Variability of Centre of Mass Velocity through Stroke recovery

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Contents

1. Abstract

This project investigated the inter-trial variability of centre of mass (COM) velocity during the sit-to-stand movement in recovering stroke patients. Patients were assessed at baseline- directly after stroke, outcome- after 6 weeks of therapy and follow up – after 12 weeks of therapy. It was expected that inter-trial variability would decrease as the patient recovered. It was difficult to draw conclusions on the change in variability throughout recovery as a significant amount of data was missing or could not be assessed.

2. Stroke Pathology

Strokes are interruptions in vascular supply to a part of the brain. They can be categorised as ischaemic: where an arterial blockage leads to tissue infarction, or haemorrhagic: where vascular damage allows extravasation of blood causing damage to surrounding brain tissue. [1-5]

The effects of a stroke are wide ranging but are largely dependant on the location of the stroke within the brain. Vascular supply for the brain comes primarily from four vessels: the right and left internal carotid arteries and right and left vertebral arteries. Once in the brain, each carotid artery branches to become the ophthalmic, anterior cerebral and middle cerebral arteries and the vertebral arteries converge to form the basilar artery. The majority of strokes occur in the middle cerebral artery and this location accounts for 75% of cerebral infarctions. [1-5]

The branches of the middle cerebral artery supply much of the brain, from the basal nuclei and parts of the thalamus up to the frontal, parietal and temporal lobes of the brain. As a result, a stroke of the left middle cerebral artery can result in contralateral hemiparesis - of the face and arm more than the leg, contralateral sensory loss, reduction in visual field, visual-spatial neglect, ipsilateral gaze preference and aphasia. [1-5]

3. Incidence and Outcomes

There are approximately 152,000 strokes per year in the UK [6] and of these around 120,000 will be first strokes. [7] Stroke recurrence is common; around 25 percent of people who recover from their first stroke will go on to have another one within 5 years.[8] Strokes are also extremely prevalent - there are currently over one million stroke survivors living in the UK.[7]

Stroke is the third biggest cause of death in the UK [7,9] and accounts for approximately 43,000 deaths annually.[6] It is also the single biggest cause of severe disability [7,9] - over 30% of people who have had a stroke will suffer from persisting disability. In addition to physical disability, one third of stroke patients develop depression. [10] Not only is this a medical problem in its own right, but, depression can hinder physical treatment and rehabilitation.

There is currently little information on specific disability outcomes post stroke. Much current literature on stroke quotes figures from the community based study, "The Influence of Gender and Age on Disability Following Ischemic Stroke". In it, Kelly-Hayes et al. (2003) report the following outcomes at 6 months post stroke: [11]

Neurological deficits (%)		Disability measures (%)	
		ADL: Barthel <60	26.2
Hemiparesis	50.0	Unable to walk unassisted	30.8
Cognitive deficits	46.2	Bladder incontinence	22.2
Hemianopsia	19.6	Depression symptoms	35.3
Aphasia	18.9	Social disability	29.9
Sensory deficits	15.4	Institutionalization	25.9
		Poor subjective health	39.6

It is widely acknowledged that haemorrhagic strokes tend to be more severe than ischaemic strokes [12] and this study focuses solely on ischaemic strokes. However, ischaemic strokes account for 87% of all stroke cases [5, 13] so these results should provide a reasonable representation of all stroke outcomes.

Stroke incidence places a huge financial burden on the NHS, through diagnosis, care and treatment. However, these costs are exceeded by the informal care and lost productivity costs placed on society. Stroke treatment costs the NHS around £4 billion per year, accounting for approximately 5% of its annual budget. Informal care for stroke patients and lost productivity costs approximately £5 billion and brings the total cost of stroke in the UK to £9 billion annually. [14]

4. Rehabilitation

Andrews (1987) offers this definition of rehabilitation: "the restoration of optimal levels of physical, psychological and social ability within the needs and desires of the individual and his/her family". At its essence, stroke rehabilitation is about optimising the patient's quality of life whilst adjusting for the new restrictions imposed by the impairment incurred as a result of the stroke. [15]

Recently, there has been much academic interest in the effectiveness of stroke rehabilitation. Questions have been raised as to the optimum time to initialise rehabilitation, the optimum duration of rehabilitation and the optimum intensity of rehabilitation.

There is increasing evidence that when it comes to effectively treating stroke, early commencement of rehabilitation is favourable. Numerous studies have established a link between early rehabilitation initialisation and better functional outcomes. [16-20]

Salter et al. (2006) investigated the relationship between time from stroke event until admission to rehabilitation and functional outcome by conducting a retrospective review of patients admitted to a specialised inpatient stroke rehabilitation program. The authors classified an admission time of 30 days or less as an early admission and an admission time of 31-150 days as a delayed admission. Functional outcome was measured using the Functional Independence Measure (FIM™). Initial comparison of change in FIM™ scores showed no significant difference between early admission and delayed admission groups. However, the authors established an inverse relationship between initial FIM™ score and admission time. That is, those with a higher FIM™ score, and hence less severe stroke, were admitted to rehabilitation earlier than those with a lower initial FIM™ score. A higher initial FIM™ score limits the amount of improvement possible in a patient and so the early admission group had a significant cap on the amount by which they could improve. Once this limitation was adjusted for, the early admission group demonstrated a significantly higher FIM™ change than the delayed admission group (26.81 as opposed to 17.97). Length of stay was significantly lower in the early admission group meaning that the early admission group had a superior FIM™ change efficiency (0.74 compared with 0.39). [16]

It could be argued that the results of Salter et al. (2006) lack generalisability as they focus on patients from a single rehabilitation unit. However, Maulden et al. (2005) also sought to investigate the relationship between rehabilitation initialisation times and functional outcomes. They studied patients from a wider pool, looking at patients from six different rehabilitation hospitals but still reached the same conclusions: early admission to rehabilitation post-stroke is associated with better functional outcomes and a shorter length of stay. [17]

Biernaskie et al. (2003) also investigated optimum rehabilitation initialisation time but from a neurological perspective, using rats. They compared four different groups of rat with cerebral infarctions: one that began rehabilitation at five days, a second that began rehabilitation at fourteen days, a third that began rehabilitation at thirty days and a final

group that received no rehabilitation at all. This study also concluded that earlier rehabilitation better aids recovery. The first group of rats, who received the earliest rehabilitation, showed the greatest improvement, followed by the second group. The third group, beginning rehabilitation at thirty days, showed no significant difference to the final, control group. [18]

While there seems to be fairly universal agreement on the benefits of early rehabilitation, there has been more controversy over immediate or very early rehabilitation.

Risedal et al. (1999) performed a study on rats and reported that rehabilitation initiated 24 hours after a focal brain ischaemia can increase the area of infarcted cortical tissue. The rats who began training at 24 hours did not improve as well as those that commenced training at 7 days, however, they still showed better recovery than the untreated control group. [21]

Bernhardt et al. (2008) conducted a randomised controlled trial into very early mobilisation. While it was a small study (71 subjects), they found very early mobilisation to be just as safe as conventional care and indeed the very early mobilisation group showed significantly better disability outcomes at 12months post-stroke. [22]

There has been less study into the optimum duration of rehabilitation treatment. This is perhaps due to the fact that treatment can be discontinued at any point, as the therapist sees fit and depending on the progress of the patient, where as there is only one chance to initiate rehabilitation at the optimum time.

The Copenhagen Stroke Study did however report a direct link between stroke severity and rehabilitation treatment time required. Patients who suffered a mild stroke obtained highest activities of daily living (ADL) score after 8.5 weeks of rehabilitation. Required treatment time increased with stroke severity with severe stroke sufferers only reaching maximum ADL score after 20 weeks of rehabilitation. [23]

Langhorne et al. (1996) and Kwakkel et al. (2004) both performed systematic reviews of randomised controlled trials to determine optimum rehabilitation intensity. Despite the difficulties in finding qualitatively similar therapy regimens provided at different levels of intensity, Langhorne et al. (1996) identified seven randomised controlled trials to include in their study and Kwakkel et al. (2004) included twenty. Langhorne et al. (1996) found that greater intensity of rehabilitation is associated with reduced impairment and disability but qualify that the effect is transient and of limited scale. Kwakkel et al. (2004) report a link between higher intensity rehabilitation and better ADL outcomes. However, the nature of

these studies has severe limitations. While the authors have endeavoured to isolate the outcome effects caused by intensity of rehabilitation alone, given the heterogeneity of the trials included in the studies, this is not truly possible. [24, 25]

In comparing four European stroke rehabilitation centres, De Wi et al. (2012) also concluded that there is a relationship between greater rehabilitation intensity and better outcomes. Functional recovery was best in the Swiss and German centres and it was there that patients received the most intense treatment. [26]

In "Management of Adult Stroke Rehabilitation Care : A Clinical Practice Guideline", endorsed by the American Heart Association and American Stroke Association, it is recommended that, where possible, stroke rehabilitation should be formally coordinated and organised across a variety of treatment disciplines to ensure consistency and reduce risk of complications. It suggests that the following individuals should be considered for the rehabilitation team: physicians, nurses, physical therapists, kinesiotherapists, speech and language pathologists, recreational therapists and family/caregivers. It promotes early commencement of rehabilitation - as soon as the patient has attained medical stability. It also advises that patients are given as much treatment as they require to re-establish their premorbid or optimal functional level. [27]

One of the primary focuses of stroke rehabilitation is retraining in activities of daily living (ADL). The Barthel ADL index is widely used to assess a patient's functional level and monitor their progress in rehabilitation and, as such, provides a good indication of the fundamental targets of physical rehabilitation. The Barthel Index scores patients in the following areas: independence/dependence in grooming, toilet use, feeding, transfers, walking, dressing, stair climbing & bathing and the presence or absence of incontinence. [28]

To complete many of the tasks assessed by the Barthel Index it is necessary or desirable to be able to perform the sit-to-stand (STS) movement. Furthermore, study has shown that an average, healthy, free living person performs around 60 STS movements per day. [29] These factors make facilitation of the STS movement a core target of stroke rehabilitation where realistically possible. That said, it is also thought to be the most mechanically challenging everyday movement that we perform. [30] Rehabilitating normal movement is about facilitating good postural control against gravity; the essential difficulty of STS is that it requires the centre of mass of the body to be raised and brought forward whilst the body moves from a large, stable support base to a smaller, less stable base. [30, 31]

5. Biomechanics of the Sit-to-Stand Movement

The sit-to-stand (STS) movement can be divided into four distinct phases. The phases consist of: flexion-momentum, momentum transfer, extension and stabilisation. [32]

The flexion-momentum phase is where the subject generates the momentum required to rise from the chair. This is achieved by rotating the torso and hips into flexion whilst holding the legs and feet stationary. [32]

During momentum transfer, the subject's buttocks lift from the chair and the momentum generated in the first phase is transferred to the whole body. The subject's centre of mass moves anteriorly and upward. The momentum transfer phase concludes at maximum ankle dorsiflexion. [32]

