can increase reliability on the CAT. These include a) having raters engage in discussion before commencing in order to ensure they have a similar understanding of the problem; b) providing raters with a definition for the measure and c) having raters assess an initial sample of items which can then be used to identify and rectify any areas of disagreement. Note that while some of these measures might improve reliability, they also compromise judge independence – a key tenet of the original procedure (Baer & Kaufman, 2019). In addition, they also involve additional time and resource costs upon what is already a highly intensive procedure in this regard.

A final issue relating to creativity assessment concerns the sensitivity of the scale. In the reported research, a rating scale of 1 (least novel) to 7 (most novel) was employed. Among proponents of the CAT method, there is no consensus on what level of granularity is optimal, with studies ranging between a 3 to 10 point scale (Cseh & Jeffries, 2019). It has been suggested, however, that 5 to 7 points is optimal and that anything above this leads to issues with reliability and validity as well as rater fatigue (Cseh & Jeffries, 2019; Preston & Colman, 2000).

While a 7-point scale may be practically advantageous, it nonetheless arguably covers a somewhat limited range. Thus, raters may not have been able to make nuanced judgements about the relative novelty of the concepts, resulting in each category containing within it a broad range of responses. Note that this could also have contributed to the relatively low predictive power of the regression model in study 1, since the novelty scale may not have been sufficiently sensitive to reflect the full variance in novelty existing within the sample. This limitation may be difficult to address since, as highlighted, scales of higher granularity also have considerable shortcomings. Nonetheless, it important to consider this issue when interpreting the results. The issue also highlights that, at present, creativity and design research are still lacking a measure of ideation performance that is both practical and sufficiently sensitive.

6.7.2 Statistical power

In the current research, the sample sizes were not predetermined using a power analysis (e.g. G-Power calculation). Rather, sample sizes reflected the maximum number achievable within the time scale of the project. Note that the sample sizes are the same or larger than some other incubation and mood studies in the literature, including those that have observed statistically significant effects (e.g. Adaman & Blaney, 1995; Al-Shorachi et al., 2015; Campion & Levita, 2014; Tsenn et al., 2014; Yamaoka, 2020). Nonetheless, it does have to be acknowledged that for the current incubation studies, the sample sizes were at the smaller end, and it is possible that this has been a contributing factor in the lack of incubation and mood effects. Indeed, study 3 in particular showed a number of trends that did not reach significance, which may be indicative of low statistical power. Future research in this area may wish to consider whether it is worth taking measures to increase sample size, such as relaxing participation criteria (e.g. recruiting from a wider range of design disciplines) or reducing the number of conditions (e.g. exclusion of negative mood group) which would increase the number of participants per group. Another useful approach may be the calculation of Bayes factor (Lakens et al., 2020), which can help establish whether observed null effects are true (i.e. the effect does not actually exist in the population) or whether the effect does exist but has not been detected e.g. due to lack of statistical power.

6.7.3 Recruitment of psychology students in study 3

There is a final limitation to be noted regarding study 3, which relates to the fact that the sample predominantly comprised undergraduate Psychology students. The use of psychology students is common in experimental research and can greatly facilitate the recruitment process (as students typically participate in return for course credits). However, it is important to recognize the limitations of this in that it can lead to a relatively homogenous sample in terms of age as well as education level and subject area. Additionally, owing to the fact that the majority of psychology undergraduates are female (Johnston et al., 2020), this approach can often lead to a gender biased sample (as was the case here). In light of these considerations, it is acknowledged that the sample in study 3 is not wholly representative of the general population.

6.8 Directions for future research

The number of incubation studies conducted in a design setting is growing, but remains relatively small. Fundamental knowledge about incubation and the factors that influence this process is still lacking. There is a need for more well-controlled studies on incubation in order to establish the role of key variables such as the duration of the preparation and incubation period, type of incubation task performed as well as participants' knowledge (or lack of knowledge) of task return.

At the same time, it is important to recognise the role of individual variation in incubation research: as discussed in chapter 4, designers likely have individual preferences regarding whether and when they like to take a break, and what they perform during this interval. Related to this, during real life incubation periods, designers may encounter a considerable degree of inspirational stimuli in the environment, and this could be a key driving factor in the eventual development of the solution when the problem is returned to (see Opportunistic Assimilation theory; reviewed in chapter 2 section 2.4.4). Thus, future research should also aim to give designers more freedom over the timing and activities performed during incubation. Inevitably, this will lead to reduced methodological control, but could potentially give a rich insight into incubation as it occurs in real life design projects.

Future research is also needed to better understand the relationship between mood and ideation, as this remains an underexplored research area. Only the current study and one other (Wodehouse et al., 2014) have utilised a mood induction procedure in a design context. Neither of the studies found evidence that this procedure influences subsequent design ideation, which could suggest that the mood-ideation link is weak or non-existent. However, it is too early to draw conclusions on this, and there are many avenues available for further research, which can build on the limitations of the existing work.

In particular, future research may wish to further explore music-based inductions and examine the utility of different genres beyond classical music. In addition, the use of more visual-based approaches (e.g. videos/images) may be a fruitful avenue given the widely observed impact of visual stimuli on the design process. For example, it could be examined whether affect-laden visual content is more likely to inspire design analogies as compared with affect-neutral content e.g. due to increased visual salience and/or by facilitating access to affect-relevant content stored in memory (see Isen et al., 1987). Future research should also explore the notion that mood inductions work more effectively during rapid brainstorming in which the goal is to generate a high number of ideas (with minimal sketching).

Note finally that the mood-design ideation link may be subtle and complex, perhaps unfolding across days and weeks. Thus, the relationship may be difficult to detect using standard experimental approaches in the lab. As such, there is also a need to utilise more naturalistic approaches (e.g. experience sampling method) to explore mood-ideation interactions 'in the wild'.

6.9 Conclusions

Incubation features prominently in one of the oldest and most well-established theoretical models of creative discovery (Wallas, 1926). Since then, incubation research has flourished, and modern theoretical accounts have continued to extol the merits of taking a break on subsequent problem-solving.. Although incubation effects have been widely observed, there remains an element of mystery regarding what processes could be occurring during incubation, and it continues to be an attractive phenomenon for those interested in the psychology of creativity.

In the domain of design, it is likely common for designers to temporarily suspend conscious work on an ideation task, but it is unknown whether this actually benefits design ideation. Related to this, there is a lack of knowledge surrounding the factors that may influence incubation in a design context. Against this background, this thesis aimed to examine whether incubation in general facilitates design ideation. Additionally, drawing on a range of anecdotal, theoretical and empirical work, the thesis also explored the notion that the mood state of the designer during incubation may have a key impact on the novelty of ideas subsequently generated.

Contrary to expectation, this thesis found no evidence that incubation in general facilitates idea generation in a design context, neither in terms of fluency or novelty. A subsequent study examining the effects of the same incubation task on visual creativity (with participants from a non-design background) also found only limited benefits of incubation (fluency declined less following incubation but novelty was unaffected). The results could relate to the fact participants were exposed to classical music during incubation, as previous work has suggested this incubation activity may over-relax and demotivate participants when the main task is resumed. Another contributing factor could have been participants' lack of awareness of a task return, as there have been some suggestions that unconscious incubation processes are goal-driven. Irrespective of the underlying mechanism, the results emphasise that incubation effects can be somewhat elusive, and simply taking a break is by no means guaranteed to enhance creativity.

Standing in contrast to the wider mood-creativity literature, the results also found no evidence that positive moods during incubation have a particularly facilitative effect on subsequent ideation, which was the case in both a design context and a domain-general context. A possible explanation for this is that the concurrent act of sketching/drawing during the creativity tasks interfered with the effects of positive mood on ideation. It could also be that the mood induction procedures were not strong enough to influence participants' performance. While self-report measures indicated that the induction procedures were generally successful, there was also evidence that the effects were somewhat hindered by the positive mood offset phenomenon.

While the present results found no evidence for the effectiveness of incubation, they demonstrate the more general benefits of time on creativity: across both incubation studies, participants tended to show improved novelty with increasing time on task.

Subsequent research is needed to better understand this phenomenon in a design context, including an examination of the cognitive/neural processes underlying it, as well as exploring whether training and experience can diminish the effect (as suggested by Parnes, 1961).

On a practical note, at beginning of this thesis, it was suggested that incubation could potentially be utilised in a more formal way by designers as a means of improving ideation performance. However, the current results do not support its utility in this regard. Of course, future research using different tasks and approaches may come to suggest otherwise; but in the meantime, designers looking for a quick and effective way to boost their creativity may need to look beyond incubation. On the basis of the current results, perhaps the most practical advice for designers is that spending increasing time on task may present a straightforward path to more creative ideas. Whether or not a break is taken en route is unlikely to matter.

References

Abraham, A., & Bubic, A. (2015). Semantic memory as the root of imagination. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.00325

Abraham, A., & Windmann, S. (2007). Creative cognition: The diverse operations and the prospect of applying a cognitive neuroscience perspective. *Methods*. https://doi.org/10.1016/j.ymeth.2006.12.007

Abraham, A., Pieritz, K., Thybusch, K., Rutter, B., Kröger, S., Schweckendiek, J., Stark, R., Windmann, S., & Hermann, C. (2012). Creativity and the brain: Uncovering the neural signature conceptual expansion. *Neuropsychologia*. https://doi.org/10.1016/j.neuropsychologia.2012.04.015

Adaman, J. E., & Blaney, P. H. (1995). The Effects of Musical Mood Induction on Creativity. *The Journal of Creative Behavior.* https://doi.org/10.1002/j.2162-6057.1995.tb00739.x

Adams, R., Aleong, R., Goldstein, M., & Solis, F. (2018). Rendering a multi-dimensional problem space as an unfolding collaborative inquiry process. *Design Studies*. https://doi.org/10.1016/j.destud.2018.03.006

Aiken, L. S., West, S. G., & Reno, R. R. (1991). Multiple regression: Testing and interpreting interactions. sage.

Aisenberg, D., Cohen, N., Pick, H., Tressman, I., Rappaport, M., Shenberg, T., & Henik, A. (2015). Social priming improves cognitive control in elderly adults - Evidence from the Simon task. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0117151

Akuzawa, E. (2021, September, 19) "Life-saving school backpack for kids caught in tsunami flooding". *The Asahi Shimbun.* https://www.asahi.com/ajw/articles/14433618

Al-Shorachi, E., Sasasmit, K., & Gonçalves, M. (2015). Creativity intervention: Using storytelling and math problems as intervening tasks for inducing incubation. *Proceedings of the International Conference on Engineering Design, ICED*.

Althuizen, N., Wierenga, B., & Rossiter, J. (2010). The validity of two brief measures of creative ability. *Creativity Research Journal*. https://doi.org/10.1080/10400410903579577

Altshuller, G., Altov, G., & Altov, H. (1996). And suddenly the inventor appeared: TRIZ, the theory of inventive problem solving. Technical Innovation Center Inc.

Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/0022-3514.43.5.997

Amabile, T. M. (1983). The social psychology of creativity: A componential conceptualization. *Journal of Personality and Social Psychology.* https://doi.org/10.1037/0022-3514.45.2.357

Amabile, T. M. (1996). Creativity in context. Update to the social psychology of creativity. Boulder, Colorado.

Amabile, T. M., & Pratt, M. G. (2016). The dynamic componential model of creativity and innovation in organizations: Making progress, making meaning. *Research in Organizational Behaviour.* https://doi.org/10.1016/j.riob.2016.10.001

Amabile, T. M., Barsade, S. G., Mueller, J. S., & Staw, B. M. (2005). Affect and creativity at work. *Administrative Science Quarterly*. https://doi.org/10.2189/asqu.2005.50.3.367

An, D., & Runco, M. A. (2016). General and domain-specific contributions to creative ideation and creative performance. Europe's Journal of Psychology. https://doi.org/10.5964/ejop.v12i4.1132

An, D., Song, Y., & Carr, M. (2016). A comparison of two models of creativity: Divergent thinking and creative expert performance. Personality and Individual Differences. https://doi.org/10.1016/j.paid.2015.10.040

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering Can Cause Forgetting: Retrieval Dynamics in Long-Term Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. https://doi.org/10.1037/0278-7393.20.5.1063

Anderson, M. Intelligence. MS Encarta online encyclopedia, 2006

Ashby, F. G., Isen, A. M., & Turken, A. U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review*. https://doi.org/10.1037/0033-295X.106.3.529

Athavankar, U. A. (1997). Mental imagery as a design tool. *Cybernetics and Systems*. https://doi.org/10.1080/019697297126236

Aziz-Zadeh, L., Liew, S. L., & Dandekar, F. (2013). Exploring the neural correlates of visual creativity. *Social Cognitive and Affective Neuroscience*. https://doi.org/10.1093/scan/nss021

Baas, M., De Dreu, C. K. W., & Nijstad, B. A. (2008). A Meta-Analysis of 25 Years of Mood-Creativity Research: Hedonic Tone, Activation, or Regulatory Focus? *Psychological Bulletin*. https://doi.org/10.1037/a0012815

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn1201

Badke-Schaub, P., & Eris, O. (2014). A Theoretical Approach to Intuition in Design: Does Design Methodology Need to Account for Unconscious Processes? In *An Anthology of Theories and Models of Design*. https://doi.org/10.1007/978-1-4471-6338-1_17

Baer, J. (1998). The case for domain specificity of creativity. *Creativity Research Journal*. https://doi.org/10.1207/s15326934crj1102_7

Baer, J. (2015). The Importance of Domain-Specific Expertise in Creativity. *Roeper Review*, 37(3), 165–178. https://doi.org/10.1080/02783193.2015.1047480

Baer, J., & Kaufman, J. C. (2019). Assessing creativity with the consensual assessment technique. In The Palgrave handbook of social creativity research (pp. 27-37). Palgrave Macmillan, Cham.

Baer, J., & McKool, S. S. (2009). Assessing creativity using the consensual assessment technique. In *Handbook of Research on Assessment Technologies, Methods, and Applications in Higher Education*. https://doi.org/10.4018/978-1-60566-667-9.ch004

Baer, J., Kaufman, J. C., & Gentile, C. A. (2004). Extension of the Consensual Assessment Technique to Nonparallel Creative Products. *Creativity Research Journal*. https://doi.org/10.1207/s15326934crj1601_11

Baird, B., Smallwood, J., Mrazek, M. D., Kam, J. W. Y., Franklin, M. S., & Schooler, J. W. (2012). Inspired by Distraction: Mind Wandering Facilitates Creative Incubation. *Psychological Science*. https://doi.org/10.1177/0956797612446024

Ball, L. J, Lambell, N. J., Reed, S. E., & Reid, F. J. . (2001). The Exploration of Solution Options in Design: A `Naturalistic Decision Making'Perspective. *Designing in Context: Proceedings of the Fifth Design Thinking Research Symposium*---*DTRS*.