During the extension phase the torso is propelled upwards by the extension of the hip. This phase ends when the hip first ceases to extend; the subject will be in an upright position. [32]

During the final phase – stabilisation, the subject makes small adjustments to steady their erect position. [32]

There are two primary STS failure modes: "sitback" failure and "step" failure. "Sitback" occurs when the patient begins the STS movement, lifts off from the chair but fails to reach an upright position and returns to the seat. During "step" failure, the patient achieves an erect position but is then unable to stabilise themselves without stepping forward. [33]

Chair seat height, use or non use of armrests and foot position have been found to be determining factors in ability to perform STS: high chair height, use of armrests and relatively posterior foot position is associated with successful movement. [34]

6. Optimum Movement Variability

There are several schools of thought as to the desirability of variation within movement. One theory suggests that variation in a given movement pattern is indicative of an individual's inability to predict the requisite parameters required to perform an underlying motor program. This would lead us to believe that variability is an undesirable quality and suggests that physical therapy should seek to eliminate it from movement patterns. [35]

Another compatible perspective suggests that humans endeavour to find the most stable solution by which to produce a movement. Variation in a movement pattern is suggestive of less cooperative behaviour between the components of the underlying control system. [35]

However, these models alone are insufficient in explaining the relationship between variability and stable, successful movement. Stergiou et al. (2006) make the observation that some seemingly stable behaviours are performed in highly variable ways. They give the example of elite sports players/musicians - these individuals may employ any number of strategies to perform a given task but achieve consistent success. As a result of this observation, Stergiou et al. (2006) propose that there is an optimal level of variability in human movement. They associate excessively high variability with instability and excessively low variability with overly rigid movements. Both conditions result in inability to adapt to new situations. They suggest that physical therapy should focus on encouraging the development of a catalogue of movement strategies. [35]

Vander Linden et al. (1994) sought to identify the characteristics of STS that are affected by movement speed and initial position of the ankle. In a study of eight elderly adults, they compared self paced STS and fast paced STS beginning at 5° and 18° of ankle dorsiflexion. 18° of dorsiflexion reflects a natural starting position and 5° represents the starting position of a patient with limited knee flexion. [36]

Between self-paced and fast trials there was a significant difference in absolute values of: reaction time, quadriceps onset time, erector spinae onset time, time to peak vertical force, phase 1 duration, phase 2 duration, time to maximum horizontal head velocity and time to vertical head velocity. However, when these values were normalised to be expressed as a proportion of overall movement time, only differences in quadriceps and erector spinae onset times remained significant. This would suggest movement strategy is largely independent of movement speed. [36]

Significant, relative timing differences were noted for several characteristics between the 5° and 18° of ankle dorsiflexion trials. While constraining the dorsiflexion of the ankle did not affect phase 1 duration, it delayed tibialis anterior onset time, prolonged phase 2 and shortened phase 3. [36]

In 5° dorsiflexion starting position, the patient is required to move their COM further than when compared to the 18° position and this requires greater momentum generation in phase 1. Linden et al. attribute the increase in phase 2 duration to the prolonged breaking force required to counter this increased momentum. [36]

7. Data

The data for this report will come from the study – "Efficacy of Functional Strength Training on Restoration of Lower-Limb Motor Function Early after Stroke: Phase I Randomized Controlled Trial". This study followed three groups of stroke patients through rehabilitation. The primary purpose of the study was to compare the recovery of patients who received functional strength training as well as conventional physiotherapy as opposed to those who received conventional physiotherapy alone. The study assessed the patients at baseline – post stroke, outcome – after six weeks of therapy and follow up – after 12 weeks of therapy. [37]

Position data was collected using the Vicon motion system. Reflective markers were secured to the patient at anatomically significant points and their trajectory recorded by a set of eight cameras. For each trial, the patient was seated on a bench and asked to commence the STS movement upon hearing an electronic cue. For this study, the position data was sampled at 120Hz and filtered with a fourth order Butterworth filter, with a cut off frequency of 6Hz. The filtered position data was then processed by a custom made model to produce a 15 segment body model.

8. Methods

Data analysis was performed on 11 subjects to determine inter-trial variability of centre of mass velocity in the x-, y- and z-directions. Ideally, there should have been 9 sets of data for each subject – 3 movement repetitions at the 3 assessment points - baseline, outcome and follow up. However, this was not always the case. The reasons for this will be addressed in the discussion. Each of the data sets consisted of centre of mass (COM) co-ordinates in (x,y,z) against time.

8.1. Data Analysis

All data analysis was performed in MATLAB. Initial data was imported from Excel in the form of 9 matrices. Column 1 contained the movement time points and columns 2, 3 & 4 contained the x, y & z co-ordinates of COM position respectively.

Time and position vectors were created by splitting all the input matrices into columns.

X, Y and Z velocity vectors were created for each trial using the following equation:

$$V(i) = \frac{(P(i+1) - P(i-1))}{(T(i+1) - T(i-1))}$$

Equation 8.1. – where V = velocity vector, P = position vector & T = time vector.

The index, i, refers to the elements of the time vector. To calculate a velocity value at a given time point requires the position values at the previous and next time point, this means that the resulting velocity vector is two elements shorter than the initial time and position vectors. The next stage of the analysis was then to remove the first and last values of the time and position vectors so that all vectors correspond to one another and are of equal length.

Movement onset was calculated by considering the COM velocity in the x-direction (or forward direction). The threshold for movement onset was calculated as the mean of the first 15 x-velocity values + 3 standard deviations of the first 15 x-velocity values. Movement onset was considered to occur when the x-velocity first exceeded this value for 20 consecutive frames.

Movement conclusion was considered to occur at maximum centre of mass position in the Z-direction (or upward direction).

All time, position and velocity vectors were then trimmed accordingly, to only contain data between these start and end points.

All times when then converted from seconds to a percentage of the total movement time.

All position and velocity vectors where then combined with their respective time vectors and turned into timeseries. These were then resampled against a standard time vector so that comparisons could be drawn between various trials.

Three figures, one for each assessment point, were created showing COM trajectory for each trial.

Velocity profiles were also plotted for each trial at baseline, outcome and follow up.

Standard deviation of velocity between trials was calculated at each time point and plotted against time.

Each standard deviation profile was then integrated to provide an overall standard deviation value for each direction, at each assessment point. This provides a rough measure of the variability of velocity between trials for a given assessment point.

STS is a simple movement, requiring little adaptability. It is expected that variability will decrease as the patient recovers and improves motor control.

9. Results

Table 9.1 shows data availability for each subject. 'ND' indicates that data was unavailable or not taken. This is most likely due to the subject being physically unable to perform the movement or not attending a particular assessment. A '√' indicates that taken was gathered and successfully analysed. An 'X' indicates that while data was available it could not be analysed. This is due to the subject, beginning the movement but being unable to complete it or inability to determine the point of movement onset. Subject colour denotes the number of assessment points where two or more analysable trials were achieved, allowing calculation of standard deviations - green denotes three, orange two and red only one.

Table 9.2 shows the standard deviation of velocity between trials where there was sufficient data for it to be calculated.

	Baseline			Outcome			Follow Up		
Subject	1	2	3	1	2	3	1	2	3
LL03	ND	ND	ND	√	√	X	√	X	X
LL09	√	X	ND	√	√	√	√	√	√
LL10	√	√	ND	X	√	ND	ND	ND	ND
LL12	√	X	ND	√	√	√	ND	ND	ND
LL22	√	√	√	X	√	√	√	√	ND
LL24	X	X	√	X	X	√	√	√	√
LL27	√	√	√	√	√	√	√	√	√
LL29	X	X	√	X	√	√	X	√	√
LL30	√	√	√	X	X	X	√	X	X
LL39	√	X	√	√	√	√	√	√	√
LL48	√	√	√	X	X	√	√	√	ND

Table 9.1 – Data Availability

	Baseline			Outcome			Follow Up		
Subject	X	Y	Z	X	Y	Z	X	Y	Z
LL03	N/A			2219.10	1975.28	1177.75	N/A		
LL09	N/A			4217.77	2154.36	5062.32	2016.60	1562.93	2550.33
LL10	5411.10	2264.67	5517.34	N/A			N/A		
LL12	N/A			4052.81	1412.32	2752.41	N/A		
LL22	5088.22	2611.54	8733.85	4572.18	2019.95	13805.39	2693.27	1939.56	6872.94
LL24	N/A			N/A			7734.44	2098.92	10650.18
LL27	6592.74	1583.41	5620.22	3354.58	2215.42	4225.15	13401.75	1875.07	10311.05
LL29	N/A			5471.16	1961.00	3827.50	1302.00	1904.16	1592.50
LL30	5561.30	1505.18	5898.69	N/A			N/A		
LL39	7900.91	1332.36	7993.18	6815.22	1833.46	7051.85	9080.36	1498.17	8781.64
LL48	9077.36	4305.60	15985.09	N/A			4871.38	1971.61	7432.57