Ball, L. J., & Christensen, B. T. (2018). Designing in the wild. In *Design Studies*. https://doi.org/10.1016/j.destud.2018.05.001

Ball, L. J., & Christensen, B. T. (2019). Advancing an understanding of design cognition and design metacognition: Progress and prospects. *Design Studies*. https://doi.org/10.1016/j.destud.2019.10.003

Ball, L. J., Ormerod, T. C., & Morley, N. J. (2004). Spontaneous analogising in engineering design: A comparative analysis of experts and novices. *Design Studies*. https://doi.org/10.1016/j.destud.2004.05.004

Bartolic, E. I., Basso, M. R., Scheff, B. K., Glauser, T., & Titanic-Schefft, M. (1999). Effects of experimentally-induced emotional states on frontal lobe cognitive task performance. *Neuropsychologia*. https://doi.org/10.1016/S0028-3932(98)00123-7

Batey, M., & Furnham, A. (2006). Creativity, intelligence, and personality: A critical review of the scattered literature. Genetic, Social, and General Psychology Monographs. https://doi.org/10.3200/MONO.132.4.355-430

Batey, M., Chamorro-Premuzic, T., & Furnham, A. (2009). Intelligence and personality as predictors of divergent thinking: The role of general, fluid and crystallised intelligence. *Thinking Skills and Creativity*. https://doi.org/10.1016/j.tsc.2009.01.002

Beaty, R. E., & Schacter, D. L. (2018). Episodic memory and cognitive control: Contributions to creative idea production. In *The Cambridge Handbook of the Neuroscience of Creativity*. https://doi.org/10.1017/9781316556238.015

Beaty, R. E., & Silvia, P. J. (2012). Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/a0029171

Beaty, R. E., & Silvia, P. J. (2013). Metaphorically speaking: Cognitive abilities and the production of figurative language. *Memory and Cognition*. https://doi.org/10.3758/s13421-012-0258-5

Beaty, R. E., Benedek, M., Barry Kaufman, S., & Silvia, P. J. (2015). Default and Executive Network Coupling Supports Creative Idea Production. *Scientific Reports*. https://doi.org/10.1038/srep10964

Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative Cognition and Brain Network Dynamics. In *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2015.10.004

Beaty, R. E., Chen, Q., Christensen, A. P., Kenett, Y. N., Silvia, P. J., Benedek, M., & Schacter, D. L. (2020). Default network contributions to episodic and semantic processing during divergent creative thinking: A representational similarity analysis. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2019.116499

Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., Fink, A., Qiu, J., Kwapil, T. R., Kane, M. J., & Silvia, P. J. (2018). Robust prediction of individual creative ability from brain functional connectivity. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1713532115

Beaty, R. E., Nusbaum, E. C., & Silvia, P. J. (2014a). Does insight problem solving predict real-world creativity? *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/a0035727

Beaty, R. E., Silvia, P. J., Nusbaum, E. C., Jauk, E., & Benedek, M. (2014b). The roles of associative and executive processes in creative cognition. *Memory and Cognition*. https://doi.org/10.3758/s13421-014-0428-8

Beck, J. (1979). The effect of variations in incubation activity and incubation time on creative response production. Unpublished doctoral dissertation, New York University.

Beedie, C. J., Terry, P. C., & Lane, A. (2003). A comparison of academic and non-academic distinctions between emotion and mood. *Journal of Sports Sciences.* https://doi.org/10.1080/0264041031000109991

Benedek, M., & Neubauer, A. C. (2013). Revisiting Mednick's model on creativity-related differences in associative hierarchies. Evidence for a common path to uncommon thought. *Journal of Creative Behavior*. https://doi.org/10.1002/jocb.35

Benedek, M., Franz, F., Heene, M., & Neubauer, A. C. (2012a). Differential effects of cognitive inhibition and intelligence on creativity. *Personality and Individual Differences*. https://doi.org/10.1016/j.paid.2012.04.014

Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., & Neubauer, A. C. (2014a). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2013.11.021

Benedek, M., Jauk, E., Sommer, M., Arendasy, M., & Neubauer, A. C. (2014b). Intelligence, creativity, and cognitive control: The common and differential involvement of executive functions in intelligence and creativity. *Intelligence*. https://doi.org/10.1016/j.intell.2014.05.007

Benedek, M., Könen, T., & Neubauer, A. C. (2012b). Associative abilities underlying creativity. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/a0027059

Benton, A., & Hamsher, K. (1983). Multilingual Aphasia Examinationle. AJA Associates. http://doi.org/10.1076/clin.15.1.13.1911

Bilda, Z., & Gero, J. S. (2007). The impact of working memory limitations on the design process during conceptualization. *Design Studies*. https://doi.org/10.1016/j.destud.2007.02.005

Bilda, Z., Gero, J. S., & Purcell, T. (2006). To sketch or not to sketch? That is the question. *Design Studies*. https://doi.org/10.1016/j.destud.2006.02.002

Binder, J. R., & Desai, R. H. (2011). The neurobiology of semantic memory. In Trends in Cognitive Sciences. https://doi.org/10.1016/j.tics.2011.10.001

Blanchette, I., & Caparos, S. (2013). When emotions improve reasoning: The possible roles of relevance and utility. *Thinking and Reasoning*. https://doi.org/10.1080/13546783.2013.791642

Blanchette, I., Gavigan, S., & Johnston, K. (2014). Does emotion help or hinder reasoning? The moderating role of relevance. *Journal of Experimental Psychology: General*. https://doi.org/10.1037/a0034996

Blanchette, I., Richards, A., Melnyk, L., & Lavda, A. (2007). Reasoning about emotional contents following shocking terrorist attacks: A tale of three cities. *Journal of Experimental Psychology: Applied*. https://doi.org/10.1037/1076-898X.13.1.47

Boccia, M., Piccardi, L., Palermo, L., Nori, R., & Palmiero, M. (2015). Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.01195

Bos, M. W., Dijksterhuis, A., & Baaren, R. B. va. (2008). On the goal-dependency of unconscious thought. *Journal of Experimental Social Psychology*. https://doi.org/10.1016/j.jesp.2008.01.001

Bowden, E. M., & Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behavior research methods, instruments, & computers*, *35*(4), 634-639.

Brand, S., Reimer, T., & Opwis, K. (2007). How do we learn in a negative mood? Effects of a negative mood on transfer and learning. *Learning and Instruction*. https://doi.org/10.1016/j.learninstruc.2006.11.002

Braver, T. S. (2001). Anterior Cingulate Cortex and Response Conflict: Effects of Frequency, Inhibition and Errors. *Cerebral Cortex*. https://doi.org/10.1093/cercor/11.9.825

Braver, Todd S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., Janowsky, J. S., Taylor, S. F., Yesavage, J. A., Mumenthaler, M. S., Jagust, W. J., & Reed, B. R. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General*. https://doi.org/10.1037/0096-3445.130.4.746

Brown, D. C. (2014). Problems with the calculation of novelty metrics. In *Proceedings of the 6th int. conf. on design computing and cognition*.

Brown, L. A., Forbes, D., & McConnell, J. (2006). Limiting the use of verbal coding in the Visual Patterns Test. *Quarterly Journal of Experimental Psychology*. https://doi.org/10.1080/17470210600665954

Brown, R. T. (1989). Creativity: What are we to measure? *Handbook of Creativity*.

Browne, B. A., & Cruse, D. F. (1988). The Incubation Effect: Illusion or Illumination? *Human Performance*. https://doi.org/10.1207/s15327043hup0103_3

Buchwald, A. M., Strack, S., & Coyne, J. C. (1981). Demand characteristics and the Velten mood induction procedure. *Journal of Consulting and Clinical Psychology*. https://doi.org/10.1037/0022-006X.49.3.478

Burch, G. S. J., Hemsley, D. R., Pavelis, C., & Corr, P. J. (2006). Personality, creativity and latent inhibition. *European Journal of Personality*. https://doi.org/10.1002/per.572

Button, K. S., Ioannidis, J. P. A., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S. J., & Munafò, M. R. (2013). Power failure: Why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn3475

Cai, D. J., Mednick, S. A., Harrison, E. M., Kanady, J. C., & Mednick, S. C. (2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.0900271106

Campbell, D. T. (1960). Blind variation and selective retentions in creative thought as in other knowledge processes. *Psychological Review*. https://doi.org/10.1037/h0040373

Campbell, G., Duffy, A. H. B., Hay, L., Gilbert, S. J., McTeague, C., Coyle, D., & Grealy, M. A. (2020) Functional activity and connectivity during creative ideation in product design engineers. Manuscript in preparation.

Campbell, J. L., Quincy, C., Osserman, J., & Pedersen, O. K. (2013) "Coding In-Depth Semistructured Interviews: Problems of Unitization and Intercoder Reliability and Agreement." *Sociological Methods & Research.* 42 (3): 294–320. doi:10.1177/0049124113500475.

Campion, M., & Levita, L. (2014). Enhancing positive affect and divergent thinking abilities: Play some music and dance. Journal of Positive Psychology. https://doi.org/10.1080/17439760.2013.848376

Cao, J., Zhao, W., & Guo, X. (2021). Utilizing EEG to Explore Design Fixation during Creative Idea Generation. Computational Intelligence and Neuroscience, 2021. https://doi.org/10.1155/2021/6619598

Cardoso, C., & Badke-Schaub, P. (2009). Give Design a Break ? the Role of Incubation Periods During Idea Generation. *Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 2, Design Theory and Research Methodology*.

Cardoso, C., & Badke-Schaub, P. (2011). The influence of different pictorial representations during idea generation. *Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.2011.tb01092.x

Carroll, J. B. (1993). Human cognitive abilities: A survey of factor-analytic studies. Cambridge, UK: Cambridge University Press

Carruthers, L. Creativity and Attention: A Multi-Method Investigation. (Thesis). Edinburgh Napier University. Retrieved from http://researchrepository.napier.ac.uk/Output/1052411

Carson, S. (2006). Creativity and Mental Illness. Invitational Panel Discussion Hosted by Yale's Mind Matters Consortium, New Haven, CT., April 19, 2006.

Carson, S. H., Higgins, D. M., & Peterson, J. B. (2003). Decreased Latent Inhibition is Associated with Increased Creative Achievement in High-functioning Individuals. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/0022-3514.85.3.499

Carter, F. A., Wilson, J. S., Lawson, R. H., & Bulik, C. M. (1995). Mood induction procedure: Importance of individualising music. Behaviour change, 12(3), 159-161.

Carver, C. S. (2003). Pleasure as a sign you can attend to something else: Placing positive feelings within a general model of affect. In *Cognition and Emotion*. https://doi.org/10.1080/02699930302294

Casakin, H. P., & Goldschmidt, G. (2000). Reasoning by visual analogy in design problem-solving: The role of guidance. *Environment and Planning B: Planning and Design*. https://doi.org/10.1068/b2565

Casakin, H., & Goldschmidt, G. (1999). Expertise and the use of visual analogy: Implications for design education. *Design Studies*. https://doi.org/10.1016/S0142-694X(98)00032-5

Casakin, H., Davidovitch, N., & Milgram, R. M. (2010). Creative Thinking as a Predictor of Creative Problem Solving in Architectural Design Students. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/a0016965

Cash, P. J. (2018). Developing theory-driven design research. *Design Studies*. https://doi.org/10.1016/j.destud.2018.03.002

Cash, P. J., Hicks, B. J., & Culley, S. J. (2013). A comparison of designer activity using core design situations in the laboratory and practice. *Design Studies*. https://doi.org/10.1016/j.destud.2013.03.002

Cash, P., & Kreye, M. (2017). Uncertainty Driven Action (UDA) model: A foundation for unifying perspectives on design activity. Design Science, 3.

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology*. https://doi.org/10.1037/h0046743

Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working memory from the psychological and neurosciences perspectives: A review. Frontiers in Psychology, 9(MAR), 1–16. https://doi.org/10.3389/fpsyg.2018.00401

Chakrabarti, A., & Khadilkar, P. (2003). A measure for assessing product novelty. In *DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm* (pp. 159-160).

Chan, J., Fu, K., Schunn, C., Cagan, J., Wood, K., & Kotovsky, K. (2011). On the benefits and pitfalls of analogies for innovative design: Ideation performance based on analogical distance, commonness, and modality of examples. *Journal of Mechanical Design, Transactions of the ASME*. https://doi.org/10.1115/1.4004396

Chandrasekera, T., Vo, N., & D'Souza, N. (2013). The effect of subliminal suggestions on Sudden Moments of Inspiration (SMI) in the design process. *Design Studies*, *34*(2), 193–215. https://doi.org/10.1016/j.destud.2012.09.002

Chang, A., & Wilson, M. (2004). Recalling emotional experiences affects performance on reasoning problems. *Evolution and Human Behavior*. https://doi.org/10.1016/j.evolhumbehav.2004.03.007

Channon, S., & Baker, J. (1994). Reasoning strategies in depression: effects of depressed mood on a syllogism task. Personality and Individual Differences. https://doi.org/10.1016/0191-8869(94)90148-1

Chen, Q., Beaty, R. E., & Qiu, J. (2020). Mapping the artistic brain: Common and distinct neural activations associated with musical, drawing, and literary creativity. *Human Brain Mapping*. https://doi.org/10.1002/hbm.25025

Chen, Q., Beaty, R. E., Cui, Z., Sun, J., He, H., Zhuang, K., Ren, Z., Liu, G., & Qiu, J. (2019). Brain hemispheric involvement in visuospatial and verbal divergent thinking. NeuroImage. https://doi.org/10.1016/j.neuroimage.2019.116065

Chermahini, S. A., & Hommel, B. (2010). The (b)link between creativity and dopamine: Spontaneous eye blink rates predict and dissociate divergent and convergent thinking. Cognition. https://doi.org/10.1016/j.cognition.2010.03.007

Chermahini, S. A., & Hommel, B. (2012). More creative through positive mood? Not everyone! Frontiers in Human Neuroscience. https://doi.org/10.3389/fnhum.2012.00319

Chiang, N. C., & Chen, M. L. (2017). Benefits of Incubation on Divergent Thinking. *Creativity Research Journal*. https://doi.org/10.1080/10400419.2017.1360058

Chiu, H. L., Chan, P. T., Kao, C. C., Chu, H., Chang, P. C., Hsiao, S. T. S., Liu, D., Chang, W. C., & Chou, K. R. (2018). Effectiveness of executive function training on mental set shifting, working memory and inhibition in healthy older adults: A double-blind randomized controlled trials. *Journal of Advanced Nursing*. https://doi.org/10.1111/jan.13519

Chiu, I., & Shu, L. H. (2010). Potential limitations of verbal protocols in design experiments. *Proceedings of the ASME Design Engineering Technical Conference*. https://doi.org/10.1115/DETC2010-28675

Cho, S. H., Te Nijenhuis, J., Van Vianen, A. E. M., Kim, H. B., & Lee, K. H. (2010). The relationship between diverse components of intelligence and creativity. *Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.2010.tb01329.x

Choi, H. H., & Kim, M. J. (2017). The effects of analogical and metaphorical reasoning on design thinking. *Thinking Skills and Creativity*. https://doi.org/10.1016/j.tsc.2016.11.004

Christensen, B. T., & Ball, L. J. (2016). Creative analogy use in a heterogeneous design team: The pervasive role of background domain knowledge. *Design Studies*. https://doi.org/10.1016/j.destud.2016.07.004

Christensen, B. T., & Schunn, C. D. (2005). Spontaneous access and analogical incubation effects. In *Creativity Research Journal*. https://doi.org/10.1207/s15326934crj1702&3_7

Christensen, B. T., & Schunn, C. D. (2007). The relationship of analogical distance to analogical function and preinventive structure: The case of engineering design. Memory and Cognition. https://doi.org/10.3758/BF03195939

Christensen, P. R., Guilford, J. P., & Wilson, R. C. (1957). Relations of creative responses to working time and instructions. *Journal of Experimental Psychology*. https://doi.org/10.1037/h0045461

Christiaans, H., & Venselaar, K. (2005). Creativity in design engineering and the role of knowledge: Modelling the expert. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-004-1904-4

Chrysikou, E. G. (2018). The costs and benefits of cognitive control for creativity. In *The Cambridge Handbook of the Neuroscience of Creativity*. https://doi.org/10.1017/9781316556238.018

Cicchetti, D. V., & Sparrow, S. A. (1981). Developing criteria for establishing interrater reliability of specific items: applications to assessment of adaptive behaviour. American journal of mental deficiency.

Clapham, M. M. (2001). The effects of affect manipulation and information exposure on divergent thinking. Creativity Research Journal. https://doi.org/10.1207/s15326934crj1334_11

Clark, D. M. (1983). On the induction of depressed mood in the laboratory: Evaluation and comparison of the velten and musical procedures. Advances in Behaviour Research and Therapy. https://doi.org/10.1016/0146-6402(83)90014-0

Cobham, T. (2021, September, 07) “Student, 22, invents device to stop stab victims bleeding out in minutes”. *My London.* https://www.mylondon.news/news/uk-world-news/22-year-old-spurred-invent-21499959

Cohen, J. (1992). A power primer. Psychological Bulletin. https://doi.org/10.1037/0033-2909.112.1.155

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*. https://doi.org/10.1037/0033-295X.82.6.407

Convergent technologies. (1983). Word Processing User’s Guide. Retrieved from http://www.bitsavers.org/pdf/convergent/manuals/A-09-00722-01-A_Word_Processing_Users_Guide_Dec83.pdf

Corsi, P. M. (1973). Human memory and the medial temporal region of the brain. In *Dissertatopm Abstracts International*.

Corson, Y. (2002). Effects of positive, negative, and neutral moods on associative and semantic priming. *Cahiers de Psychologie Cognitive*.

Cramer-Petersen, C. L., Christensen, B. T., & Ahmed-Kristensen, S. (2019). Empirically analysing design reasoning patterns: Abductive-deductive reasoning patterns dominate design idea generation. Design Studies, 60, 39-70.

Crilly, N. (2019) Creativity and fixation in the real world: a literature review of case study research. Design Studies. 64, 154–168; doi:10.1016/J.DESTUD.2019.07.002.

Crilly, N., & Cardoso, C. (2017). Where next for research on fixation, inspiration and creativity in design? *Design Studies*. https://doi.org/10.1016/j.destud.2017.02.001

Cristofori, I., Cohen-Zimerman, S., & Grafman, J. (2019). Executive functions. In Handbook of Clinical Neurology (1st ed., Vol. 163). Elsevier B.V. https://doi.org/10.1016/B978-0-12-804281-6.00011-2

Cropley, A. (2006). In praise of convergent thinking. In *Creativity Research Journal*. https://doi.org/10.1207/s15326934crj1803_13

Cross, N. (1999). Natural intelligence in design. *Design Studies*. https://doi.org/10.1016/s0142-694x(98)00026-x

Cross, N. (2004). Expertise in design: an overview. *Design Studies*, *25*(5), 427–441. https://doi.org/10.1016/J.DESTUD.2004.06.002

Cseh, G. M., & Jeffries, K. K. (2019). A scattered CAT: A critical evaluation of the consensual assessment technique for creativity research. Psychology of Aesthetics, Creativity, and the Arts, 13(2), 159.

Cseh, G. M., Phillips, L. H., & Pearson, D. G. (2015). Flow, affect and visual creativity. Cognition and Emotion. https://doi.org/10.1080/02699931.2014.913553

Csikszentmihalyi, M. (1975). Beyond boredom and anxiety. San Francisco: Jossey-Bas

da Costa, C. G., Zhou, Q., & Ferreira, A. I. (2020). State and Trait Anger Predicting Creative Process Engagement—The Role of Emotion Regulation. Journal of Creative Behavior. https://doi.org/10.1002/jocb.236

Dahl, D. W., & Moreau, P. (2002). The influence and value of analogical thinking during new product ideation. *Journal of Marketing Research*. https://doi.org/10.1509/jmkr.39.1.47.18930

Dahl, D. W., Chattopadhyay, A., & Gorn, G. J. (2001). The importance of visualisation in concept design. *Design Studies*. https://doi.org/10.1016/S0142-694X(99)00028-9

Daly, S. R., Yilmaz, S., Christian, J. L., Seifert, C. M., & Gonzalez, R. (2012). Design heuristics in engineering concept generation.

Davidson, R. J. S. G. (1979). Frontal versus perietal EEG asymmetry during positive and negative affect. *Psychophysiology*, *16*(2), 202-203

Davis, M. A. (2009). Understanding the relationship between mood and creativity: A meta-analysis. *Organizational Behavior and Human Decision Processes*. https://doi.org/10.1016/j.obhdp.2008.04.001

Dawson, J. F. (2014). Moderation in management research: What, why, when, and how. Journal of business and psychology, 29(1), 1-19.

de Dreu, C. K. W., Nijstad, B. A., Baas, M., Wolsink, I., & Roskes, M. (2012). Working memory benefits creative insight, musical improvisation, and original ideation through maintained task-focused attention. *Personality and Social Psychology Bulletin*. https://doi.org/10.1177/0146167211435795

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulusesponse correspondence. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037//0096-1523.20.4.731

Della Sala, S., Gray, C., Baddeley, A., Allamano, N., & Wilson, L. (1999). Pattern span: A tool for unwelding visuo-spatial memory. Neuropsychologia. http://doi.org/10.1016/S0028-3932(98)00159-6

Derryberry, D., & Tucker, D. M. (1994). Motivating the Focus of Attention. In *The Heart's Eye*. https://doi.org/10.1016/b978-0-12-410560-7.50014-4

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*. https://doi.org/10.1146/annurev-psych-113011-143750

Dickerson, B. C., & Eichenbaum, H. (2010). The episodic memory system: Neurocircuitry and disorders. Neuropsychopharmacology, 35(1), 86–104. https://doi.org/10.1038/npp.2009.126

Diener, E., Kanazawa, S., Suh, E. M., & Oishi, S. (2015). Why People Are in a Generally Good Mood. Personality and Social Psychology Review. https://doi.org/10.1177/1088868314544467

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin and Review*. https://doi.org/10.3758/BF03196731

Dietrich, A. (2007). Who's afraid of a cognitive neuroscience of creativity? *Methods*. https://doi.org/10.1016/j.ymeth.2006.12.009

Dietrich, A. (2019). Where in the brain is creativity: a brief account of a wild-goose chase. In *Current Opinion in Behavioral Sciences*. https://doi.org/10.1016/j.cobeha.2018.09.001

Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. Psychological Bulletin, 136(5), 822–848. https://doi.org/10.1037/a0019749

Dijksterhuis, A., & Meurs, T. (2006). Where creativity resides: The generative power of unconscious thought. *Consciousness and Cognition*. https://doi.org/10.1016/j.concog.2005.04.007

Dijksterhuis, A., & Nordgren, L. F. (2006). A Theory of Unconscious Thought. *Perspectives on Psychological Science*. https://doi.org/10.1111/j.1745-6916.2006.00007.x

Dinar, M., Shah, J. J., Cagan, J., Leifer, L., Linsey, J., Smith, S. M., & Hernandez, N. V. (2015). Empirical Studies of Designer Thinking: Past, Present, and Future. *Journal of Mechanical Design, Transactions of the ASME*. https://doi.org/10.1115/1.4029025

Dodds, R. A., Smith, S. M., & Ward, T. B. (2002). The use of environmental clues during incubation. *Creativity Research Journal*. https://doi.org/10.1207/S15326934CRJ1434_1

Dodds, R. A., Ward, T. B., & Smith, S. M. (2004). A review of experimental research on incubation in problem solving and creativity. *Review Literature And Arts Of The Americas*.

Dominowski, R. L., & Jenrick, R. (1972). Effects of hints and interpolated activity on solution of an insight problem. *Psychonomic Science*. https://doi.org/10.3758/BF03328636

Dorfman, J. (1990). Metacognitions and incubation effects in insight problem solving

Dorst, K., & Cross, N. (2001). Creativity in the design process: co-evolution of problem–solution. *Design Studies*, *22*(5), 425–437. https://doi.org/10.1016/S0142-694X(01)00009-6

Dorta, T., Lesage, A., Pérez, E., & Bastien, J. M. C. (2011). Signs of Collaborative Ideation and the Hybrid Ideation Space. In Design Creativity 2010. https://doi.org/10.1007/978-0-85729-224-7_26

Dorta, T., Pérez, E., & Lesage, A. (2008). The ideation gap: hybrid tools, design flow and practice. Design Studies. https://doi.org/10.1016/j.destud.2007.12.004

Drace, S. (2013). Evidence for the role of affect in mood congruent recall of autobiographic memories. Motivation and Emotion. https://doi.org/10.1007/s11031-012-9322-5

Duff, M. C., Kurczek, J., Rubin, R., Cohen, N. J., & Tranel, D. (2013). Hippocampal amnesia disrupts creative thinking. *Hippocampus*. https://doi.org/10.1002/hipo.22208

Duffy, A., Hay, L., Grealy, M., & Vuletic, T. (2019, October). ImagineD: a vision for cognitive driven creative design. In *30th Anniversary Heron Island Conference on Computational and Cognitive Models of Creativity*.

Dumas, D. (2017). Relational reasoning in science, medicine, and engineering. Educational Psychology Review, 29(1), 73-95.

Dumas, D., Schmidt, L. C., & Alexander, P. A. (2016). Predicting creative problem solving in engineering design. *Thinking Skills and Creativity*. https://doi.org/10.1016/j.tsc.2016.05.002

Dumas, D., Schmidt, L. C., & Alexander, P. A. (2016). Predicting creative problem solving in engineering design. Thinking Skills and Creativity, 21, 50-66.

Duncker, K. (1945). On Problem Solving: Psychological Monographs. *American Psychological Assiciation Psychological Bulletin*.

Eckert, C., & Stacey, M. (2003). Sources of Inspiration in Industrial Practice. The Case of Knitwear Design. *J. of Design Research*. https://doi.org/10.1504/jdr.2003.009826

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*. https://doi.org/10.1038/nn1594

Egner, T., Delano, M., & Hirsch, J. (2007). Separate conflict-specific cognitive control mechanisms in the human brain. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2006.11.061

Ekstrom, R. B., Dermen, D., & Harman, H. H. (1976). *Manual for kit of factor-referenced cognitive tests* (Vol. 102). Princeton, NJ: Educational testing service.

Ellwood, S., Pallier, G., Snyder, A., & Gallate, J. (2009). The incubation effect: Hatching a solution? *Creativity Research Journal*. https://doi.org/10.1080/10400410802633368

Engeser, S., & Schiepe-Tiska, A. (2012). Historical lines and an overview of current research on flow. In Advances in Flow Research. https://doi.org/10.1007/978-1-4614-2359-1_1

Eysenck, H. J. (1993). Creativity and Personality: Suggestions for a Theory. *Psychological Inquiry*. https://doi.org/10.1207/s15327965pli0403_1

Eysenck, H. J. (1995). Creativity as a Product of Intelligence and Personality. In *International Handbook of Personality and Intelligence*. https://doi.org/10.1007/978-1-4757-5571-8_12

Fartoukh, M., Chanquoy, L., & Piolat, A. (2014). Mood induction in children: Effect of the affective valence of a text on phonological working memory. Advances in Cognitive Psychology. https://doi.org/10.5709/acp-0162-z

Feist, G. J. (2010). #6 The Function of Personality in Creativity. The Nature and Nurture of the Creative Personality. In The Cambridge Handbook of Creativity.

Fernández-Abascal, E. G., & Díaz, M. D. M. (2013). Affective Induction and Creative Thinking. Creativity Research Journal. https://doi.org/10.1080/10400419.2013.783759

Figueira, J. S. B., Oliveira, L., Pereira, M. G., Pacheco, L. B., Lobo, I., Motta-Ribeiro, G. C., & David, I. A. (2017). An unpleasant emotional state reduces working memory capacity: Electrophysiological evidence. Social Cognitive and Affective Neuroscience, 12(6), 984–992.

Finke, R A. (1990). Creative Imagery: Discoveries and Inventions in Visualization. In *Hillsdale NJ England Lawrence Erlbaum Associates Inc 1990 ix*.

Finke, R. A. (1996). Imagery, creativity, and emergent structure. Consciousness and Cognition. https://doi.org/10.1006/ccog.1996.0024

Finke, R. A., & Slayton, K. (1988). Explorations of creative visual synthesis in mental imagery. Memory & Cognition. https://doi.org/10.3758/BF03197758

Forgas, J. P. (2002). Feeling and doing: Affective influences on interpersonal behavior. In Psychological Inquiry. https://doi.org/10.1207/S15327965PLI1301_01

Fredrickson, B. L. (2001). The Role of Positive Emotions in Positive Psychology. The American Psychologist. https://doi.org/10.1037/0003-066x.56.3.218

Friedman, N. P., & Miyake, A. (2004). The Relations Among Inhibition and Interference Control Functions: A Latent-Variable Analysis. *Journal of Experimental Psychology: General*. https://doi.org/10.1037/0096-3445.133.1.101

Friedman, R. S., & Förster, J. (2010). Implicit affective cues and attentional tuning: An integrative review. *Psychological Bulletin*, Friedman, R. S., Förster, J. (2010). Implicit af. https://doi.org/10.1037/a0020495

Friedman, R. S., Förster, J., & Denzler, M. (2007). Interactive effects of mood and task framing on creative generation. Creativity Research Journal. https://doi.org/10.1080/10400410701397206

Frijda, N. H. (1993). Moods, emotion episodes, and emotions. Handbook of emotions. In Handbook of emotions.

Frith, E., Elbich, D., Christensen, A. P., Rosenberg, M. D., Chen, Q., Silvia, P., ... & Beaty, R. E. (2019). Intelligence and Creativity Share a Common Cognitive and Neural Basis.

Frühholz, S., Fehr, T., & Herrmann, M. (2009). Interference control during recognition of facial affect enhances the processing of expression specific properties - An event-related fMRI study. *Brain Research*. https://doi.org/10.1016/j.brainres.2009.03.017

Fu, K. K., Sylcott, B., & Das, K. (2019). Using fMRI to deepen our understanding of design fixation. *Design Science*. https://doi.org/10.1017/dsj.2019.21

Fulford, J., Milton, F., Salas, D., Smith, A., Simler, A., Winlove, C., & Zeman, A. (2018). The neural correlates of visual imagery vividness – An fMRI study and literature review. *Cortex*. https://doi.org/10.1016/j.cortex.2017.09.014

Gallate, J., Wong, C., Ellwood, S., Roring, R. W., & Snyder, A. (2012). Creative People Use Nonconscious Processes to Their Advantage. Creativity Research Journal. https://doi.org/10.1080/10400419.2012.677282

Gendolla, G. H., & Krüsken, J. A. N. (2001). The joint impact of mood state and task difficulty on cardiovascular and electrodermal reactivity in active coping. Psychophysiology, 38(3), 548-556.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*. https://doi.org/10.1016/S0364-0213(83)80009-3

George, J. M., & Zhou, J. (2002). Understanding when bad moods foster creativity and good ones don't: The role of context and clarity of feelings. Journal of Applied Psychology. https://doi.org/10.1037/0021-9010.87.4.687

George, T., & Wiley, J. (2020). Need something different? Here's what's been done: Effects of examples and task instructions on creative idea generation. *Memory and Cognition*. https://doi.org/10.3758/s13421-019-01005-4

Georgiev, G. V., & Georgiev, D. D. (2018). Enhancing user creativity: Semantic measures for idea generation. *Knowledge-Based Systems*. https://doi.org/10.1016/j.knosys.2018.03.016

Gero, J. S. (1996). Creativity, emergence and evolution in design. Knowledge-Based Systems. https://doi.org/10.1016/S0950-7051(96)01054-4

Gero, J. S., & Tang, H. H. (2001). The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process. *Design Studies*. https://doi.org/10.1016/S0142-694X(00)00030-2

Gero, J. S., Jiang, H., & Williams, C. B. (2013). Design cognition differences when using unstructured, partially structured, and structured concept generation creativity techniques. *International Journal of Design Creativity and Innovation*. https://doi.org/10.1080/21650349.2013.801760

Ghiselin, B. (1952). The Creative Process. New York, NY: New American Library.