Table 9.2 – Standard Deviation of Velocity between Trials

9.1.   Subject LL22
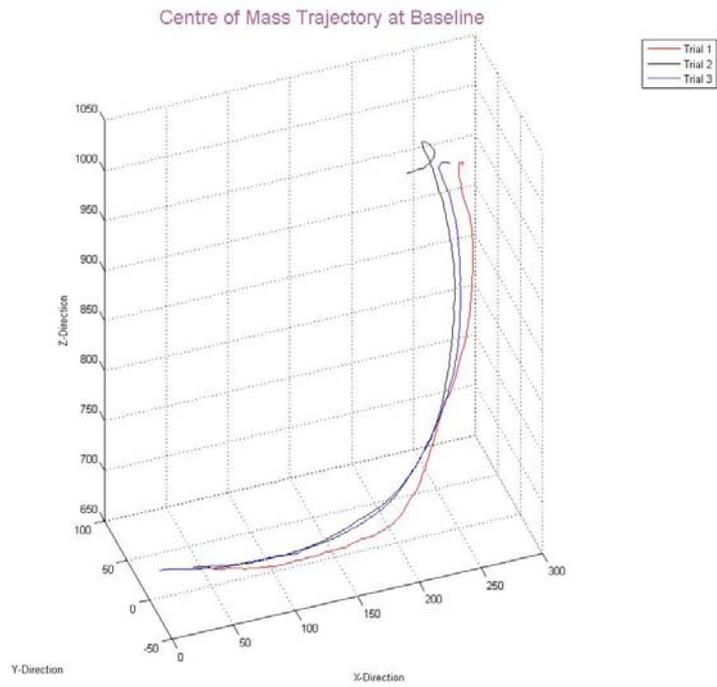
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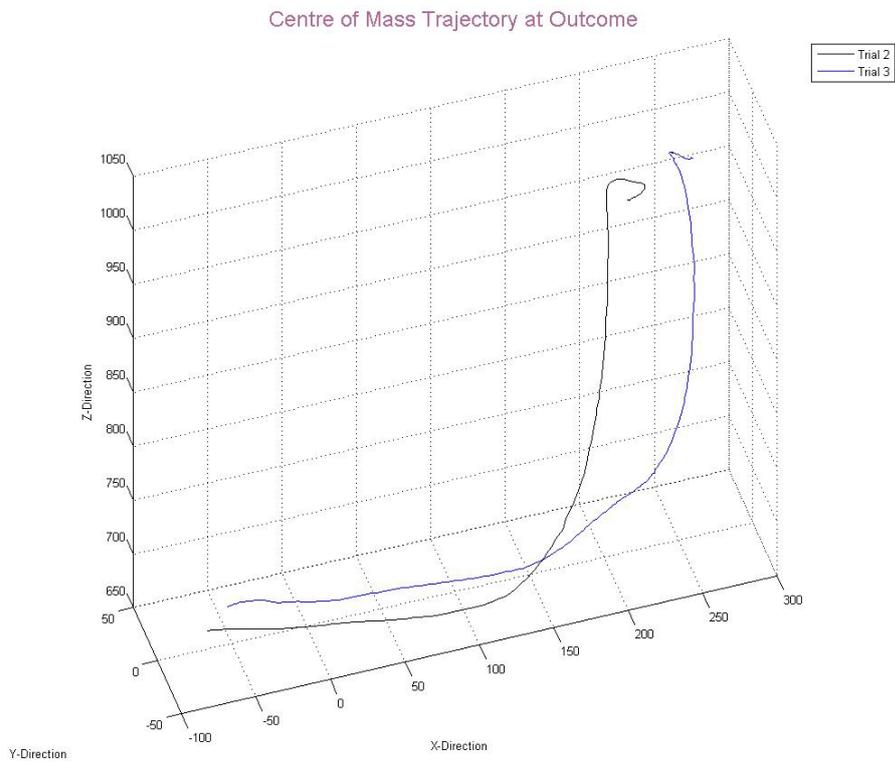
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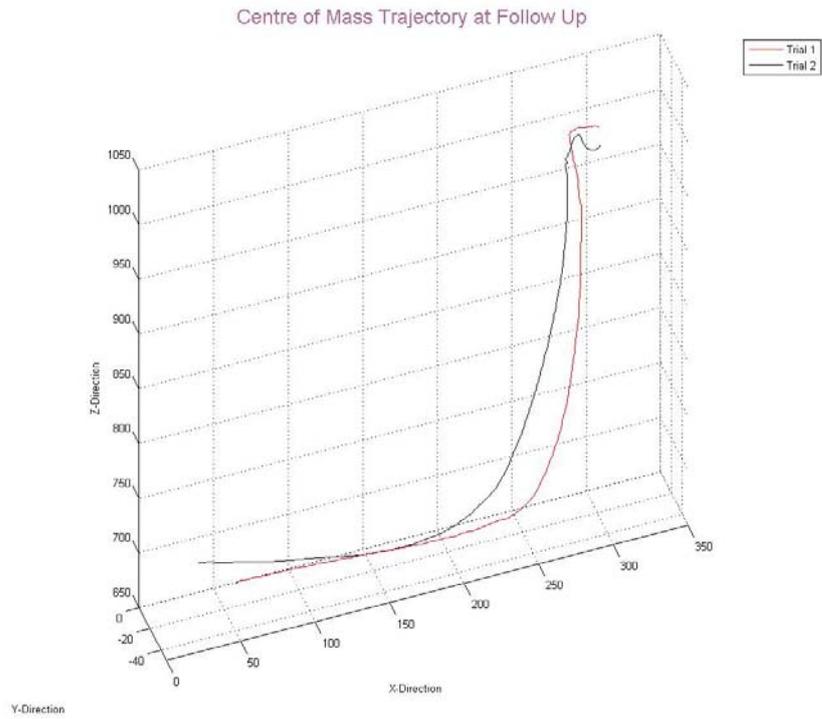
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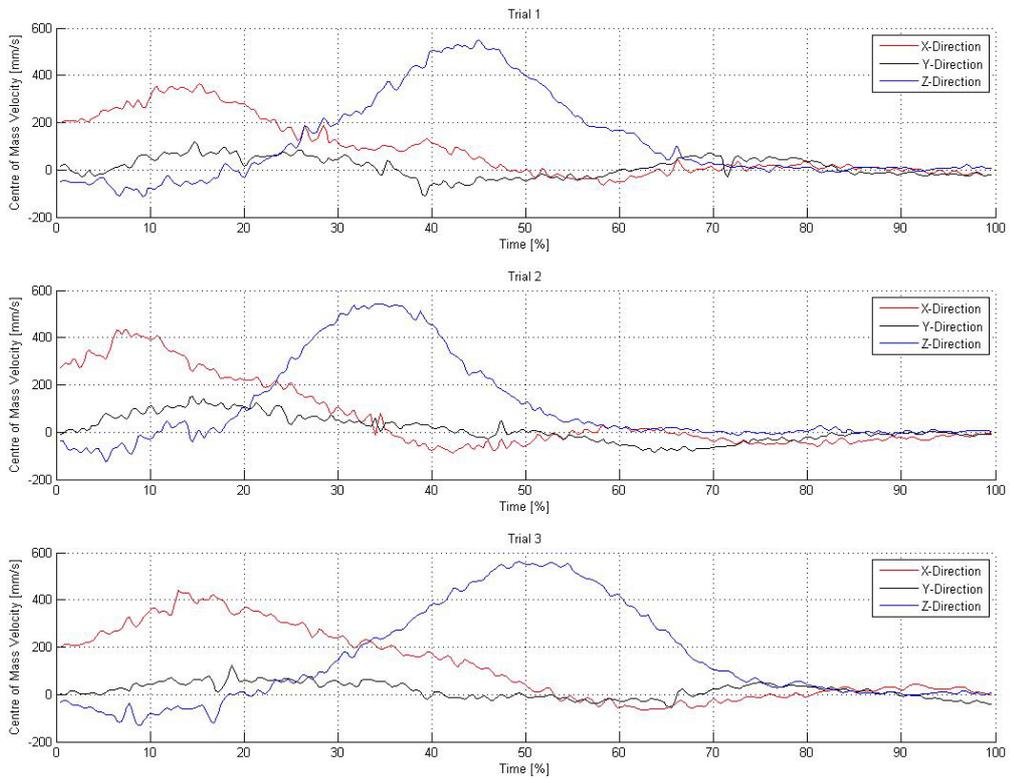
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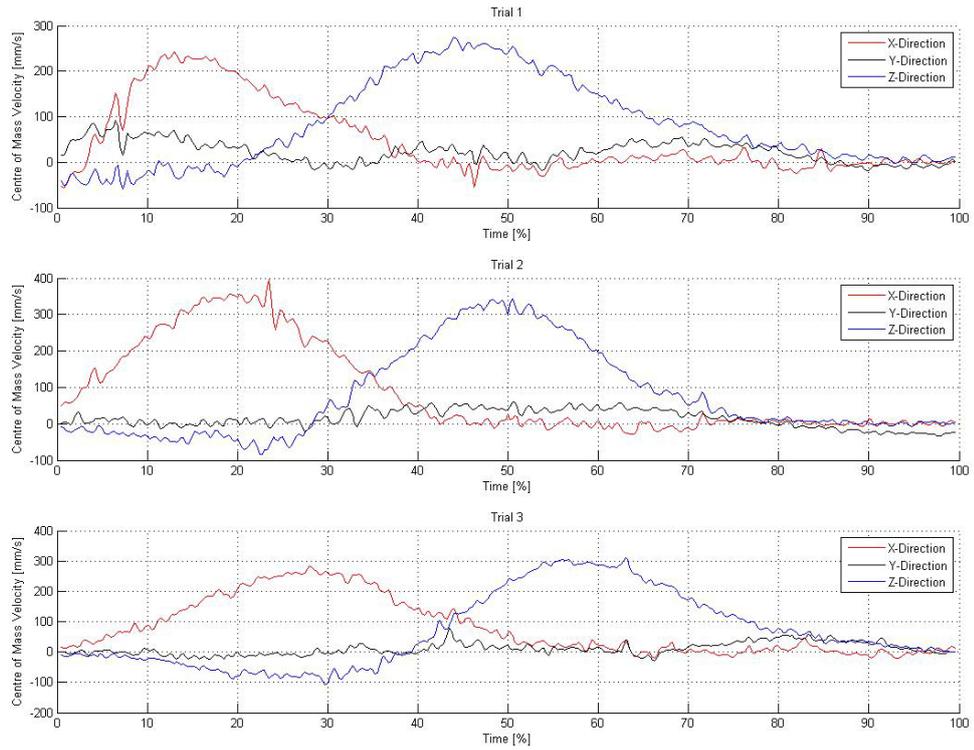
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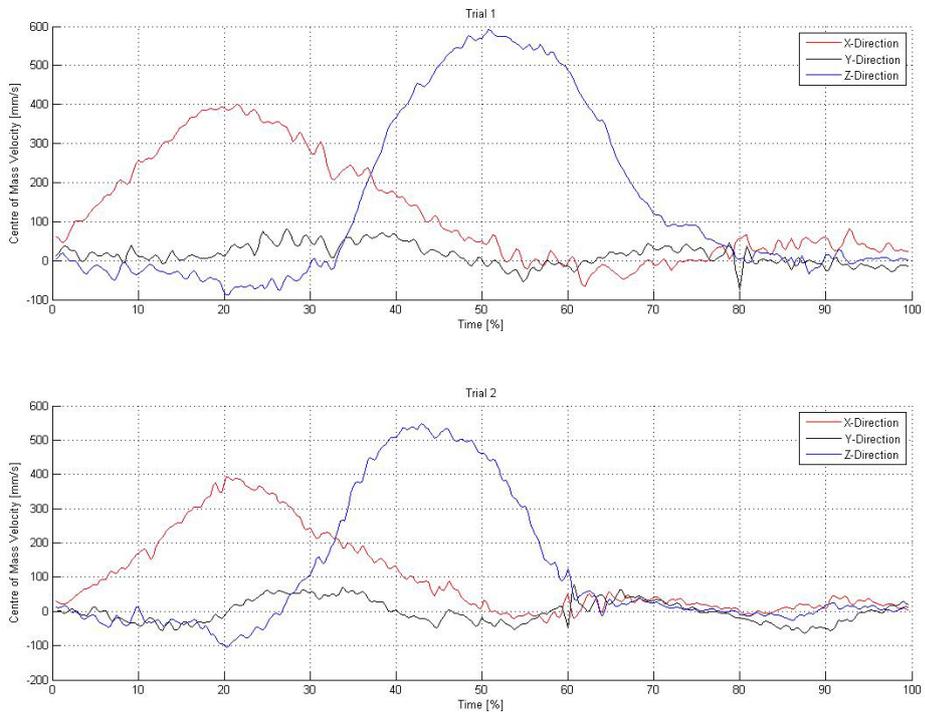
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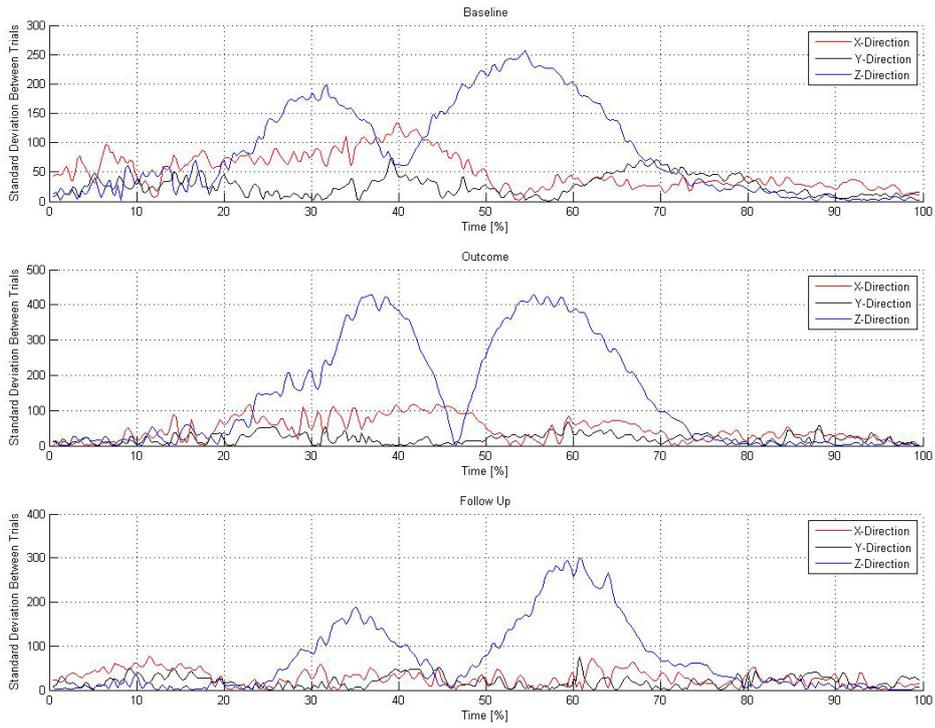
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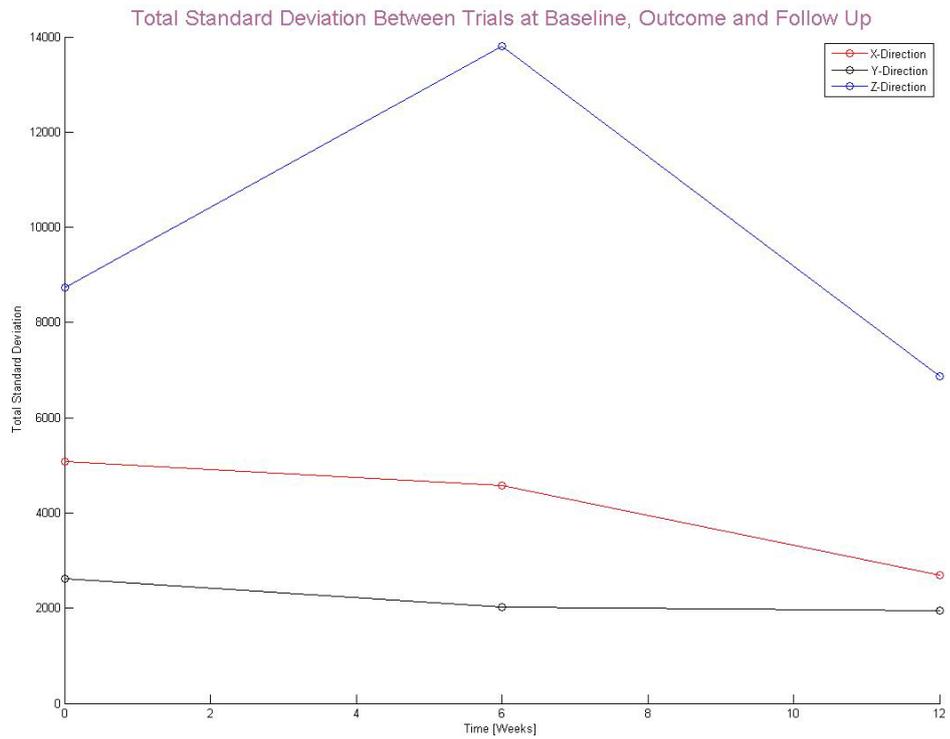
Figure 8. – Subject L22

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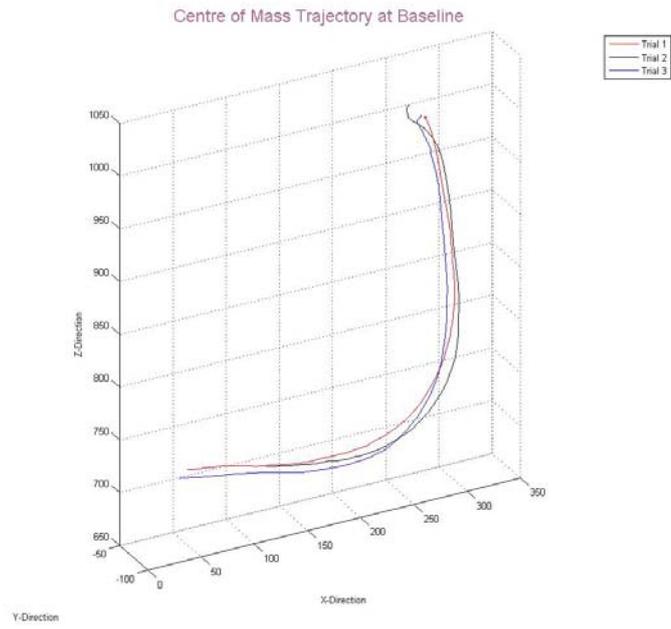
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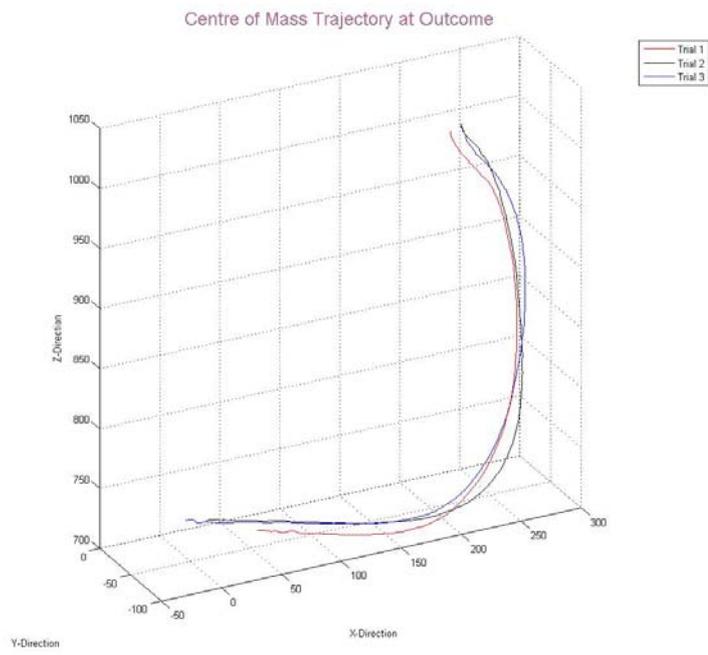
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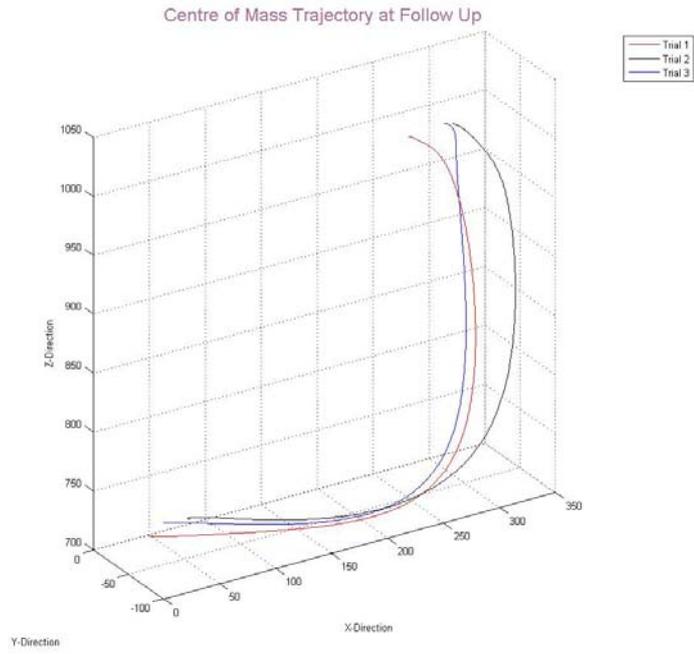
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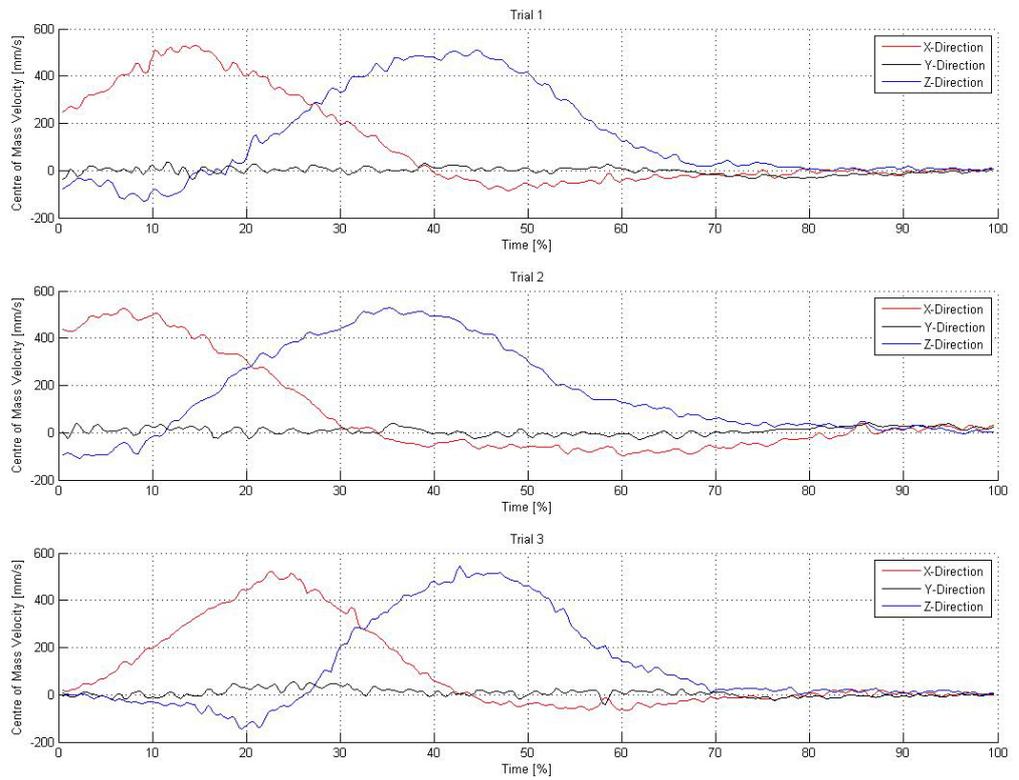
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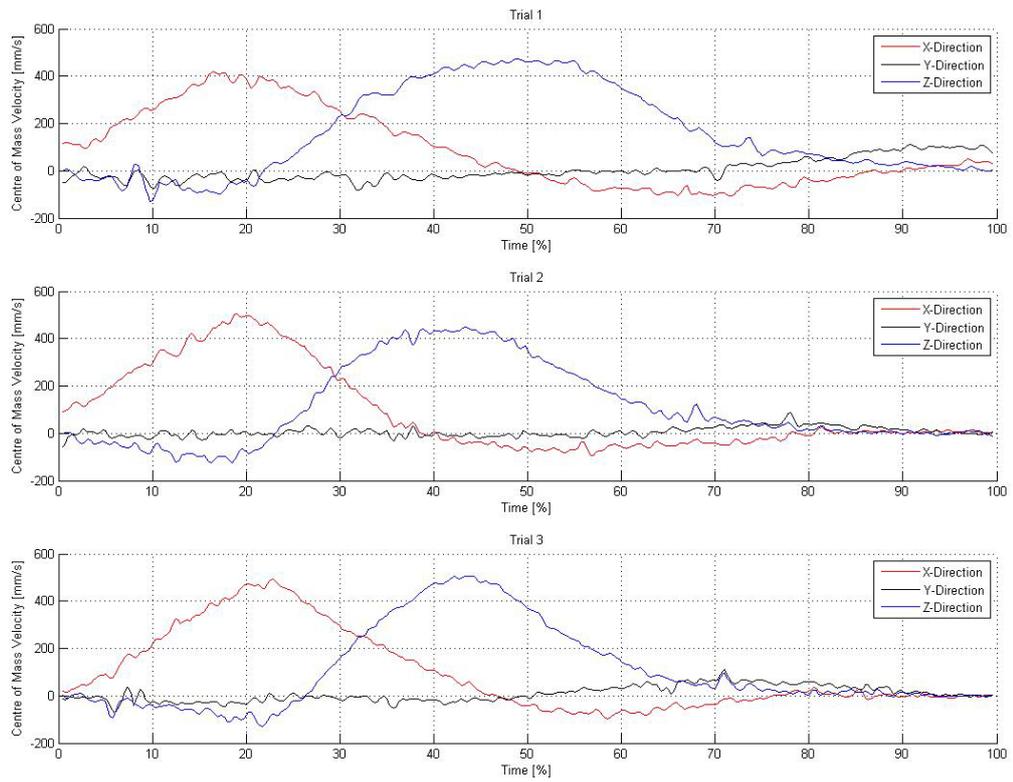