Gilhooly, K. J., (2016). Incubation and intuition in creative problem solving. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2016.01076

Gilhooly, K. J., Fioratou, E., Anthony, S. H., & Wynn, V. (2007). Divergent thinking: Strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology*. https://doi.org/10.1348/096317907X173421

Gilhooly, K. J., Georgiou, G. J., Garrison, J., Reston, J. D., & Sirota, M. (2012). Don't wait to incubate: Immediate versus delayed incubation in divergent thinking. *Memory and Cognition*. https://doi.org/10.3758/s13421-012-0199-z

Gilhooly, K. J., Georgiou, G. J., Sirota, M., & Paphiti-Galeano, A. (2015). Incubation and suppression processes in creative problem solving. Thinking and Reasoning. https://doi.org/10.1080/13546783.2014.953581

Gilhooly, K. J., Georgiou, G., & Devery, U. (2013). Incubation and creativity: Do something different. *Thinking and Reasoning*. https://doi.org/10.1080/13546783.2012.749812

Goel, V., & Pirolli, P. (1992). The structure of design problem spaces. *Cognitive Science*. https://doi.org/10.1016/0364-0213(92)90038-V

Goff, K., & Torrance, E. P. (2002). Abbreviated Torrance Test for Adults manual. Bensenville, IL: Scholastic Testing Service, Inc

Göker, M. H. (1997). The effects of experience during design problem solving. *Design Studies*. https://doi.org/10.1016/s0142-694x(97)00009-4

Goldschmidt, G. (1991). The Dialectics of Sketching. *Creativity Research Journal*. https://doi.org/10.1080/10400419109534381

Goldschmidt, G. (2014). Modeling the Role of Sketching in Design Idea Generation. In *An Anthology of Theories and Models of Design*. https://doi.org/10.1007/978-1-4471-6338-1_21

Goldschmidt, G. (2016). Linkographic Evidence for Concurrent Divergent and Convergent Thinking in Creative Design. *Creativity Research Journal*. https://doi.org/10.1080/10400419.2016.1162497

Goldschmidt, G. (2017). *Manual Sketching: Why Is It Still Relevant?* https://doi.org/10.1007/978-3-319-56466-1_4

Goldschmidt, G., & Sever, A. L. (2011). Inspiring design ideas with texts. *Design Studies*. https://doi.org/10.1016/j.destud.2010.09.006

Goldschmidt, G., & Smolkov, M. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies*. https://doi.org/10.1016/j.destud.2006.01.002

Gonçalves, M., & Cash, P. (2021). The life cycle of creative ideas: Towards a dual-process theory of ideation. Design Studies, 72, 100988.

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2016). Inspiration choices that matter: The selection of external stimuli during ideation. *Design Science*. https://doi.org/10.1017/dsj.2016.10

Göritz, A. S., & Moser, K. (2003). Mood and flexibility in categorization: A conceptual replication. Perceptual and Motor Skills. https://doi.org/10.2466/pms.2003.97.1.107

Goucher-Lambert, K., Moss, J., & Cagan, J. (2019). A neuroimaging investigation of design ideation with and without inspirational stimuli—understanding the meaning of near and far stimuli. *Design Studies*. https://doi.org/10.1016/j.destud.2018.07.001

Gray-Burrows, K., Taylor, N., O'Connor, D., Sutherland, E., Stoet, G., & Conner, M. (2019). A systematic review and meta-analysis of the executive function-health behaviour relationship. In *Health Psychology and Behavioral Medicine*. https://doi.org/10.1080/21642850.2019.1637740

Greenberg, J., & Meiran, N. (2014). The role of emotional engagement and mood valence in retrieval fluency of mood incongruent autobiographical memory. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2014.00083

Groborz, M., & Nęcka, E. (2003). Creativity and Cognitive Control: Explorations of Generation and Evaluation Skills. *Creativity Research Journal*. https://doi.org/10.1207/s15326934crj152&3_09

Guilford, J. P. (1950). Creativity. *American Psychologist*. https://doi.org/10.1037/h0063487

Guilford, J. P. (1957). Creative abilities in the arts. *Psychological Review*. https://doi.org/10.1037/h0048280

Haager, J. S., Kuhbandner, C., & Pekrun, R. (2014). Overcoming fixed mindsets: The role of affect. Cognition and Emotion. https://doi.org/10.1080/02699931.2013.851645

Han, W., Feng, X., Zhang, M., Peng, K., & Zhang, D. (2019). Mood states and everyday creativity: Employing an experience sampling method and a day reconstruction method. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2019.01698

Hänze, M., & Hesse, F. W. (1993). Emotional Influences on Semantic Priming. *Cognition and Emotion*. https://doi.org/10.1080/02699939308409184

Hao, N., Ku, Y., Liu, M., Hu, Y., Grabner, R. H., & Fink, A. (2014). Enhancing Verbal Creativity via Brief Interventions During an Incubation Interval. Creativity Research Journal. https://doi.org/10.1080/10400419.2014.873658

Hao, N., Liu, M., Ku, Y., Hu, Y., & Runco, M. A. (2015). Verbal divergent thinking facilitated by a pleasurable incubation interval. Psychology of Aesthetics, Creativity, and the Arts. https://doi.org/10.1037/a0038851

Hatcher, G., Ion, W., Maclachlan, R., Wodehouse, A., Sheridan, M., & Simpson, B. (2016). Humour processes for creative engineering design. Proceedings of International Design Conference, DESIGN.

Hay, L., Duffy, A. H. B., Gilbert, S. J., Lyall, L., Campbell, G., Coyle, D., & Grealy, M. A. (2019a). The neural correlates of ideation in product design engineering practitioners. *Design Science*. https://doi.org/10.1017/dsj.2019.27

Hay, L., Duffy, A. H. B., McTeague, C., Pidgeon, L. M., Vuletic, T., & Grealy, M. (2017a). A systematic review of protocol studies on conceptual design cognition: Design as search and exploration. *Design Science*, *3*, 1–36. https://doi.org/10.1017/dsj.2017.11

Hay, L., Duffy, A. H. B., McTeague, C., Pidgeon, L. M., Vuletic, T., & Grealy, M. (2017b). Towards a shared ontology: A generic classification of cognitive processes in conceptual design. *Design Science*, *3*, 1–42. https://doi.org/10.1017/dsj.2017.6

Hay, L., Duffy, A. H., Grealy, M., Tahsiri, M., McTeague, C., & Vuletic, T. (2020). A novel systematic approach for analysing exploratory design ideation. *Journal of Engineering Design*, *31*(3), 127-149.

Hay, L., Duffy, A., & Grealy, M. (2019b). The novelty perspectives framework: a new conceptualisation of novelty for cognitive design studies. In *Proceedings of the Design Society: International Conference on Engineering Design* (Vol. 1, No. 1, pp. 389-398). Cambridge University Press.

Hayes, A. F., & Rockwood, N. J. (2017). Regression-based statistical mediation and moderation analysis in clinical research: Observations, recommendations, and implementation. Behaviour research and therapy, 98, 39-57.

He, W. J., Wong, W. C., & Hui, A. N. N. (2017). Emotional reactions mediate the effect of music listening on creative thinking: Perspective of the arousal-and-mood hypothesis. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2017.01680

Hélie, S., & Sun, R. (2010). Incubation, insight, and creative problem solving: A unified theory and a connectionist model. *Psychological Review*. https://doi.org/10.1037/a0019532

Helm, K. C., Jablokow, K. W., Daly, S. R., Silk, E. M., Yilmaz, S., & Suero, R. (2016). Evaluating the impacts of different interventions on quality in concept generation. ASEE Annual Conference and Exposition, Conference Proceedings, 2016-June. https://doi.org/10.18260/p.26766

Hendrik, B., Ali, N. M., Sulaiman, R., Masril, M., & Fikri, H. T. (2019). Relationship between intellectual intelligence, Figural Creativity, and Innovation. 229(Iciap 2018), 545–555. https://doi.org/10.2991/iciap-18.2019.46

Henok, N., Vallée-Tourangeau, F., & Vallée-Tourangeau, G. (2020). Incubation and interactivity in insight problem solving. Psychological Research, 84(1), 128–139. https://doi.org/10.1007/s00426-018-0992-9

Hervas, G., & López-Gómez, I. (2016). The power of extraverts: Testing positive and negative mood regulation. Anales de Psicología / Annals of Psychology. https://doi.org/10.6018/analesps.32.3.261641

Hills, A. M., Hill, S., Mamone, N., & Dickerson, M. (2001). Induced mood and persistence at gaming. Addiction. https://doi.org/10.1046/j.1360-0443.2001.961116299.x

Howard, S. J., Johnson, J., & Pascual-Leone, J. (2014). Clarifying inhibitory control: Diversity and development of attentional inhibition. *Cognitive Development*. https://doi.org/10.1016/j.cogdev.2014.03.001

Hunt, E. (1994). Creative approches to cognition. Creative cognition: Theory, research and applications. R. A. Finke, T. B. Ward and S. M. Smith. Cambridge, MA: MIT Press (Bradford Books), 1992. No. of pages 240. ISBN 0-262-06150-3. *Applied Cognitive Psychology*. https://doi.org/10.1002/acp.2350080511

Isen, A. M., & Daubman, K. A. (1984). The influence of affect on categorization. Journal of Personality and Social Psychology. https://doi.org/10.1037/0022-3514.47.6.1206

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive Affect Facilitates Creative Problem Solving. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/0022-3514.52.6.1122

Isen, A. M., Johnson, M. M. S., Mertz, E., & Robinson, G. F. (1985). The Influence of Positive Affect on the Unusualness of Word Associations. Journal of Personality and Social Psychology. https://doi.org/10.1037/0022-3514.48.6.1413

Jaarsveld, S., & Lachmann, T. (2017). Intelligence and creativity in problem solving: The importance of test features in cognition research. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2017.00134

Jackson, B. (2020, November, 17) “The Mountain Rescue Drone Revolution”. *COPTRZ.com https://coptrz.com/the-mountain-rescue-drone-revolution/*

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National*

Academy of Sciences of the United States of America. https://doi.org/10.1073/pnas.0801268105

Jallais, C., & Gilet, A. L. (2010). Inducing changes in arousal and valence: Comparison of two mood induction procedures. Behavior Research Methods. https://doi.org/10.3758/BRM.42.1.318

Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*. https://doi.org/10.1016/0142-694X(91)90003-F

Jefferies, L. N., Smilek, D., Eich, E., & Enns, J. T. (2008). Emotional valence and arousal interact in attentional control. Psychological science, 19(3), 290-295.

Jeon, K. N., Moon, S. M., & French, B. (2011). Differential effects of divergent thinking, domain knowledge, and interest on creative performance in art and math. Creativity Research Journal. https://doi.org/10.1080/10400419.2011.545750

Jin, Y., & Benami, O. (2010). Creative patterns and stimulation in conceptual design. Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM. https://doi.org/10.1017/S0890060410000053

Jin, Y., & Chusilp, P. (2006). Study of mental iteration in different design situations. *Design Studies*. https://doi.org/10.1016/j.destud.2005.06.003

Johnston, R., Jones, K., & Manley, D. (2018). Confounding and collinearity in regression analysis: a cautionary tale and an alternative procedure, illustrated by studies of British voting behaviour. Quality and Quantity. https://doi.org/10.1007/s11135-017-0584-6

Johnston, J., Madill, A., Koutsopoulou, G., Brown, C., & Harris, R. (2020, September). Tackling gender imbalance in psychology. The Psychologist.

https://thepsychologist.bps.org.uk/volume-33/september-2020/tackling-gender-imbalance-psychology

Jonides, J., & Smith, E. E. (1997). The architecture of working. *Cognitive neuroscience*, *243*.

Joormann, J., & Siemer, M. (2004). Memory Accessibility, Mood Regulation, and Dysphoria: Difficulties in Repairing Sad Mood with Happy Memories? Journal of Abnormal Psychology. https://doi.org/10.1037/0021-843X.113.2.179

Joormann, J., Cooney, R. E., Henry, M. L., & Gotlib, I. H. (2012). Neural correlates of automatic mood regulation in girls at high risk for depression. Journal of Abnormal Psychology. https://doi.org/10.1037/a0025294

Joseph, D. L., Chan, M. Y., Heintzelman, S. J., Tay, L., Diener, E., & Scotney, V. S. (2020). The Manipulation of Affect: A Meta-Analysis of Affect Induction Procedures. Psychological Bulletin. https://doi.org/10.1037/bul0000224

Jung, N., Wranke, C., Hamburger, K., & Knauff, M. (2014). How emotions affect logical reasoning: evidence from experiments with mood-manipulated participants, spider phobics, and people with exam anxiety. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2014.00570

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., Reber, P. J., & Kounios, J. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biology*. https://doi.org/10.1371/journal.pbio.0020097

Kaplan, C. A., & Davidson, J. (1989). Hatching a theory of incubation effects. Technical Report AIP-98, The Artificial Intelligence and Psychology Project.

Kaufman, J C, Plucker, J. a, & Baer, J. (2008a). Essentials of creativity assessment. In *Essentials of psychological assessment series*.

Kaufman, James C., Baer, J., Cole, J. C., & Sexton, J. D. (2008b). A comparison of expert and nonexpert raters using the consensual assessment technique. *Creativity Research Journal*. https://doi.org/10.1080/10400410802059929

Kaufman, S. B., Quilty, L. C., Grazioplene, R. G., Hirsh, J. B., Gray, J. R., Peterson, J. B., & Deyoung, C. G. (2016). Openness to Experience and Intellect Differentially Predict Creative Achievement in the Arts and Sciences. Journal of Personality. https://doi.org/10.1111/jopy.12156

Kaufmann, G., & Vosburg, S. K. (2002). The effects of mood on early and late idea production. Creativity Research Journal. https://doi.org/10.1207/S15326934CRJ1434_3

Keane, M. (1985). On drawing analogies when solving problems: A theory and test of solution generation in an analogical problem-solving task. *British Journal of Psychology*. https://doi.org/10.1111/j.2044-8295.1985.tb01968.x

Keller, A. I., Pasman, G. J., & Stappers, P. J. (2006). Collections designers keep: Collecting visual material for inspiration and reference. *CoDesign*. https://doi.org/10.1080/15710880600571123

Kenealy, P. (1988). Validation of a Music Mood Induction Procedure: Some Preliminary Findings. Cognition and Emotion. https://doi.org/10.1080/02699938808415228

Kenett, Y. N., & Faust, M. (2019). A Semantic Network Cartography of the Creative Mind. In *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2019.01.007

Kenett, Y. N., Anaki, D., & Faust, M. (2014). Investigating the structure of semantic networks in low and high creative persons. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2014.00407

Kent, G. H., & Rosanoff, A. J. (1910). A study of association in insanity. American Journal of

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior Cingulate Conflict Monitoring and Adjustments in Control. *Science*. https://doi.org/10.1126/science.1089910

Khalfa, S., Roy, M., Rainville, P., Dalla Bella, S., & Peretz, I. (2008). Role of tempo entrainment in psychophysiological differentiation of happy and sad music? International Journal of Psychophysiology. https://doi.org/10.1016/j.ijpsycho.2007.12.001

Khalil, R., Godde, B., & Karim, A. A. (2019). The link between creativity, cognition, and creative drives and underlying neural mechanisms. Frontiers in Neural Circuits, 13(March), 1–16. https://doi.org/10.3389/fncir.2019.00018

Kim, J. E., Bouchard, C., Omhover, J. F., & Aoussat, A. (2010). Towards a model of how designers mentally categorise design information. *CIRP Journal of Manufacturing Science and Technology*. https://doi.org/10.1016/j.cirpj.2010.11.004

Kim, K. H. (2005). Can Only Intelligent People Be Creative? A Meta-Analysis. *Journal of Secondary Gifted Education*. https://doi.org/10.4219/jsge-2005-473

Kim, Y. S., Kim, M. H., & Jin, S. T., Cognitive characteristics and design creativity: and experimental, Cognitive Characteristics and Design Creativity: An Experimental

Study, Proc. ASME Int'l. Conf. Design Theory and Methodology, Long Beach, 2005.

Kim, Y., Jin, S., & Lee, H. (2005). Dual protocol analysis based on design information and design process : A case study. *Studying Designers '05*.

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of Experimental Psychology*. https://doi.org/10.1037/h0043688

Kleinmintz, O. M., Ivancovsky, T., & Shamay-Tsoory, S. G. (2019). The twofold model of creativity: the neural underpinnings of the generation and evaluation of creative ideas. In *Current Opinion in Behavioral Sciences*. https://doi.org/10.1016/j.cobeha.2018.11.004

Kohn, N., & Smith, S. M. (2009). Partly versus completely out of your mind: Effects of incubotion and distraction on resolving fixation. *Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.2009.tb01309.x

Kokotovich, V., & Purcell, T. (2000). Mental synthesis and creativity in design: An experimental examination. Design Studies, 21(5), 437–449. https://doi.org/10.1016/s0142-694x(00)00017-x

Kolodner, J. L., & Wills, L. M. (1996). Powers of observation in creative design. *Design Studies*. https://doi.org/10.1016/S0142-694X(96)00021-X

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. Journal of chiropractic medicine, 15(2), 155-163.

Koppel, R. H., & Storm, B. C. (2014). Escaping mental fixation: Incubation and inhibition in creative problem solving. *Memory*. https://doi.org/10.1080/09658211.2013.789914

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus-response compatibility--a model and taxonomy [published erratum appears in Psychol Rev 1992 Jan;99(1):44]. *Psychological Review*.

Kosslyn, S. M. 1995 Mental imagery. In Visual Cognition: An Invitation to Cognitive Science, Vol. 2 (ed. S. M. Kosslyn & D. N. Osherson), pp. 267–296. Cambridge)

Kosslyn, S. M., & Thompson, W. L. (2003). When Is Early Visual Cortex Activated during Visual Mental Imagery? In *Psychological Bulletin*. https://doi.org/10.1037/0033-2909.129.5.723

Kounios, J., Fleck, J. I., Green, D. L., Payne, L., Stevenson, J. L., Bowden, E. M., & Jung-Beeman, M. (2008). The origins of insight in resting-state brain activity. *Neuropsychologia*. https://doi.org/10.1016/j.neuropsychologia.2007.07.013

Krawczyk, D. C. (2018). Deduction and Induction. In *Reasoning*. https://doi.org/10.1016/b978-0-12-809285-9.00009-0

Kudrowitz, B. M. (2010). HaHa and Aha! Creativity, Idea Generation, Improvisational Humour, and Product Design. M.S. Mechanical Engineering, 116. http://hdl.handle.net/1721.1/61610

Kwon, J., Bromback, L., & Kudrowitz, B. (2017). Divergent thinking ability + interest = Creative ideas: Exploring the relationships between cognitive creativity assessments and product design idea generation. *Proceedings of the ASME Design Engineering Technical Conference*. https://doi.org/10.1115/DETC2017-67261

Lakens, D., McLatchie, N., Isager, P. M., Scheel, A. M., & Dienes, Z. (2020). Improving Inferences about Null Effects with Bayes Factors and Equivalence Tests. Journals of Gerontology - Series B Psychological Sciences and Social Sciences, 75(1), 45–57. https://doi.org/10.1093/geronb/gby065

Lapteva, E. M., Valueva, E. A., Zaidelman, L. Y., & Zinina, A. A. (2020). Incubation Research: Potential of Within Subject and Between Subject Experimental Design. Experimental Psychology (Russia), 13(2), 28-39.

Lavric, A., Rippon, G., & Gray, J. R. (2003). Threat-evoked anxiety disrupts spatial working memory performance: An attentional account. Cognitive Therapy and Research, 27(5), 489–504. https://doi.org/10.1023/A:1026300619569

LeBoutillier, N., & Marks, D. F. (2003). Mental imagery and creativity: A meta-analytic review study. In *British Journal of Psychology*. https://doi.org/10.1348/000712603762842084

Lee, C. S., & Therriault, D. J. (2013). The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes. *Intelligence*. https://doi.org/10.1016/j.intell.2013.04.008

Lee, C. S., Huggins, A. C., & Therriault, D. J. (2014). A measure of creativity or intelligence?: Examining internal and external structure validity evidence of the remote associates test. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/a0036773

Legg, S., & Hutter, M. (2007). Universal intelligence: A definition of machine intelligence. *Minds and machines*, *17*(4), 391-444.

Leszczynski, M., Chaieb, L., Reber, T. P., Derner, M., Axmacher, N., & Fell, J. (2017). Mind wandering simultaneously prolongs reactions and promotes creative incubation. *Scientific Reports*. https://doi.org/10.1038/s41598-017-10616-3

Li, Y., Wang, J., Li, X., & Zhao, W. (2007). Design creativity in product innovation. International Journal of Advanced Manufacturing Technology, 33(3–4), 213–222. https://doi.org/10.1007/s00170-006-0457-y

Liao, S. C., Hunt, E. A., & Chen, W. (2010). Comparison between inter-rater reliability and inter-rater agreement in performance assessment. *Annals Academy of Medicine Singapore*, *39*(8), 613.

Linsey, J. S., Wood, K. L., & Markman, A. B. (2008). Increasing innovation: Presentation and evaluation of the wordtree design-by-analogy method. *Proceedings of the ASME Design Engineering Technical Conference*. https://doi.org/10.1115/DETC2008-49317

Linsey, J., Tseng, I., Fu, K., Cagan, J., & Wood, K. L. (2009). Reducing and perceiving design fixation: Initial results from an NSF-sponsored workshop. *DS 58-9: Proceedings of ICED 09, the 17th International Conference on Engineering Design*.

Liu, L., Li, Y., Xiong, Y., Cao, J., & Yuan, P. (2018a). An EEG study of the relationship between design problem statements and cognitive behaviors during conceptual design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM*. https://doi.org/10.1017/S0890060417000683

Liu, S., Erkkinen, M. G., Healey, M. L., Xu, Y., Swett, K. E., Chow, H. M., & Braun, A. R. (2015). Brain activity and connectivity during poetry composition: Toward a multidimensional model of the creative process. *Human Brain Mapping*. https://doi.org/10.1002/hbm.22849

Liu, Y. C., Bligh, T., & Chakrabarti, A. (2003). Towards an "ideal" approach for concept generation. *Design Studies*. https://doi.org/10.1016/S0142-694X(03)00003-6

Liu, Y. T. (1996). Is designing one search or two? A model of design thinking involving symbolism and connectionism. *Design Studies*. https://doi.org/10.1016/S0142-694X(96)00018-X

Liu, Ye, Fu, Q. F., & Fu, X. L. (2009). The interaction between cognition and emotion. In Chinese Science Bulletin. https://doi.org/10.1007/s11434-009-0632-2

Liu, Z., Zhang, J., Xie, X., Rolls, E. T., Sun, J., Zhang, K., Jiao, Z., Chen, Q., Zhang, J., Qiu, J., & Feng, J. (2018b). Neural and genetic determinants of creativity. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2018.02.067

Lloyd, P., & Oak, A. (2018). Cracking open co-creation: Categories, stories, and value tension in a collaborative design process. *Design Studies*. https://doi.org/10.1016/j.destud.2018.02.003

Lloyd, P., Lawson, B., & Scott, P. (1995). Can concurrent verbalization reveal design cognition? *Design Studies*. https://doi.org/10.1016/0142-694X(94)00011-2

Luchins, A. S. (1942). Mechanization in problem solving: The effect of Einstellung. *Psychological Monographs*. https://doi.org/10.1037/h0093502

Luo, C., & Proctor, R. W. (2018). The location-, word-, and arrow-based Simon effects: An ex-Gaussian analysis. *Memory and Cognition*. https://doi.org/10.3758/s13421-017-0767-3

Ma, G. L., Li, Y., Li, W. Q., & Pan, P. Y. (2011). A process model and method of idea generation for conceptual design. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225(4), 568–586. https://doi.org/10.1177/2041297510394103

MacDonald, R., Byrne, C., & Carlton, L. (2006). Creativity and flow in musical composition: an empirical investigation. Psychology of Music. https://doi.org/10.1177/0305735606064838

MacGregor, J. N., Ormerod, T. C., & Chronicle, E. P. (2001). Information processing and insight. Journal of Experimental Psychology: Learning, Memory, and Cognition, 27, 176–120. https://doi.org/10.1037/0278-7393.27.1.176.

Madore, K. P., Addis, D. R., & Schacter, D. L. (2015). Creativity and memory: Effects of an episodic-specificity induction on divergent thinking. *Psychological Science*. https://doi.org/10.1177/0956797615591863

Madore, K. P., Jing, H. G., & Schacter, D. L. (2016a). Divergent creative thinking in young and older adults: Extending the effects of an episodic specificity induction. *Memory and Cognition*. https://doi.org/10.3758/s13421-016-0605-z

Madore, K. P., Szpunar, K. K., Addis, D. R., & Schacter, D. L. (2016b). Episodic specificity induction impacts activity in a core brain network during construction of imagined future experiences. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1612278113

Madore, K. P., Thakral, P. P., Beaty, R. E., Addis, D. R., & Schacter, D. L. (2019). Neural Mechanisms of Episodic Retrieval Support Divergent Creative Thinking. *Cerebral Cortex*. https://doi.org/10.1093/cercor/bhx312

Maher, M. Lou, & Tang, H. H. (2003). Co-evolution as a computational and cognitive model of design. *Research in Engineering Design*. https://doi.org/10.1007/s00163-002-0016-y

Marcusson-Clavertz, D., Kjell, O. N. E., Persson, S. D., & Cardeña, E. (2019). Online validation of combined mood induction procedures. PLoS ONE. https://doi.org/10.1371/journal.pone.0217848

Marks, D. F. (1973). Visual Imagery Differences in the Recal of Pictures. *British Journal of Psychology*. https://doi.org/10.1111/j.2044-8295.1973.tb01322.x

Martin, A. (2009). Semantic memory. In *Encyclopedia of Neuroscience*. https://doi.org/10.1016/B978-008045046-9.00786-5

Martin, E. A., & Kerns, J. G. (2011). The influence of positive mood on different aspects of cognitive control. *Cognition and Emotion*. https://doi.org/10.1080/02699931.2010.491652

Martin, L. L. (2001). Mood as input: A configural view of mood effects. In Theories of Mood and Cognition: A User's Guidebook.

Martin, L. L., Ward, D. W., Achee, J. W., & Wyer, R. S. (1993). Mood as Input: People Have to Interpret the Motivational Implications of Their Moods. Journal of Personality and Social Psychology. https://doi.org/10.1037/0022-3514.64.3.317

Martin, M. A., & Metha, A. (1997). Recall of early childhood memories through musical mood induction. The Arts in Psychotherapy.

Martindale, C. (1995). Creativity and connectionism. In *Creative cognition approach*.

Marvel, C. L., & Paradiso, S. (2004). Cognitive and neurological impairment in mood disorders. In Psychiatric Clinics of North America. https://doi.org/10.1016/S0193-953X(03)00106-0

Mauss, I. B., & Robinson, M. D. (2009). Measures of emotion: A review. In Cognition and Emotion. https://doi.org/10.1080/02699930802204677

McAdams, D. A., & Wood, K. L. (2002). A quantitative similarity metric for design-by-analogy. *Journal of Mechanical Design, Transactions of the ASME*. https://doi.org/10.1115/1.1475317

McCambridge, J., de Bruin, M., & Witton, J. (2012). The effects of demand characteristics on research participant behaviours in non-laboratory settings: A systematic review. In PLoS ONE. https://doi.org/10.1371/journal.pone.0039116

McCrae, R. R., & Costa, P. T. (1999). A five-factor theory of personality In Pervin LA & John OP (Eds.), Handbook of personality: Theory and research (pp. 139–153). New York: Guilford.[Google Scholar].

McGee, P.E. (1989) Humour and children's development: a guide to practical applications, The Hawthword Press, London, UK

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. Psychological methods, 1(1), 30.

McGrew, K. S. (2005). The Cattell-Horn-Carroll Theory of Cognitive Abilities: Past, Present, and Future. In *Contemporary Intellectual Assessment: Theories, Tests, and Issues*.

McTeague, C., Duffy, A., Campbell, G., Grealy, M., Hay, L., Pidgeon, L., & Vuletic, T. (2017). An exploration of design synthesis. In DS 87-8 Proceedings of the 21st

International Conference on Engineering Design (ICED 17) Vol 8: Human Behaviour in Design, Vancouver, Canada, 21-25.08. 2017 (pp. 279-288).

McTeague, C., Duffy, A., Hay, L., Vuletic, T., Campbell, G., Choo, P. L., & Grealy, M. (2018). Extending the structural alignment model to similarity judgements of design concepts. Design Computing Cognition DCC18.

Mednick, M. T., Mednick, S. A., & Mednick, E. V. (1964). Incubation of creative performance and specific associative priming. *Journal of Abnormal and Social Psychology*. https://doi.org/10.1037/h0045994

Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*. https://doi.org/10.1037/h0048850

Melton, R. J. (1995). The Role of Positive Affect in Syllogism Performance. *Personality and Social Psychology Bulletin*. https://doi.org/10.1177/0146167295218001

Memon, M. A., Cheah, J. H., Ramayah, T., Ting, H., Chuah, F., & Cham, T. H. (2019). Moderation analysis: issues and guidelines. Journal of Applied Structural Equation Modeling, 3(1), 1-11.

Milgram, R. M., & Milgram, N. A. (1976). Tel Aviv Creativity Test (TACT). Ramat-Aviv, Israel: Tel Aviv University, School of Education.

Miller, E. K., & Cohen, J. D. (2001). An Integrative Theory of Prefrontal Cortex Function. *Annual Review of Neuroscience*. https://doi.org/10.1146/annurev.neuro.24.1.167

Mills, C., & D'Mello, S. (2014). On the validity of the autobiographical emotional memory task for emotion induction. PLoS ONE. https://doi.org/10.1371/journal.pone.0095837

Milojevic, H., & Jin, Y. (2019). Design Computing and Cognition ’18. In Design Computing and Cognition ’18. Springer International Publishing. https://doi.org/10.1007/978-3-030-05363-5

Misalidi, P., & Bonoti, F. (2014). Children’s expressive drawing strategies: The effects of mood, age and topic. Early Child Development and Care. https://doi.org/10.1080/03004430.2013.823409

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. Cognitive Psychology. https://doi.org/10.1006/cogp.1999.0734

Montani, F., Dagenais-Desmarais, V., Giorgi, G., & Grégoire, S. (2018). A Conservation of Resources Perspective on Negative Affect and Innovative Work Behaviour: the Role of Affect Activation and Mindfulness. Journal of Business and Psychology. https://doi.org/10.1007/s10869-016-9480-7

Moreno, D. P., Blessing, L. T., Yang, M. C., Hernández, A. A., & Wood, K. L. (2016). Overcoming design fixation: Design by analogy studies and nonintuitive findings. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM*. https://doi.org/10.1017/S0890060416000068

Moreno, D. P., Hernández, A. A., Yang, M. C., Otto, K. N., Hölttä-Otto, K., Linsey, J. S., Wood, K. L., & Linden, A. (2014). Fundamental studies in Design-by-Analogy: A focus on domain-knowledge experts and applications to transactional design problems. *Design Studies*. https://doi.org/10.1016/j.destud.2013.11.002

Morrison, R. G., McCarthy, S. W., & Molony, J. M. (2017). The Experience of Insight Follows Incubation in the Compound Remote Associates Task. *Journal of*

Creative Behavior. https://doi.org/10.1002/jocb.96

Moscovitch, M., Cabeza, R., Winocur, G., & Nadel, L. (2016). Episodic Memory and Beyond: The Hippocampus and Neocortex in Transformation. *Annual Review of Psychology*. https://doi.org/10.1146/annurev-psych-113011-143733

Moss, J., & Cagan, J. (2007). Design ideas and impasses: The role of open goals. *Proceedings of ICED 2007, the 16th International Conference on Engineering Design*.

Moss, J., Kotovsky, K., & Cagan, J. (2007). The Influence of Open Goals on the Acquisition of Problem-Relevant Information. *Journal of Experimental Psychology: Learning Memory and Cognition*. https://doi.org/10.1037/0278-7393.33.5.876

Moss, J., Kotovsky, K., & Cagan, J. (2011). The Effect of Incidental Hints When Problems Are Suspended Before, During, or After an Impasse. *Journal of Experimental Psychology: Learning Memory and Cognition*. https://doi.org/10.1037/a0021206

Multon, K. D. (2010). Interrater reliability. Encyclopedia of research design, 2, 626-628.