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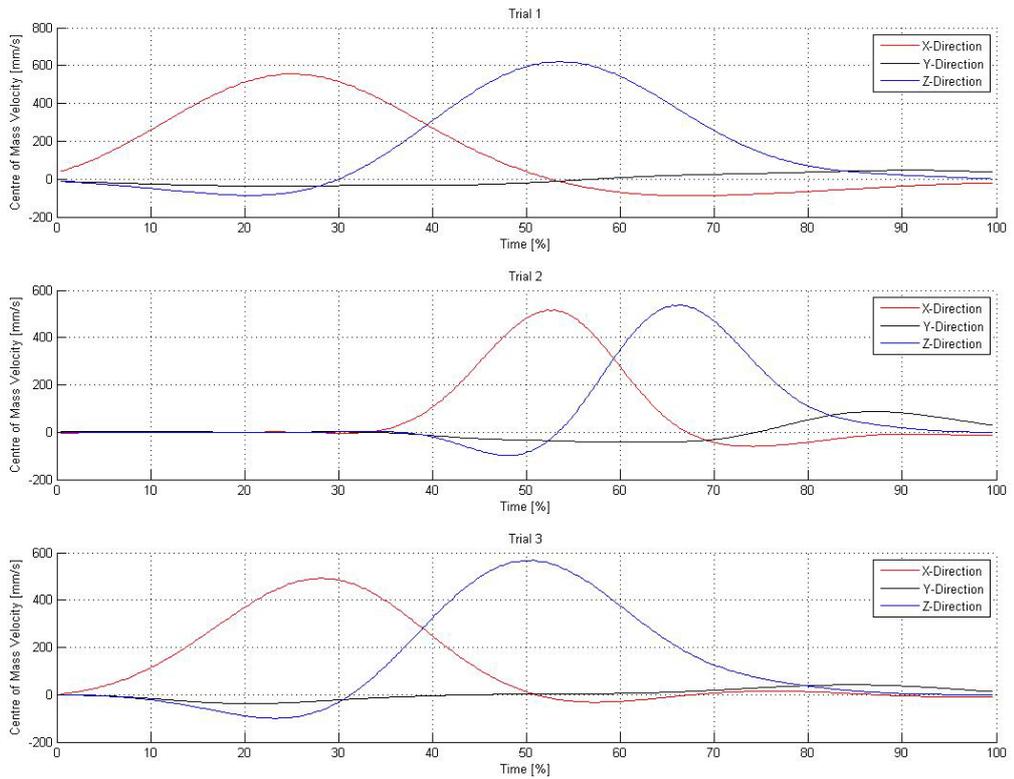
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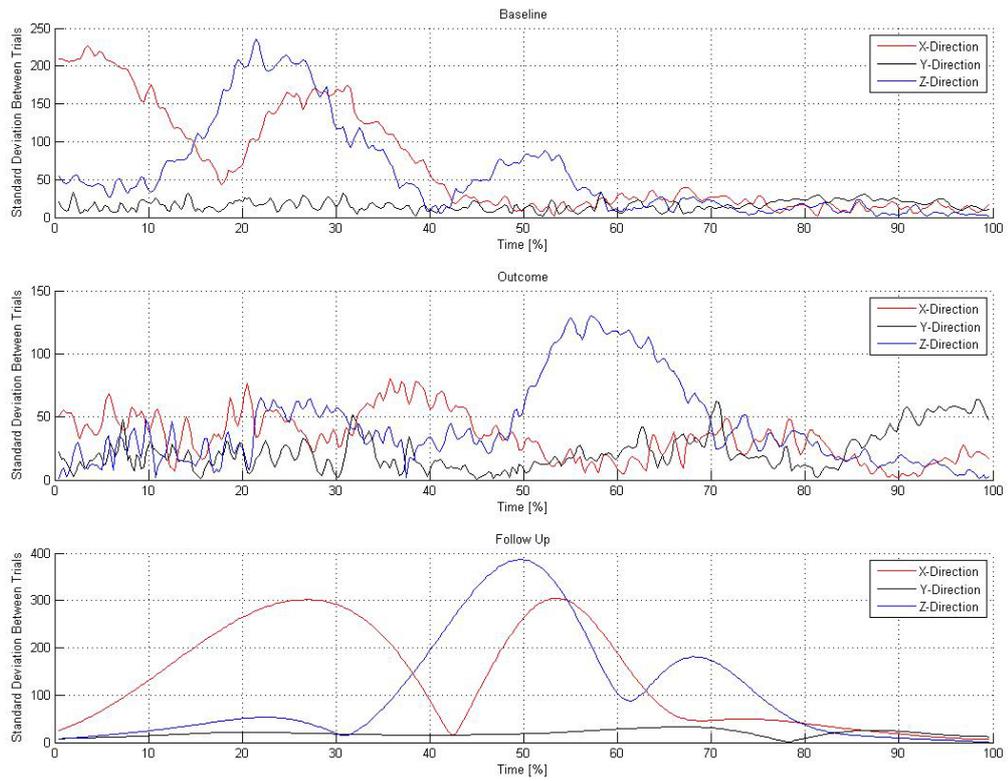
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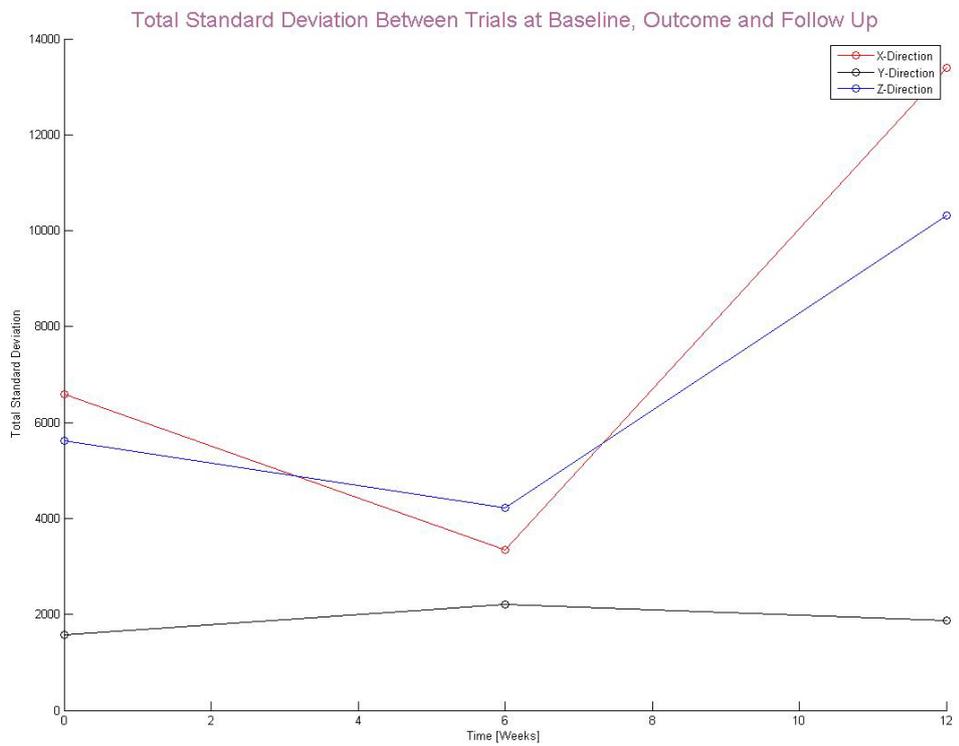
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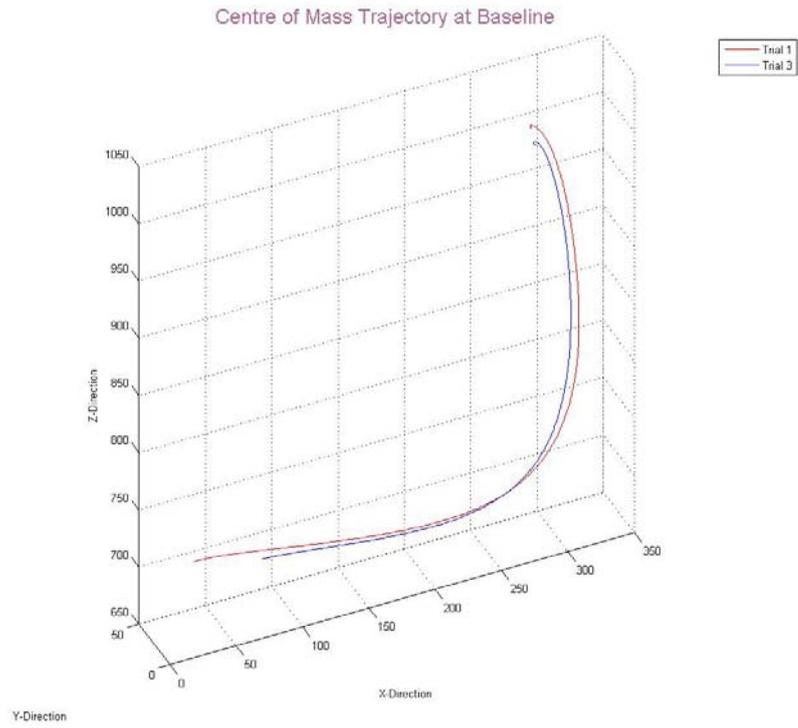
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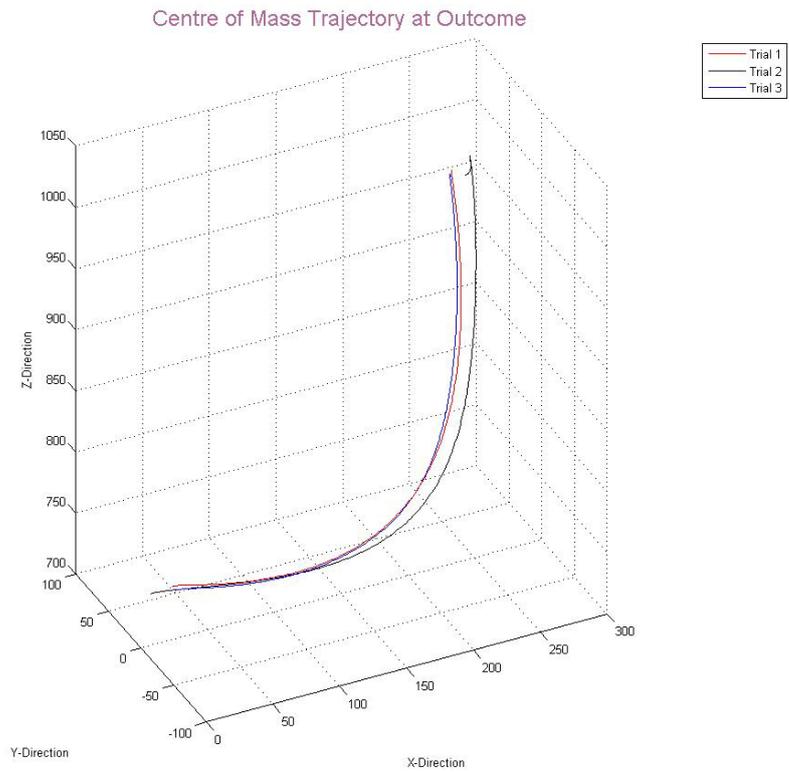
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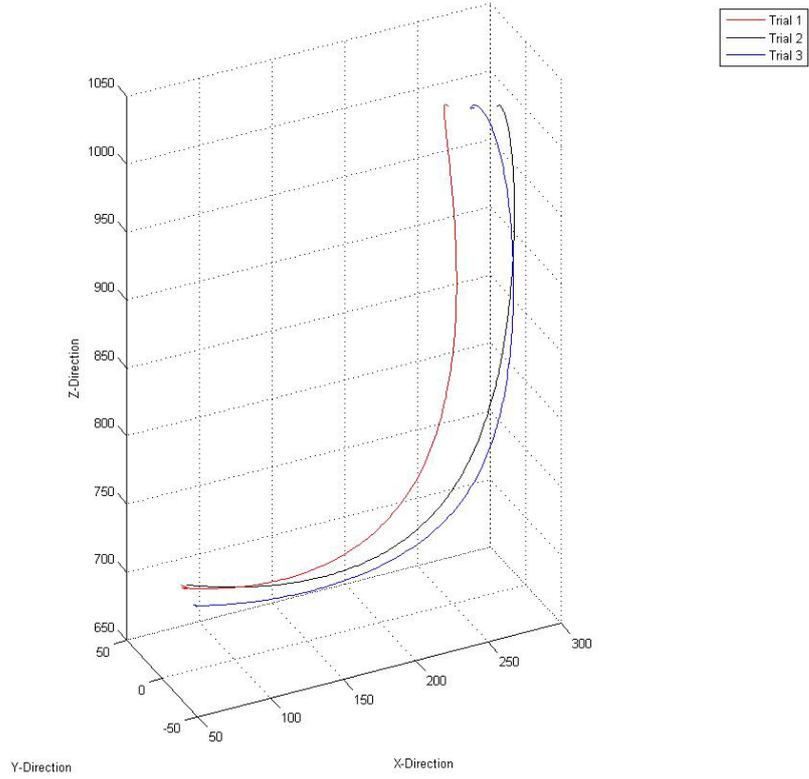