Mumford, M. D. (2003). Where have we been, where are we going? Taking stock in creativity research. *Creativity research journal*, *15*(2-3), 107-120.

Mumford, M. D., Medeiros, K. E., & Partlow, P. J. (2012). Creative thinking: Processes, strategies, and knowledge. *Journal of Creative Behavior*. https://doi.org/10.1002/jocb.003

Nam, H., & Lee, C. H. (2015). The immediate incubation effect on creative problem solving: using the remote association task. Psychologia, 58(2), 98-113.

Neely, H., J. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In *Basic processes in reading: Visual word recognition*.

Nelson, H. E. (1982). The National Adult Reading Test (NART): Test Manual. *Windsor, UK: NFER-Nelson*. https://doi.org/Thesis_references-Converted #319

Neroni, M. A., & Crilly, N. (2019). Whose ideas are most fixating, your own or other people's? The effect of idea agency on subsequent design behaviour. Design Studies, 60, 180–212. https://doi.org/10.1016/j.destud.2018.05.004

Nguyen, P., Nguyen, T. A., & Zeng, Y. (2018). Empirical approaches to quantifying effort, fatigue and concentration in the conceptual design process: An EEG study. *Research in Engineering Design*. https://doi.org/10.1007/s00163-017-0273-4

Nguyen, T. A., & Zeng, Y. (2010). Analysis of design activities using EEG signals. *Proceedings of the ASME Design Engineering Technical Conference*. https://doi.org/10.1115/DETC2010-28477

Nguyen, T. A., & Zeng, Y. (2012). Clustering Designers ' Mental Activities Based on Eeg Power. *Tools and Methods of Competitive Engineering*.

Nguyen, T. A., & Zeng, Y. (2014a). A physiological study of relationship between designer's mental effort and mental stress during conceptual design. *CAD Computer Aided Design*. https://doi.org/10.1016/j.cad.2013.10.002

Nguyen, T. A., & Zeng, Y. (2014b). A preliminary study of EEG spectrogram of a single subject performing a creativity test. *Proceedings of the 2014 International Conference on Innovative Design and Manufacturing, ICIDM 2014*. https://doi.org/10.1109/IDAM.2014.6912664

Nusbaum, A. T., Wilson, C. G., Stenson, A., Hinson, J. M., & Whitney, P. (2018). Induced positive mood and cognitive flexibility: Evidence from task switching and reversal learning. *Collabra: Psychology*. https://doi.org/10.1525/collabra.150

Nusbaum, E. C., & Silvia, P. J. (2011). Are intelligence and creativity really so different?. Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence*. https://doi.org/10.1016/j.intell.2010.11.002

Oaksford, M., Grainger, B., Morris, F., & Williams, J. M. G. (1996). Mood, reasoning, and central executive processes. *Journal of Experimental Psychology: Learning Memory and Cognition*. https://doi.org/10.1037/0278-7393.22.2.476

Oberauer, K., Süß, H. M., Wilhelm, O., & Wittmann, W. W. (2008). Which working memory functions predict intelligence? *Intelligence*. https://doi.org/10.1016/j.intell.2008.01.007

Olton, R. M., & Johnson, D. M. (1976). Mechanisms of incubation in creative problem solving. The American Journal of Psychology, 617-630.

Oppezzo, M., & Schwartz, D. L. (2014). Give your ideas some legs: the positive effect of walking on creative thinking. Journal of experimental psychology: learning, memory, and cognition, 40(4), 1142.

Orne, M. T. (1959). The nature of hypnosis: Artifact and essence. Journal of Abnormal and Social Psychology. https://doi.org/10.1037/h0046128

Pahl, Gerhard, Beitz, W, Feldhusen, Jörg, & Grote, Karl-Heinrich. (2006). Engineering Design (Third ed.). London: Springer London, Limited.

Pallier, G. & Tiliopoulos, N. Take a break: A look at the incubation effect on creativity. In S. Boag & N. Tiliopoulos (Eds.), *Personality and Individual Differences : Theory, Assessment, and Application* (pp. 83-92). Nova Science Publishers, Inc, 2011.

Palmiero, M., Nori, R., Aloisi, V., Ferrara, M., & Piccardi, L. (2015). Domain-specificity of creativity: A study on the relationship between visual creativity and visual mental imagery. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.01870

Palmiero, M., Piccardi, L., Nori, R., Palermo, L., Salvi, C., & Guariglia, C. (2016). Editorial: Creativity and mental imagery. In *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2016.01280

Park, J. A., & Kim, Y. S. (2007). Visual reasoning and design processes. *Proceedings of ICED 2007, the 16th International Conference on Engineering Design*.

Parkinson, B., Totterdell, P., Briner, R. B., & Reynolds, S. (1996). Changing moods: The psychology of mood and mood regulation. Harlow, England: Addison Wesley Longman.

Parnes, S. J. (1961). Effects of extended effort in creative problem solving. Journal of Educational Psychology, 52(3), 117–122. https://doi.org/10.1037/h0044650

Pearson, D. G., Logie, R. H., & Gilhooly, K. J. (1999). Verbal representations and spatial manipulation during mental synthesis. European Journal of Cognitive Psychology, 11(3), 295–314. https://doi.org/10.1080/713752317

Peirce, C. S. (1960). *Collected papers of charles sanders peirce* (Vol. 2). Harvard University Press

Pepples, L. (2020, October, 06) “Face masks: what the data say”. *Nature*. https://www.nature.com/articles/d41586-020-02801-8

Pereira, I., & Vargas, G. (2005). Efectos del estado de ánimo inducido sobre el recuerdo de palabras cargadas afectivamente [Effects of induced mood over the recall of affectively laden words]. Master’s thesis. Faculty of Humanities and Education, Psychology School. Andrés Bello Catholic University. Caracas, Venezuela. Retrieved on February 26, 2013, from: http://biblioteca2.ucab.edu.ve/anexos/biblioteca/marc/texto/AAQ4578.pdf

Perttula, M. K., & Liikkanen, L. A. (2006). Structural tendencies and exposure effects in design idea generation. *Proceedings of the ASME Design Engineering Technical Conference*. https://doi.org/10.1115/detc2006-99123

Pessoa, L. (2008). On the relationship between emotion and cognition. In Nature Reviews Neuroscience. https://doi.org/10.1038/nrn2317

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn vandenberg and kuse mental rotations test - different versions and factors that affect performance. *Brain and Cognition*. https://doi.org/10.1006/brcg.1995.1032

Petrides, M. (2015). The Ventrolateral Frontal Region. In *Neurobiology of Language*. https://doi.org/10.1016/B978-0-12-407794-2.00003-1

Phelps, E. A., Hyder, F., Blamire, A. M., & Shulman, R. G. (1997). FMRI of the prefrontal cortex during overt verbal fluency. *NeuroReport*. https://doi.org/10.1097/00001756-199701200-00036

Phillips, L. H., Bull, R., Adams, E., & Fraser, L. (2002). Positive Mood and Executive Function. Evidence From Stroop and Fluency Tasks. *Emotion*. https://doi.org/10.1037/1528-3542.2.1.12

Pidgeon, L. M., Grealy, M., Duffy, A. H. B., Hay, L., McTeague, C., Vuletic, T., Coyle, D., & Gilbert, S. J. (2016). Functional neuroimaging of visual creativity: a systematic review and meta-analysis. *Brain and Behavior*. https://doi.org/10.1002/brb3.540

Pinho, A. L., Ullén, F., Castelo-Branco, M., Fransson, P., & De Manzano, Ö. (2016). Addressing a paradox: Dual strategies for creative performance in introspective and extrospective networks. *Cerebral Cortex*. https://doi.org/10.1093/cercor/bhv130

Poincaré, H. (1910). Mathematical Creation. *Monist*. https://doi.org/10.5840/monist19102037

Posner, M. I. (1973). Cognition. Glenview, IL: Scott Foresman.

Preston, C. C., & Colman, A. M. (2000). Optimal number of response categories in rating scales: Reliability, validity, discriminating power, and respondent preferences. Acta Psychologica, 104(1), 1–15. https://doi.org/10.1016/S0001-6918(99)00050-5

Psychiatry, 67(1), 37–96.

Purcell, A. T., & Gero, J. S. (1996). Design and other types of fixation. *Design Studies*. https://doi.org/10.1016/S0142-694X(96)00023-3

Putkinen, V., Makkonen, T., & Eerola, T. (2017). Music-induced positive mood broadens the scope of auditory attention. Social Cognitive and Affective Neuroscience. https://doi.org/10.1093/scan/nsx038

Rauscher, F. H., Shaw, G. L., & Ky, C. N. (1993). Music and spatial task performance [6]. In *Nature*. https://doi.org/10.1038/365611a0

Raven, J., Raven, J. C., & Court, J. (1998). Manual for Raven's progressive matrices and vocabulary scales. In *Raven manual*.

Reber, P. J., Wong, E. C., & Buxton, R. B. (2002). Encoding activity in the medial temporal lobe examined with anatomically constrained fMRI analysis. In *Hippocampus*. https://doi.org/10.1002/hipo.10018

Reiter-Palmon, R. (2020). The Consensual Assessment Technique: Refinement and Further Development. In Creativity at Work (pp. 157-165). Palgrave Macmillan, Cham.

Ribeiro, F. S., Santos, F. H., Albuquerque, P. B., & Oliveira-Silva, P. (2019). Emotional induction through music: Measuring cardiac and electrodermal responses of emotional states and their persistence. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2019.00451

Richell, R. A., & Anderson, M. (2004). Reproducibility of negative mood induction: a self-referent plus musical mood induction procedure and a controllable/uncontrollable stress paradigm. Journal of Psychopharmacology, 18(1), 94-101.

Ritter, S. M., & Dijksterhuis, A. (2014). Creativity-the unconscious foundations of the incubation period. In *Frontiers in Human Neuroscience*.

https://doi.org/10.3389/fnhum.2014.00215

Ritter, S. M., & Ferguson, S. (2017). Happy creativity: Listening to happy music facilitates divergent thinking. PLoS ONE. https://doi.org/10.1371/journal.pone.0182210

Rogatko, T. P. (2009). The influence of flow on positive affect in college students. Journal of Happiness Studies. https://doi.org/10.1007/s10902-007-9069-y

Roisman, G. I., Fortuna, K., & Holland, A. (2006). An experimental manipulation of retrospectively defined earned and continuous attachment security. Child Development. https://doi.org/10.1111/j.1467-8624.2006.00856.x

Root-Bernstein, R., & Root-Bernstein, M. (1999). Thirteen Thinking Tools of Creative People. In *Sparks of Genius: The Thirteen Thinking Tools of the World's Most Creative People*.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*. https://doi.org/10.1037//0096-3445.126.3.211

Rottenberg, J., Kovacs, M., & Yaroslavsky, I. (2018). Non-response to sad mood induction: implications for emotion research. In Cognition and Emotion. https://doi.org/10.1080/02699931.2017.1321527

Rottenberg, J., Ray, R. D., & Gross, J. J. (2007). Emotion elicitation using films. Handbook of emotion elicitation and assessment. In Handbook of emotion elicitation and assessment Series in affective science.

Rotteveel, M., & Phaf, R. H. (2007). Mere exposure in reverse: Mood and motion modulate memory bias. *Cognition and Emotion*. https://doi.org/10.1080/02699930701438319

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.0605198104

Runco, M. A. (1986). The Discriminant Validity of Gifted Children's Divergent Thinking Test Scores. *Gifted Child Quarterly*. https://doi.org/10.1177/001698628603000207

Runco, M. A. (2004). Creativity. Annual Review of Psychology. https://doi.org/10.1146/annurev.psych.55.090902.141502

Runco, M. A., & Acar, S. (2012). Divergent Thinking as an Indicator of Creative Potential. In *Creativity Research Journal*. https://doi.org/10.1080/10400419.2012.652929

Runco, M. A., & Chand, I. (1995). Cognition and creativity. Educational Psychology Review. https://doi.org/10.1007/BF02213373

Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity research journal*, *24*(1), 92-96.

Russell, J. A. (1980). A circumplex model of affect. Journal of personality and social psychology, 39(6), 1161.

Safin, S., Dorta, T., Pierini, D., Kinayoglu, G., & Lesage, A. (2016). Design Flow 2.0, assessing experience during ideation with increased granularity: A proposed method. Design Studies. https://doi.org/10.1016/j.destud.2016.08.002

Sánchez López, A. (2011). Atención selectiva como mecanismo de regulación emocional y factor de vulnerabilidad a la depresión [Selective attention as an emotional regulation mechanism and vulnerability factor for depression]. Doctoral dissertation. Faculty of Psychology. Complutense University of Madrid. Retrieved on February 26, 2013, from: http://eprints.ucm.es/14460/1/T33365.pdf

Sanchez, A., Vazquez, C., Marker, C., LeMoult, J., & Joormann, J. (2013). Attentional disengagement predicts stress recovery in depression: an eye-tracking study. Journal of Abnormal Psychology

Sanginabadi, B. (2020). The Impact of Education on Fluid Intelligence. *Applied Economics and Finance*. https://doi.org/10.11114/aef.v7i3.4774

Sanz, J. (2001). Un instrumento para evaluar la eficacia de los procedimientos de inducción de estado de ánimo: "La Escala de Valoración del Estado de Ánimo" (EVEA) [An instrument to evaluate the efficacy of mood induction procedures: the Scale for Mood Assessment (EVEA)]. Análisis y Modificación de Conducta, 27, 71-110.Sarkar, P., & Chakrabarti, A. (2017). A model for the process of idea generation. *The Design Journal*, *20*(2), 239-257.

Sarkar, P., & Chakrabarti, A. (2017). A model for the process of idea generation. The Design Journal, 20(2), 239-257.

Scerrati, E., Lugli, L., Nicoletti, R., & Umiltà, C. (2017). Comparing Stroop-like and Simon Effects on Perceptual Features. *Scientific Reports*. https://doi.org/10.1038/s41598-017-18185-1

Schacter, D. L., & Addis, D. R. (2007). The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2007.2087

Schacter, D. L., Benoit, R. G., & Szpunar, K. K. (2017). Episodic future thinking: mechanisms and functions. In *Current Opinion in Behavioral Sciences*. https://doi.org/10.1016/j.cobeha.2017.06.002

Schellenberg, E. G., Nakata, T., Hunter, P. G., & Tamoto, S. (2007). Exposure to music and cognitive performance: tests of children and adults. *Psychology of Music*. https://doi.org/10.1177/0305735607068885

Schon, D. A. (1983). The Reflective Practitioner: How Professionals Think in Action (Arena). In *Basic Books*.

Schubert, E., Hargreaves, D. J., & North, A. C. (2014). A dynamically minimalist cognitive explanation of musical preference: Is familiarity everything? Frontiers in Psychology, 5(FEB). https://doi.org/10.3389/fpsyg.2014.00038

Schuldberg, D. (2001). Six subclinical spectrum traits in normal creativity. *Creativity Research Journal*. https://doi.org/10.1207/s15326934crj1301_2

Schultz, P. W., & Searleman, A. (2002). Rigidity of thought and behavior: 100 years of research. *Genetic, social, and general psychology monographs*, *128*(2), 165.

Schwarz, N, & Bless, H. (1991). Happy and mindless, but sad and smart? The impact of affective states on analytic reasoning. In Emotion and social judgments.

Schwarz, N. (1990). Feelings as information: Informational and motivational functions of affective states. *Handbook of Motivation and Cognition*. https://doi.org/10.2307/2072281

Schwarz, N. (1994). Judgment in a Social Context: Biases, Shortcomings, and the Logic of Conversation. *Advances in Experimental Social Psychology*. https://doi.org/10.1016/S0065-2601(08)60153-7

Schwarz, Norbert. (1990). Feelings as information: Informational and motivational functions of affective states. Handbook of Motivation and Cognition. https://doi.org/10.2307/2072281

Seibert, P. S., & Ellis, H. C. (1991). Irrelevant thoughts, emotional mood states, and cognitive task performance. *Memory & Cognition*. https://doi.org/10.3758/BF03199574

Seifert, M. C., Meyer, D. E., Davidson, N., Patalano, A. L., & Yaniv, I. (1995). Demystification of cognitive insight: Opportunistic assimilation. In *The nature of insight*.

Serino, S., & Repetto, C. (2018). New trends in episodic memory assessment: Immersive 360° ecological videos. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2018.01878

Shah, J. J., Millsap, R. E., Woodward, J., & Smith, S. M. (2012). Applied tests of design skills-part 1: Divergent thinking. *Journal of Mechanical Design, Transactions of the ASME*. https://doi.org/10.1115/1.4005594

Shah, J. J., Smith, S. M., & Vargas-Hernandez, N. (2003a). Metrics for measuring ideation effectiveness. *Design Studies*, *24*(2), 111–134. https://doi.org/10.1016/S0142-

694X(02)00034-0

Shah, J. J., Smith, S. M., Vargas-Hernandez, N., Gerkens, D. R., & Wulan, M. (2003b). Empirical studies of design ideation: Alignment of design experiments with lab experiments. In ASME 2003 International design engineering technical conferences and computers and information in engineering conference (pp. 847-856). American Society of Mechanical Engineers Digital Collection.

Shao, Y., Zhang, C., Zhou, J., Gu, T., & Yuan, Y. (2019). How does culture shape creativity? A mini-review. In *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2019.01219

Shaw, M. P.1999 "On the role of affect in scientific discovery." In S. W.Russ (ed.), Affect, Creative Experience, and Psychological Adjustment: 147–164. Philadelphia: Brunner/Mazel

Shen, W., Yuan, Y., Liu, C., & Luo, J. (2017). The roles of the temporal lobe in creative insight: an integrated review. In *Thinking and Reasoning*. https://doi.org/10.1080/13546783.2017.1308885

Shen, W., Zhao, Y., Hommel, B., Yuan, Y., Zhang, Y., Liu, Z., & Gu, H. (2019). The impact of spontaneous and induced mood states on problem solving and memory. Thinking Skills and Creativity. https://doi.org/10.1016/j.tsc.2019.03.002

Siangliulue, P., Chan, J., Gajos, K. Z., & Dow, S. P. (2015). Providing timely examples improves the quantity and quality of generated ideas. *C and C 2015 - Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition*. https://doi.org/10.1145/2757226.2757230

Siemer, M. (2001). Mood-specific effects on appraisal and emotion judgements. Cognition and Emotion. https://doi.org/10.1080/02699930126083

Silvia, P. J., Beaty, R. E., & Nusbaum, E. C. (2013). Verbal fluency and creativity: General and specific contributions of broad retrieval ability (Gr) factors to divergent thinking. *Intelligence*. https://doi.org/10.1016/j.intell.2013.05.004

Silvia, P. J., Nusbaum, E. C., Berg, C., Martin, C., & O'Connor, A. (2009). Openness to experience, plasticity, and creativity: Exploring lower-order, high-order, and interactive effects. Journal of Research in Personality. https://doi.org/10.1016/j.jrp.2009.04.015

Silvia, P. J., Winterstein, B. P., Willse, J. T., Barona, C. M., Cram, J. T., Hess, K. I., Martinez, J. L., & Richard, C. A. (2008). Assessing Creativity With Divergent Thinking Tasks: Exploring the Reliability and Validity of New Subjective Scoring Methods. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/1931-3896.2.2.68

Sim, S. K., & Duffy, A. H. B. (2003). Towards an ontology of generic engineering design activities. *Research in Engineering Design*. https://doi.org/10.1007/s00163-003-0037-1

Simon, J., & Wolf, J. D. (1963). Choice Reaction Time As A Function Of Angular Stimulus-Response Correspondence And Age. *Ergonomics*. https://doi.org/10.1080/00140136308930679

Simonton, D. K. (2007). Creativity: Specialised expertise or general cognitive processes? In *Integrating the mind: Domain general vs domain specific processes in higher cognition.*

Sio, U. N., & Ormerod, T. C. (2009). Does Incubation Enhance Problem Solving? A Meta-Analytic Review. *Psychological Bulletin*. https://doi.org/10.1037/a0014212

Sio, U. N., & Ormerod, T. C. (2015). Incubation and cueing effects in problem-solving: Set aside the difficult problems but focus on the easy ones. *Thinking and Reasoning*. https://doi.org/10.1080/13546783.2014.886626

Smallwood, J., Obonsawin, M., & Heim, D. (2003). Task unrelated thought: The role of distributed processing. *Consciousness and Cognition*. https://doi.org/10.1016/S1053-8100(02)00003-X

Smith, J. (2016, January 14) "72% of people get their best ideas in the shower — here's why". Business Insider

Smith, S. M. (2003). The Constraining Effects of Initial Ideas Steven M. Smith Texas A&M University. *Oxford University Press*.

Smith, S. M. (2011). Incubation. In *Encyclopedia of Creativity*. https://doi.org/10.1016/b978-0-12-375038-9.00121-7

Smith, S. M., & Blankenship, S. E. (1991). Incubation and the persistence of fixation in problem solving. *The American Journal of Psychology*. https://doi.org/10.2307/1422851

Smith, S. M., & Linsey, J. (2011). A three-pronged approach for overcoming design fixation. *Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.2011.tb01087.x

Smith, S.M., Linsey, J. S., & Kerne, A. (2011). Using Evolved Analogies to Overcome Creative Design Fixation. In *Design Creativity 2010*.

https://doi.org/10.1007/978-0-85729-224-7_6

Smith, S.M., Sifonis, C. M., & Angello, G. (2012). Clue Insensitivity in Remote Associates Test Problem Solving. *The Journal of Problem Solving*. https://doi.org/10.7771/1932-6246.1124

Snyder, A., Mitchell, J., Ellwood, S., Yates, A., & Pallier, G. (2004). Nonconscious idea generation. In Psychological Reports. https://doi.org/10.2466/pr0.94.3c.1325-1330

Snyder, H. R., Miyake, A., & Hankin, B. L. (2015). Advancing understanding of executive function impairments and psychopathology: Bridging the gap between clinical and cognitive approaches. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.00328

Starkey, E. M., Alzayed, M. A., Hunter, S., & Miller, S. R. (2020). Dissection Versus Incubation: The Within-Subject Effects of Product Dissection Activities on Design Variety. *Journal of Mechanical Design*. https://doi.org/10.1115/1.4043584

Stauffer, L. A., & Ullman, D. G. (1991). Fundamental processes of mechanical designers based on empirical data. Journal of Engineering Design, 2(2), 113-125.

Sternberg, R. J. (2006). The nature of creativity. In Creativity Research Journal. https://doi.org/10.1207/s15326934crj1801_10

St-Louis, A. C., & Vallerand, R. J. (2015). A Successful Creative Process: The Role of Passion and Emotions. Creativity Research Journal. https://doi.org/10.1080/10400419.2015.1030314

Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behavior Research Methods*. https://doi.org/10.3758/BRM.42.4.1096

Storbeck, J., & Clore, G. L. (2008). The Affective Regulation of Cognitive Priming. *Emotion*. https://doi.org/10.1037/1528-3542.8.2.208

Storbeck, J., & Maswood, R. (2016). Happiness increases verbal and spatial working memory capacity where sadness does not: Emotion, working memory and executive control. *Cognition and Emotion*. https://doi.org/10.1080/02699931.2015.1034091

Storm, B. C., & Angello, G. (2010). Overcoming fixation: Creative problem solving and retrieval-induced forgetting. *Psychological Science*, *21*(9), 1263-1265.

Storm, B. C., & Levy, B. J. (2012). A progress report on the inhibitory account of retrieval-induced forgetting. *Memory & Cognition*, *40*(6), 827-843.

Strack, F., Schwarz, N., & Gschneidinger, E. (1985). Happiness and Reminiscing. The Role of Time Perspective, Affect, and Mode of Thinking. Journal of Personality and Social Psychology. https://doi.org/10.1037/0022-3514.49.6.1460

Stroebe, W., Nijstad, B. A., & Rietzschel, E. F. (2010). Beyond Productivity Loss in Brainstorming Groups. The Evolution of a Question. In Advances in Experimental Social Psychology. https://doi.org/10.1016/S0065-2601(10)43004-X

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*. https://doi.org/10.1037/h0054651

Stürmer, B., & Leuthold, H. (2003). Control over response priming in visuomotor processing: A lateralized event-related potential study. *Experimental Brain Research*. https://doi.org/10.1007/s00221-003-1579-1

Stürmer, B., Soetens, E., Leuthold, H., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037/0096-1523.28.6.1345

Suwa, M., & Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies*. https://doi.org/10.1016/s0142-694x(97)00008-2

Suwa, M., Gero, J., & Purcell, T. (2000). Unexpected discoveries and S-invention of design requirements: important vehicles for a design process. *Design Studies*, *21*(6), 539–567.

Suwa, M., Purcell, T., & Gero, J. (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies*. https://doi.org/10.1016/S0142-694X(98)00016-7

Swick, D., Ashley, V., & Turken, A. U. (2008). Left inferior frontal gyrus is critical for response inhibition. *BMC Neuroscience*. https://doi.org/10.1186/1471-2202-9-102

Takeuchi, H., Taki, Y., Hashizume, H., Sassa, Y., Nagase, T., Nouchi, R., & Kawashima, R. (2011). Failing to deactivate: The association between brain activity during a working memory task and creativity. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2010.11.052

Ter Kuile, M. M., Both, S., & van Uden, J. (2010). The effects of experimentally-induced sad and happy mood on sexual arousal in sexually healthy women. Journal of Sexual Medicine. https://doi.org/10.1111/j.1743-6109.2009.01632.x

Toh, C. A., & Miller, S. R. (2013). Visual inspection or product dissection? The impact of designer-product interactions on engineering design creativity. *Proceedings of the ASME Design Engineering Technical Conference*. https://doi.org/10.1115/DETC2013-13087

Toh, C. A., & Miller, S. R. (2016). Creativity in design teams: the influence of personality traits and risk attitudes on creative concept selection. Research in Engineering Design. https://doi.org/10.1007/s00163-015-0207-y

Topolinski, S., & Deutsch, R. (2012). Phasic affective modulation of creativity. *Experimental Psychology*. https://doi.org/10.1027/1618-3169/a000159

Topolinski, S., & Deutsch, R. (2013). Phasic affective modulation of semantic priming. *Journal of Experimental Psychology: Learning Memory and Cognition*. https://doi.org/10.1037/a0028879

Torrance, E. P. (1974). The Torrance Tests of Creative Thinking-Norms-Technical Manual Research Edition-Verbal Tests, Forms A and B- Figural Tests, Forms A and B. *Princeton, NJ: Personnel Press*.

Torrance-Perks, J. (1997). The incubation effect: Implication for underlying mechanisms. Unpublished doctoral dissertation, University of Waterloo, Ontario, Canada.

Troyer, A. K., Moscovitch, M., Winocur, G., Leach, L., & Freedman, M. (1998). Clustering and switching on verbal fluency tests in Alzheimer's and Parkinson's disease.

Journal of the International Neuropsychological Society

Tse, C. S., & Neely, J. H. (2007). Semantic and repetition priming effects for Deese/Roediger-McDermott (DRM) critical items and associates produced by DRM and unrelated study lists. *Memory and Cognition*. https://doi.org/10.3758/BF03193477

Tseng, I., Moss, J., Cagan, J., & Kotovsky, K. (2008). The role of timing and analogical similarity in the stimulation of idea generation in design. *Design Studies*. https://doi.org/10.1016/j.destud.2008.01.003

Tseng, W. S. W. (2018). Can visual ambiguity facilitate design ideation? *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-016-9393-9

Tsenn, J., Atilola, O., McAdams, D. A., & Linsey, J. S. (2014). The effects of time and incubation on design concept generation. *Design Studies*. https://doi.org/10.1016/j.destud.2014.02.003

Tulving, E. (1983). Elements of Episodic Memory. *Canadian Psychology*.

Tversky, B., & Chou, J. Y. (2010). Creativity: Design and breadth. In T. Taura, & Y. Nagai (Eds.), Design creativity 2010 (pp. 209–214). London, UK: Springer.

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2011). Variation in verbal fluency: A latent variable analysis of clustering, switching, and overall performance. *Quarterly Journal of Experimental Psychology*. https://doi.org/10.1080/17470218.2010.505292

Van Der Zwaag, M. D., Dijksterhuis, C., De Waard, D., Mulder, B. L., Westerink, J. H., & Brookhuis, K. A. (2012). The influence of music on mood and performance while driving. Ergonomics, 55(1), 12-22.

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*. https://doi.org/10.2466/pms.1978.47.2.599

Vanlessen, N., Rossi, V., De Raedt, R., & Pourtois, G. (2013). Positive emotion broadens attention focus through decreased position-specific spatial encoding in early visual cortex: Evidence from ERPs. *Cognitive, Affective and Behavioral Neuroscience*. https://doi.org/10.3758/s13415-012-0130-x

Vargas-Hernandez, N. (2007). A basis for the development and validation of design ideation models for conceptual engineering design, Ph.D. Dissertation, Arizona State University, Tempe, AZ.

Vargas-Hernandez, N., Shah, J. J., & Smith, S. M. (2010). Understanding design ideation mechanisms through multilevel aligned empirical studies. Design Studies. https://doi.org/10.1016/j.destud.2010.04.001

Vartanian, O. (2002). Cognitive disinhibition and creativity. Unpublished Doctoral Dissertation

Vasconcelos, L. A., & Crilly, N. (2016). Inspiration and fixation: Questions, methods, findings, and challenges. Design Studies, 42, 1-32.

Vasconcelos, L. A., Cardoso, C. C., Sääksjärvi, M., Chen, C. C., & Crilly, N. (2017). Inspiration and Fixation: The Influences of Example Designs and System

Properties in Idea Generation. Journal of Mechanical Design, Transactions of the ASME, 139(3), 1–35. https://doi.org/10.1115/1.4035540

Västfjäll, D. (2001). Emotion induction through music: A review of the musical mood induction procedure. Musicae Scientiae, 5(1_suppl), 173-211.

Velten, E. (1968). A laboratory task for induction of mood states. Behaviour Research and Therapy. https://doi.org/10.1016/0005-7967(68)90028-4

Vendrell, P., Junqué, C., Pujol, J., Jurado, M. A., Molet, J., & Grafman, J. (1995). The role of prefrontal regions in the Stroop task. *Neuropsychologia*. https://doi.org/10.1016/0028-3932(94)00116-7

Verghese, A., Mattingley, J. B., Palmer, P. E., & Dux, P. E. (2018). From eyes to hands: Transfer of learning in the Simon task across motor effectors. *Attention, Perception, and Psychophysics*. https://doi.org/10.3758/s13414-017-1427-1

Verhaeghen, P., Joormann, J., & Khan, R. (2005). Why we sing the blues: The relation between self-reflective rumination, mood, and creativity. Emotion. https://doi.org/10.1037/1528-3542.5.2.226

Vernon, P. E. (1970). Creativity. Middlesex, UK: Penguin Books.