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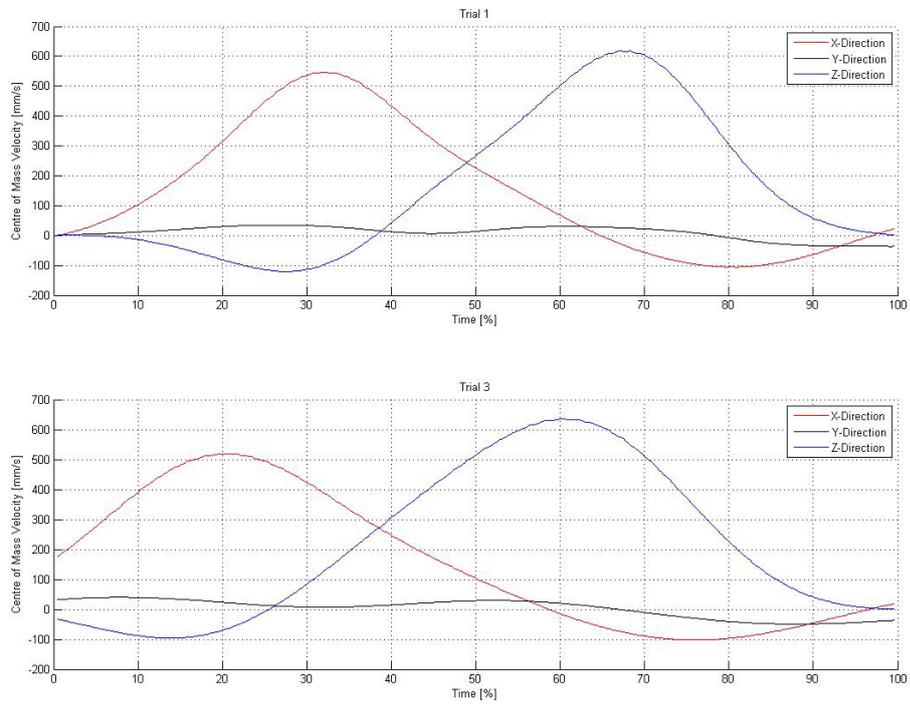
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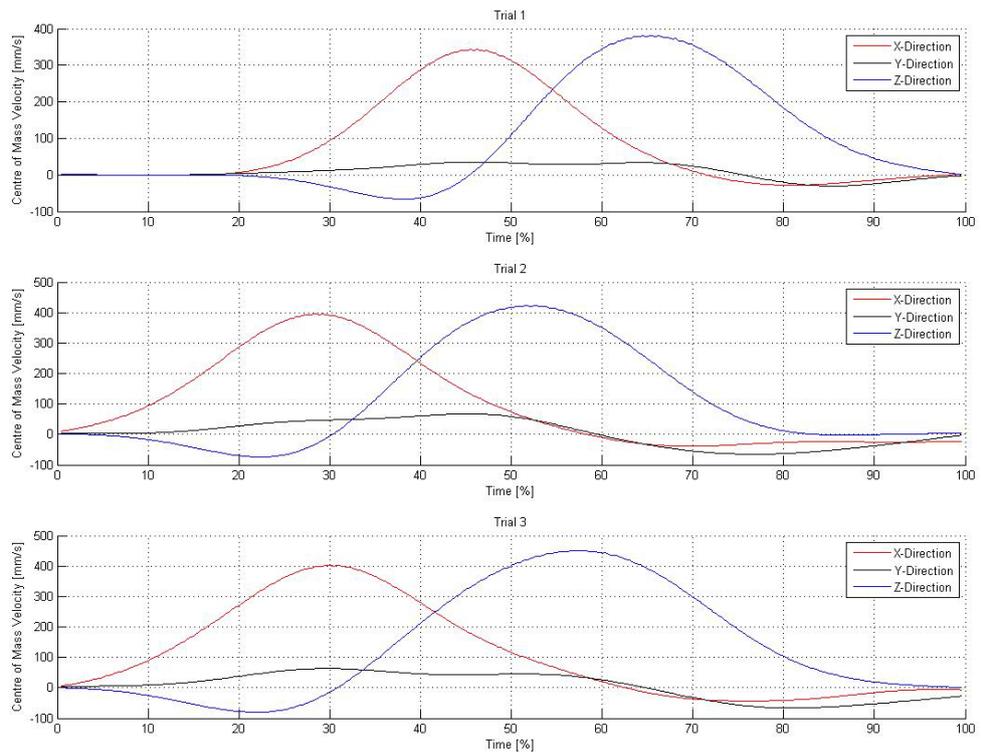
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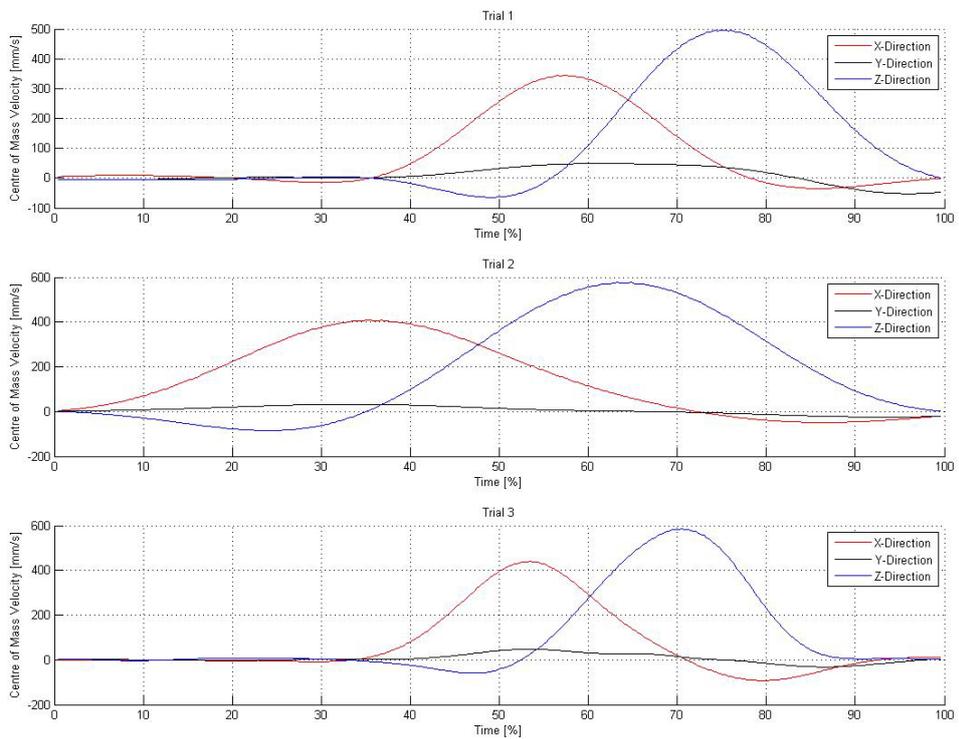
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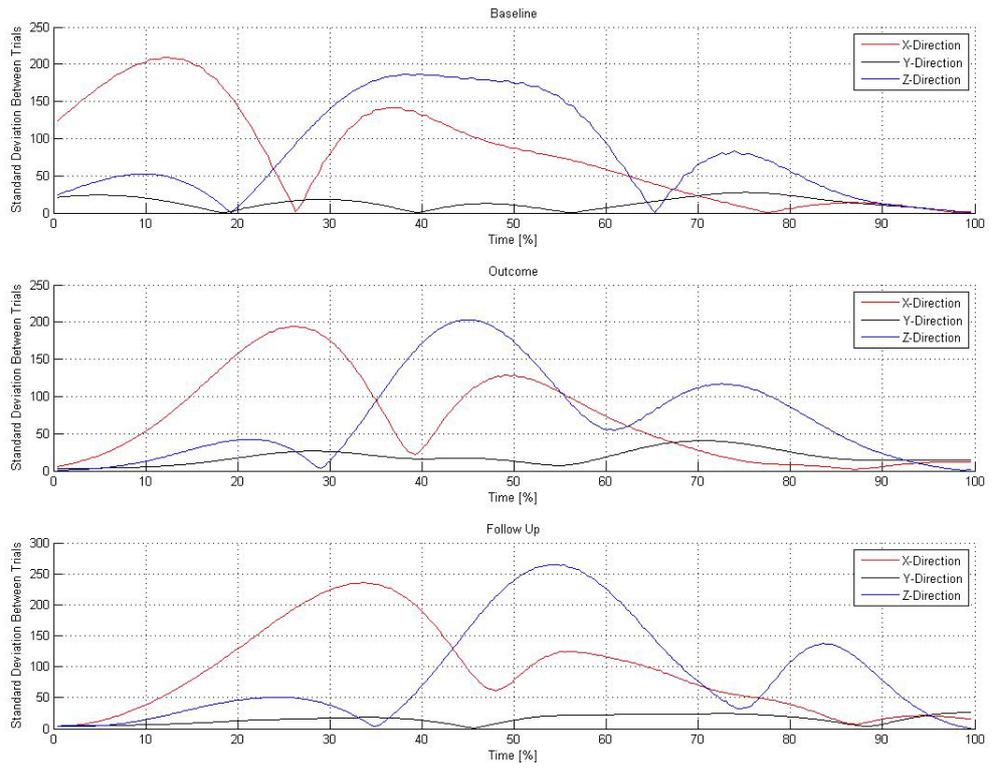
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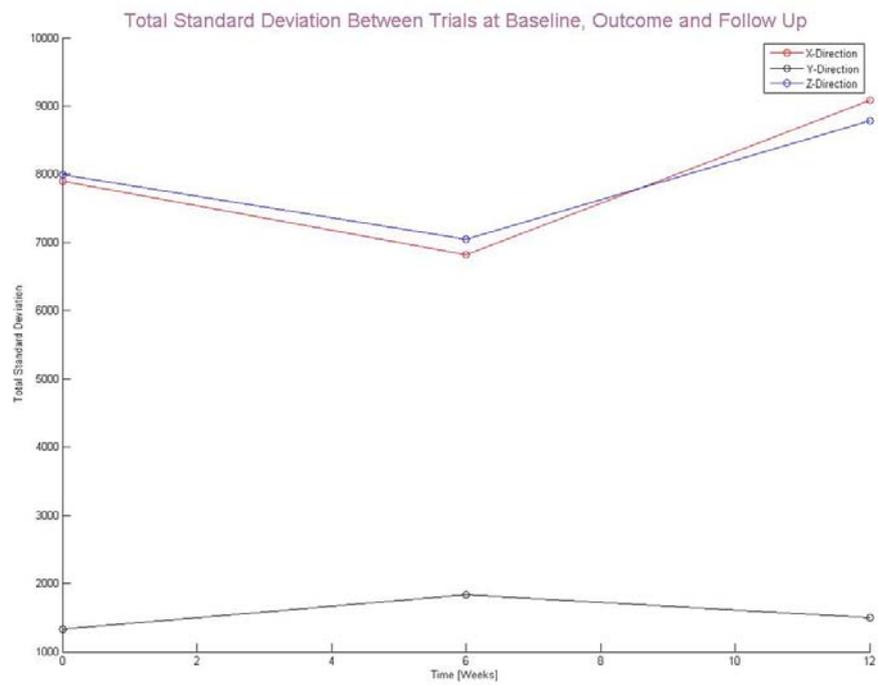
Figure 24 – Subject LL39

10. Discussion & Conclusions

Meaningful investigation of the variability of COM through stroke recovery requires a minimum of two successfully analysed trials at each assessment point and ideally three. As this was only achieved with three subjects it is difficult to draw conclusions on the variability of the STS movement as a patient recovers from stroke.

These results demonstrate that STS has highly characteristic velocity profiles. As you would expect, Y velocity remains fairly constant around 0. X-velocity and Z-velocity both have a single peak with the X-peak always occurring before the Z-peak.

While the standard deviation profiles are less characteristic, all exhibit a double peak in the Z-direction and to a lesser extent in the X-direction too. The time at which the valley between these peaks reaches a minimum appears to coincide with the time at which maximum velocity is achieved. Consider figures 20 – 22: maximum x-velocity at baseline occurs between 20-32% of the movement time, maximum x-velocity at outcome occurs between 29-46% of the movement time and maximum x-velocity at follow up occurs at 35-58% of the movement time. If we then consider figure 23: the between peak minima occur at 27%, 39% and 48% of the movement time respectively. These values correlate exactly with the times of maximum velocity. Similarly in the z-direction, maximum velocities at baseline, outcome and follow up occur at 60-68%, 52-65% and 62-75% of movement time respectively. These coincide with standard deviation between-peak minima positions of 65%, 60% and 74%. Subject LL22 exhibits the same relationship between maximum velocities and between peak minima times in the Z-direction [see figures 4-7] and subject LL27 exhibits the same relationship in both the x- and z-directions. [See figures 12 – 15]

At a point of maximum velocity, acceleration is zero. It would appear that the two peaks in standard deviation correspond to acceleration to and deceleration from maximum velocity. This suggests that periods of acceleration and deceleration are particularly unstable for recovering stroke patients.

Of the three successfully analysed subjects, there are few similarities between how the total standard deviation changes as the patient recovers. The total standard deviation and hence variability did not decrease between assessment points as was expected.

While it was expected that all data taken for analysis in this study was raw and unfiltered, inspection of figures 14 and 20-22 show that this is not the case. While this was unintended

and unfavourable - in that some data sets have been treated differently to others, filtering all the data may have been useful.

Gathering this type of data has inherent problems. Stroke patients, by nature, are going to struggle to perform multiple repetitions of the STS movement, particularly straight after their stroke has occurred. Investigation of variability may be improved by focussing on younger stroke patients who have experienced less severe strokes and assessing completion of STS at more than three time points.

The original data for this study was obtained using the Vicon system and this has its limitations. In order for COM position to be determined, the Vicon cameras must be able to "see" a particular set of markers on the body. If any of the markers are obscured, COM position can not be obtained. One of the difficulties encountered in this study was identification of movement onset. Movement onset was taken to occur when forward velocity exceeded a threshold value for 20 consecutive frames and often this never happened. One possible reason for this was that data from the start of the movement was not being captured due to obstruction of markers.

The method presented here is only one approach to assessing variability. Another approach would be to consider the "smoothness" of the velocity profiles. Smooth curves should indicate good postural control and jagged curves should indicate poor postural control.

This study is severely limited by the small number of subjects: it is not possible to draw valid conclusions based on such a small cohort.

Further work could look at analysing a larger subject group at more assessment points. According to The Copenhagen Stroke Study, those who suffer a severe stroke will take around 20 weeks of rehabilitation to obtain optimum ADL score [23]; this means that a patient who has had a severe stroke will still be some way from full recovery at the follow up assessment. Also, more assessment points would provide a cleare picture of variability trends through recovery. This study assumes that the patients' functional ability is improving with time but this may not be the case. Rather than assuming improvement, it might be useful to compare the variability at each assessment stage with ADL score at each assessment stage.