Vieira, S., Gero, J. S., Delmoral, J., Parente, M., Fernandes, A. A., Gattol, V., & Fernandes, C. (2020). Industrial designers problem-solving and designing: An EEG study. In *Research & Education in Design: People & Processes & Products & Philosophy*. https://doi.org/10.1201/9781003046103-24

Völker, J. (2019). Personalising music for more effective mood induction: Exploring activation, underlying mechanisms, emotional intelligence, and motives in mood regulation. Musicae Scientiae. https://doi.org/10.1177/1029864919876315

Vosburg, S. K. (1998). The effects of positive and negative mood on divergent-thinking performance. Creativity Research Journal. https://doi.org/10.1207/s15326934crj1102_6

Vul, E., & Pashler, H. (2007). Incubation benefits only after people have been misdirected. *Memory and Cognition*. https://doi.org/10.3758/BF03193308

Vuletic, T., Du, A., Hay, L., Mcteague, C., Campbell, G., & Grealy, M. (2019). International Journal of Human-Computer Studies Systematic literature review of hand gestures used in human computer interaction interfaces. 129(September 2018), 74–94. https://doi.org/10.1016/j.ijhcs.2019.03.011

Vuletic, T., Duffy, A., Mcteague, C., Hay, L., Brisco, R., Campbell, G., & Grealy, M. (2021). International Journal of Human - Computer Studies A novel user-based gesture vocabulary for conceptual design. International Journal of Human - Computer Studies, 150(February), 102609. https://doi.org/10.1016/j.ijhcs.2021.102609

Wallach, M. A., & Kogan, N. (1965). Modes of thinking in young children.

Wallas, G. (1926). The art of thought.

Wang, M., Hao, N., Ku, Y., Grabner, R. H., & Fink, A. (2017). Neural correlates of serial order effect in verbal divergent thinking. Neuropsychologia, 99(July 2016), 92–100. https://doi.org/10.1016/j.neuropsychologia.2017.03.001

Wang, Y., Yang, J., Yuan, J., Fu, A., Meng, X., & Li, H. (2011). The impact of emotion valence on brain processing of behavioral inhibitory control: Spatiotemporal dynamics. *Neuroscience Letters*. https://doi.org/10.1016/j.neulet.2011.07.039

Watts, L. L., McIntosh, T. J., Gibson, C., Mulhearn, T. J., Medeiros, K. E., Mecca, J. T., & Cohen-Charash, Y. (2019). Mild Affective Shifts and Creativity: Effects on Idea Generation, Evaluation, and Implementation Planning. Journal of Creative Behavior. https://doi.org/10.1002/jocb.427

Weisberg, R. W. R. W. (2006). Creativity: Understanding innovation in problem solving, science, invention, and the arts. *Creativity*.

Westermann, R., Spies, K., Stahl, G., & Hesse, F. W. (1996). Relative effectiveness and validity of mood induction procedures: A meta-analysis. European Journal of Social Psychology. https://doi.org/10.1002/(SICI)1099-0992(199607)26:4<557::AID-EJSP769>3.0.CO;2-4

Wheeler, M. (2001). Episodic and Autobiographical Memory: Psychological and Neural Aspects. In *International Encyclopedia of the Social & Behavioral Sciences*. https://doi.org/10.1016/b0-08-043076-7/03514-2

Willner, P., & Healy, S. (1994). Decreased hedonic responsiveness during a brief depressive mood swing. Journal of Affective Disorders. https://doi.org/10.1016/0165-0327(94)90056-6

Wilson, J. O., Rosen, D., Nelson, B. A., & Yen, J. (2010). The effects of biological examples in idea generation. *Design Studies*. https://doi.org/10.1016/j.destud.2009.10.003

Wodehouse, A., Maclachlan, R., & Gray, J. (2014). The best form of medicine? Using humor to enhance design creativity. International Journal of Design Creativity and Innovation. https://doi.org/10.1080/21650349.2013.815597

Yamada, Y., & Nagai, M. (2015). Positive mood enhances divergent but not convergent thinking. Japanese Psychological Research. https://doi.org/10.1111/jpr.12093

Yamaoka, A. (2020). Does Mind Wandering During the Thought Incubation Period Improve Creativity and Worsen Mood ? https://doi.org/10.1177/0033294119896039

Yaniv, I., & Meyer, D. E. (1987). Activation and metacognition of inaccessible stored information: potential bases for incubation effects in problem solving. Journal of Experimental Psychology: Learning, Memory, and Cognition, 13(2), 187.

Yefet, M., & Glicksohn, J. (2020). Examining the Influence of Mood on the Bright Side and the Dark Side of Creativity. The Journal of Creative Behaviour.

Yi, H., Nguyen, T. A., & Zeng, Y. (2013). Humour and creative design: Twins or partners? Journal of Integrated Design and Process Science. https://doi.org/10.3233/jid-2013-0020

Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. In *Cognition and Emotion*. https://doi.org/10.1080/02699930903205698

Zabelina, D. L., & Robinson, M. D. (2010). Child's Play: Facilitating the Originality of Creative Output by a Priming Manipulation. Psychology of Aesthetics, Creativity, and the Arts. https://doi.org/10.1037/a0015644

Zeigarnik, B. (1927). Über das Behalten von erledigten und unerledigten Handlungen. *Psychologische Forschung*.

Zhang, H., Liu, J., & Zhang, Q. (2014a). Neural representations for the generation of inventive conceptions inspired by adaptive feature optimization of biological species. *Cortex*. https://doi.org/10.1016/j.cortex.2013.01.015

Zhang, X., Yu, H. W., & Barrett, L. F. (2014b). How does this make you feel? A comparison of four affect induction procedures. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2014.00689

Zhang, Z., Zhang, W., Wu, X., Tan, T., & Luo, J. (2019). Incubation optimizes the promoting effects of rewards on creativity. *PsyCh Journal*. https://doi.org/10.1002/pchj.251

Zhu, W., Chen, Q., Xia, L., Beaty, R. E., Yang, W., Tian, F., Sun, J., Cao, G., Zhang, Q., Chen, X., & Qiu, J. (2017). Common and distinct brain networks underlying verbal and visual creativity. *Human Brain Mapping*. https://doi.org/10.1002/hbm.23507

Appendices

Appendix 1: Ideation tasks

Appendix 1.1 Study 1 ideation tasks

Camping is a popular activity but can have negative environmental impacts through disruption to wildlife; litter and pollution of water sources. Generate concepts for products that reduce the negative impacts of camping.

Domestic food waste is a serious problem due to global food shortages and socio-economic imbalances. Generate concepts for products that may reduce unnecessary food wastage in the home.

Dog excrement on pavements is unsightly and unhygienic but its disposal may be unpleasant and unhygienic for dog owners. Generate concepts for products that may improve dog excrement disposal for dog owners.

Sitting in the same position for long periods may be harmful to health. Generate concepts for products that may facilitate physical exercise whilst completing activities in a seated position in the home and office.

Long distance water transportation may be necessary in drought-prone developing nations but can be problematic due to lack of resources and infrastructure. Generate concepts for products that may facilitate water transportation in developing nations.

Chores such as cooking and cleaning may be difficult for wheelchair users due to space and height limitations. Generate concepts for products that may facilitate domestic chores for wheelchair users.

Rain and wind make it difficult for pedestrians to keep dry and pose dangers e.g. slipping; falling trees. Generate concepts for products to reduce the discomfort and danger of poor weather for pedestrians.

Inner city pavements are often congested due to large numbers of people and obstructions like street furniture; parked cars; other pedestrians. Generate concepts for products that may reduce congestion for inner city pedestrians.

Air travel may be problematic for wheelchair users due to difficulties with manual handling and manoeuvring. Generate concepts for products that may make airports and planes more wheelchair-friendly.

Train stations and airports are often congested due to many people transporting large items in a confined space. Generate concepts for products that may reduce congestion in transportation hubs.

Appendix 1.2 Study 2 ideation task

Working while travelling may be noisy; full of distractions; and physically uncomfortable. Generate concepts for products that may reduce the difficulties associated with on the go working.

Appendix 2. Mood induction sentences

Appendix 2.1 Happy induction sentences

Source: Velten (1968)

1. I feel pretty good today
2. This might turn out to have been one of my good days
3. If your attitude is good, then things are good and my attitude is good
4. I feel cheerful and lively
5. I've certainly got energy and self-confidence to share
6. My friends & family are pretty proud of me most of the time
7. I’m in a good position to make a success of things
8. For the rest of the day, I bet things will go really well
9. I'm pleased that most people are so friendly to me
10. My judgments about most things are sound
11. The more I get into things the easier they become for me
12. I'm full of energy and ambition - I feel like I could go a long time without sleep

13. This is one of those days when I can get things done with practically no effort at all
14. My judgment is keen and precise today. Just let someone try to put something over me
15. When I want to, I can make friends extremely easily
16. If I set my mind to it, I can make things turn out fine
17. I feel enthusiastic and confident now
18. There should be opportunity for a lot of good times coming along
19. Some of my friends are so lively and optimistic
20. I feel talkative - I feel like talking to almost anybody
21. I'm full of energy, and am really getting to like the things I'm doing
22. I feel an exhilarating animation in all I do
23. My memory is in rare form today
24. I'm able to do things accurately and efficiently
25. I know good and well that I can achieve the goals I set
26. I have a sense of power and vigour
27. I feel so vivacious and efficient today - sitting on top of the world
28. It would really take something to stop me now
29. I'm optimistic that I can get along very well with most of the people I meet
30. I'm too absorbed in things to have time for worry
31. I'm feeling amazingly good today
32. I am particularly inventive and resourceful in this mood
33. I feel superb! I think I can work to the best of my ability
34. Things look good Things look great!
35. I feel highly perceptive and refreshed
36. I can find the good in almost everything
37. I can concentrate hard on anything I do
38. My thinking is clear and rapid
39. Life is so much fun; it seems to offer so many sources of fulfilment
40. Things will be better and better today
41. I feel industrious as heck - I want something to do!
42. Life is firmly in my control
43. This is great -- I really do feel good. I am elated about things!
44. I'm really feeling sharp now
45. Wow, I feel great!

Appendix 2.2 Sad induction statements

Source: Velten (1968)

1. People annoy me; I wish I could be by myself
2. I've had important decisions to make in the past, and I've sometimes made the wrong one
3. I do feel somewhat discouraged and drowsy - maybe I'll need a nap when I get home
4. I just don't seem to be able to get going as fast as I used to
5. I couldn't remember things well right now if I had to

6. Just a little bit of effort tires me out
7. I've had daydreams in which my mistakes kept occurring to me - sometimes I wish I could start over again
8. I'm ashamed that I've caused my parents needless worry
9. I feel terribly tired and indifferent to things today
10. I'm getting tired out. I can feel my body getting exhausted and heavy
11. At times I've been so tired and discouraged that I went to sleep rather than face important problems
12. My life is so tiresome - the same old thing day after day depresses me
13. I can't make up my mind; it's so hard to make simple decisions
14. I want to go to sleep - I feel like just closing my eyes and going to sleep right here
15. I’m not very alert; I feel listless and vaguely sad
16. I've doubted that I'm a worthwhile person
17. It often seems that no matter how hard I try, things still go wrong
18. I've noticed that no one seems to really understand or care when I complain or feel unhappy
19. I'm uncertain about my future
20. I'm discouraged and unhappy about myself
21. I've lain awake at night worrying so long that I hated myself
22. Things are worse now than when I was younger
23. I feel rather sluggish now
24. The way I feel now, the future looks boring and hopeless
25. My parents never really tried to understand me
26. Some very important decisions are almost impossible for me to make
27. I feel tired and depressed; I don't feel like working on the things I know I must get done
28. I feel horribly guilty about how I've treated my parents at times
29. I want to go to sleep and never wake up
30. I have the feeling that I just can't reach people
31. I have the feeling that I just can't reach people
32. Often people make me very upset. I don't like to be around them
33. I feel dizzy and faint. I need to put my head down and not move
34. It takes too much effort to convince people of anything. There's no point in trying
35. I fail in communicating with people about my problems
36. It’s so discouraging the way people don't really listen to me
37. I've felt so lonesome before, that I could have cried
38. My thoughts are so slow and downcast. I don't want to think or talk
39. I just don't care about anything. Life just isn't any fun
40. Life seems too much for me - my efforts are wasted
41. I'm so tired
42. I don't concentrate or move. I just want to forget about everything
43. I have too many bad things in my life
44. Everything seems utterly futile and empty
45. I don't want to do anything

Appendix 2.3 Neutral induction statements

Source: word-processing instruction manual (Convergent Technologies, 1983)

1. The installation guide describes the procedure for powering up a system.
2. If the sign on form is not on the screen, consult the system administrator.
3. If BACKSPACE is pressed, the cursor moves to the left
4. The hardware manual describes the expansion system for the work station.
5. Press f9 to invoke Mark Line.
6. The Documents command allows you to manipulate entire documents
7. Closing the document requires the use of the CODE and c keys together.
8. The Pascal Manual is supplemented by a popular text, Pascal Usual Manual
9. This section describes how the screen looks when a document has been created
10. The cursor is an underline that shows where the next typed character will be
11. The operating system manual specifies services for managing memory
12. The Logout command ends session, and the Sign On form appears again
13. The wraparound feature allows text to be automatically entered on the next line in a new paragraph
14. When the keyboard is in overtype mode, each typed character replaces the existing one
15. The Operator's guide addresses the needs of the average user
16. Sometimes, the bottom of the main text area contains messages from the Word Processor
17. Ensure that the cursor is moved to the correct location in the text
18. The executive manual describes the command interpreter
19. Any words that extent beyond the margin are moved to the next line
20. Command names begin with uppercase letters, which makes them easy to identify in the text
21. This removes the boldface option.
22. A command is an action that tells the word processor what to do
23. The hardware manual specifies system architecture
24. The document status line indicates that the cursor page 1 of the document named "convergent".
25. A document is any written material that is typed into the Word Processor.
26. The entire document is now justified.

27. Each character you type replaces the existing one at the cursor position
28. The Central Processing unit describes the main processor
29. A decision can be made to press the GO key to create a new document
30. The cursor pad keys include four keys that control cursor movement
31. The display is used for purposes that are described later in the session
32. Pressing keys to issue a command is known as “invoking a command”
33. The RETURN key moves the cursor to the next line
34. The ruler display is separated from the main text
35. The Open document form now appears on the screen
36. Programmers have been trying to consolidate the broadest range of capabilities
37. The purpose of the SEARCH function is to locate a specific phrase
38. When the Executive Command form appears, it is added to the bottom of the screen
39. These functions are especially useful when the document is long
40. In a word processing menu, you can make only one choice from the list
41. When insertion is in use, the key board is described as being in that “mode”.
42. The Documents command has been invoked, and the Documents menu appears on the screen.
43. The third item, L, is the line number of the cursor within the current page.
44. The Go to Beginning command moves the cursor directly to the beginning.
45. Press GO to execute Review Document.

Appendix 3. The Scale for Mood Assessment (EVEA)

EVEA

Below you will find a series of statements that describe different feelings and moods and a 0-10 scale beside each statement. Read each statement and circle the number from 0 ("Not at all") to 10 ("Very much") that best indicates how you **FEEL RIGHT NOW,** at this moment. Do not spend too much time on each statement and choose a response for each of them.

	Not at all										**Very much**
I feel nervous	0	1	2	3	4	5	6	7	8	9	10
I feel irritated	0	1	2	3	4	5	6	7	8	9	10
I feel happy	0	1	2	3	4	5	6	7	8	9	10
I feel melancholy	0	1	2	3	4	5	6	7	8	9	10
I feel tense	0	1	2	3	4	5	6	7	8	9	10
I feel optimistic	0	1	2	3	4	5	6	7	8	9	10
I feel depressed	0	1	2	3	4	5	6	7	8	9	10
I feel angry	0	1	2	3	4	5	6	7	8	9	10
I feel anxious	0	1	2	3	4	5	6	7	8	9	10
I feel downcast	0	1	2	3	4	5	6	7	8	9	10
I feel annoyed	0	1	2	3	4	5	6	7	8	9	10
I feel joyful	0	1	2	3	4	5	6	7	8	9	10
I feel restless	0	1	2	3	4	5	6	7	8	9	10
I feel displeased	0	1	2	3	4	5	6	7	8	9	10
I feel cheerful	0	1	2	3	4	5	6	7	8	9	10
I feel sad	0	1	2	3	4	5	6	7	8	9	10