11. References

1. Fawcus, R. (2000). Sroke Rehabilitation, A Collaborative Approach. Blackwell Science.
2. Laidler, P. (1994). Stroke Rehabilitation, Structure and Strategy. Chapman & Hall.
3. Sandin, K. J. et al. (1996). Manual of Stroke Rehabilitation. Butterworth Heinemann.
4. Martini, F. H. et al. (2012). Fundamentals of Anatomy & Physiology Ninth Edition. Pearson.
5. Cleveland Clinic, Centre for Continuing Education. (2012) Stroke.
   Available at: Cleveland Clinic Website.
   <http://www.clevelandclinicmeded.com/medicalpubs/diseasemanagement/neurology/ischemic-stroke/> (accessed 10/09/12)
6. British Heart Foundation. Our Heart Disease Facts.
   Available at: British Heart Foundation Website
   <http://www.bhf.org.uk/media/news-from-the-bhf/bhf-facts.aspx> (accessed: 10/09/12)
7. Patient.co.uk. Stroke.
   Available at: Patient.co.uk Website.
   <http://www.patient.co.uk/health/Stroke.htm > (accessed: 10/09/12)
8. National Institute of Neurological Disorders and Stroke. NINDS Stroke Information Page. Available at: National Institute of Neurological Disorders and Stroke Website. <http://www.ninds.nih.gov/disorders/stroke/stroke.htm> (accessed: 10/09/12)
9. Scottish Intercollegiate Guidelines Network. (2010). Management of patients with stroke: Rehabilitation, prevention and management of complications, and discharge planning. Edinburgh: SIGN.
10. Department of Health. (2007). National Stroke Strategy.
11. Kelly-Hayes, M. et al. (2003). The influence of gender and age on disability following ischemic stroke: The Framingham study. Journal of Stroke and Cerebrovascular Diseases.
12. Andersen, K. K. et al. (2009). Hemorrhagic and Ischemic Strokes Compared: Stroke Severity, Mortality, and Risk Factors. Stroke.
13. Lloyd-Jones, D. et al. (2009). Heart Disease and Stroke Statistics – 2010 Update: A Report from the American Heart Association. Circulation
14. Saka, Ö. Et al. (2009). Cost of Stroke in the United Kingdom. Age and Ageing.
15. Andrews, K (1987). Rehabilitation of the Older Adult. Edward Arnold.
16. Salter, K. et al. (2006). Impact of Early VS Delayed Admission to Rehabilitation on Functional Outcomes in Persons with Stroke. J Rehabil Med.
17. Maulden, S. A. et al. (2005). Timing of Initiation of Rehabilitation After Stroke. Phys Med Rehabil.
18. Biernaskie, J. et al. (2003). Efficacy of Rehabilitative Experience Declines with Time after Focal Ischemic Brain Injury. The Journal of Neuroscience.

19. Musicco, M. et al. (2003). Early and Long-Term Outcome of Rehabilitation in Stroke Patients: The Role of Patient Characteristics, Time of Initiation, and Duration of Interventions.
20. Murie-Fernández, M. et al. (2010). Neuro-rehabilitation after Stroke. Neurologia.
21. Risedal, A. et al. (1999). Early Training may exacerbate Brain Damage after Focal Brain Ischemia in the Rat. Journal of Cerebral Brain Flow and Metabolism.
22. Bernhardt, J. et al. (2008). A Very Early Rehabilitation Trial for Stroke (AVERT): Phase II Safety and Feasibility. Stroke.
23. Jorgensen, H. S. (1995). Outcome and Time Course of Recovery in Stroke. Part II: Time Course of Recovery. The Copenhagen Stroke Study. Arch Phys Med Rehabil.
24. Langhorne, P. et al. (1996). Physiotherapy after Stroke: More is better? Physiotherapy Research International.
25. Kwakkel, G. et al. (2004). Effects of Augmented Exercise Therapy Time after Stroke: A Meta-Analysis. Stroke.
26. De Wi, L. et al. (2012). Motor and Functional Recover After Stroke: A Comparison of 4 European Rehabilitation Centres. Stroke.
27. Duncan, P. W. et al. (2005). Management of Adult Stroke Rehabilitation Care: A Clinical Practice Guideline.
28. Quinn, T. J. et al. (2011). Barthel Index for Stroke Trials: Development, Properties and Applications. Stroke.
29. Dall, P. M. & Kerr, A. (2009). Frequency of the sit to stand task: An observational study of free-living adults. Applied Ergonomics.
30. Schot, P. K. et al. (2002). Sit-to-Stand Performance of Older Adults Following Strength Training. Research Quarterly for Exercise and Sport
31. Sakineh, A. B. & McIlroy, W. E. (2011). Challenging Horizontal Movement of the Body during Sit-to-Stand: Impact on Stability in the Young and Elderly. Journal of Motor Behaviour
32. Schenkman, M. et al. (1990). Whole-Body Movements during Rising to Standing from Sitting. Physical Therapy.
33. Riley, P. O. et al. (1997). Biomechanical Analysis of Failed Sit-to-Stand. Transactions on Rehabilitation Engineering
34. Janssen, W. G. M. et al. (2002). Determinants of the Sit-to-Stand Movement: A Review. Physical Therapy
35. Stergiou, N. et al. (2006). Optimal Movement Variability: A New Theoretical Perspective for Neurologic Physical Therapy. Journal of Neurologic Physical Therapy.
36. Vander Linden, D. W. et al. (1994). Variant and Invariant Characteristics of the Sit-to-Stand Task in Healthy Elderly Adults.
37. Cooke, E. V. et al. (2009). Efficacy of Functional Strength Training on Restoration of Lower-Limb Motor Function Early After Stroke: Phase I Randomized Controlled Trial. Neurorehabilitation and Neural Repair.

12. Appendices

12.1. MATLAB Code

```
clear all
clc
load LL27

BT1 = B1(:,1);
BPX1 = B1(:,2);
BPY1 = B1(:,3);
BPZ1 = B1(:,4);


BT2 = B2(:,1);
BPX2 = B2(:,2);
BPY2 = B2(:,3);
BPZ2 = B2(:,4);


BT3 = B3(:,1);
BPX3 = B3(:,2);
BPY3 = B3(:,3);
BPZ3 = B3(:,4);


OT1 = O1(:,1);
OPX1 = O1(:,2);
OPY1 = O1(:,3);
OPZ1 = O1(:,4);


OT2 = O2(:,1);
OPX2 = O2(:,2);
OPY2 = O2(:,3);
OPZ2 = O2(:,4);


OT3 = O3(:,1);
OPX3 = O3(:,2);
OPY3 = O3(:,3);
OPZ3 = O3(:,4);


FT1 = F1(:,1);
FPX1 = F1(:,2);
FPY1 = F1(:,3);
FPZ1 = F1(:,4);


FT2 = F2(:,1);
FPX2 = F2(:,2);
FPY2 = F2(:,3);
FPZ2 = F2(:,4);


FT3 = F3(:,1);
FPX3 = F3(:,2);
FPY3 = F3(:,3);
FPZ3 = F3(:,4);


for i = 1:(length(BPX1)-2)
```

```matlab
        BVX1(i) = (BPX1(i+2) - BPX1(i))/(BT1(i+2) - BT1(i));
        BVY1(i) = (BPY1(i+2) - BPY1(i))/(BT1(i+2) - BT1(i));
        BVZ1(i) = (BPZ1(i+2) - BPZ1(i))/(BT1(i+2) - BT1(i));

    end

    for i = 1:(length(BPX2)-2)

        BVX2(i) = (BPX2(i+2) - BPX2(i))/(BT2(i+2) - BT2(i));
        BVY2(i) = (BPY2(i+2) - BPY2(i))/(BT2(i+2) - BT2(i));
        BVZ2(i) = (BPZ2(i+2) - BPZ2(i))/(BT2(i+2) - BT2(i));

    end

    for i = 1:(length(BPX3)-2)

        BVX3(i) = (BPX3(i+2) - BPX3(i))/(BT3(i+2) - BT3(i));
        BVY3(i) = (BPY3(i+2) - BPY3(i))/(BT3(i+2) - BT3(i));
        BVZ3(i) = (BPZ3(i+2) - BPZ3(i))/(BT3(i+2) - BT3(i));

    end


    for i = 1:(length(OPX1)-2)

        OVX1(i) = (OPX1(i+2) - OPX1(i))/(OT1(i+2) - OT1(i));
        OVY1(i) = (OPY1(i+2) - OPY1(i))/(OT1(i+2) - OT1(i));
        OVZ1(i) = (OPZ1(i+2) - OPZ1(i))/(OT1(i+2) - OT1(i));

    end

    for i = 1:(length(OPX2)-2)

        OVX2(i) = (OPX2(i+2) - OPX2(i))/(OT2(i+2) - OT2(i));
        OVY2(i) = (OPY2(i+2) - OPY2(i))/(OT2(i+2) - OT2(i));
        OVZ2(i) = (OPZ2(i+2) - OPZ2(i))/(OT2(i+2) - OT2(i));

    end

    for i = 1:(length(OPX3)-2)

        OVX3(i) = (OPX3(i+2) - OPX3(i))/(OT3(i+2) - OT3(i));
        OVY3(i) = (OPY3(i+2) - OPY3(i))/(OT3(i+2) - OT3(i));
        OVZ3(i) = (OPZ3(i+2) - OPZ3(i))/(OT3(i+2) - OT3(i));

    end


    for i = 1:(length(FPX1)-2)

        FVX1(i) = (FPX1(i+2) - FPX1(i))/(FT1(i+2) - FT1(i));
        FVY1(i) = (FPY1(i+2) - FPY1(i))/(FT1(i+2) - FT1(i));
        FVZ1(i) = (FPZ1(i+2) - FPZ1(i))/(FT1(i+2) - FT1(i));
```

```
        end

for i = 1:(length(FPX2)-2)

    FVX2(i) = (FPX2(i+2) - FPX2(i))/(FT2(i+2) - FT2(i));
    FVY2(i) = (FPY2(i+2) - FPY2(i))/(FT2(i+2) - FT2(i));
    FVZ2(i) = (FPZ2(i+2) - FPZ2(i))/(FT2(i+2) - FT2(i));

end

for i = 1:(length(FPX3)-2)

    FVX3(i) = (FPX3(i+2) - FPX3(i))/(FT3(i+2) - FT3(i));
    FVY3(i) = (FPY3(i+2) - FPY3(i))/(FT3(i+2) - FT3(i));
    FVZ3(i) = (FPZ3(i+2) - FPZ3(i))/(FT3(i+2) - FT3(i));

end

BT1 = BT1(2:(length(BT1)-1));
BPX1 = BPX1(2:(length(BPX1)-1));
BPY1 = BPY1(2:(length(BPY1)-1));
BPZ1 = BPZ1(2:(length(BPZ1)-1));


BT2 = BT2(2:(length(BT2)-1));
BPX2 = BPX2(2:(length(BPX2)-1));
BPY2 = BPY2(2:(length(BPY2)-1));
BPZ2 = BPZ2(2:(length(BPZ2)-1));


BT3 = BT3(2:(length(BT3)-1));
BPX3 = BPX3(2:(length(BPX3)-1));
BPY3 = BPY3(2:(length(BPY3)-1));
BPZ3 = BPZ3(2:(length(BPZ3)-1));

OT1 = OT1(2:(length(OT1)-1));
OPX1 = OPX1(2:(length(OPX1)-1));
OPY1 = OPY1(2:(length(OPY1)-1));
OPZ1 = OPZ1(2:(length(OPZ1)-1));


OT2 = OT2(2:(length(OT2)-1));
OPX2 = OPX2(2:(length(OPX2)-1));
OPY2 = OPY2(2:(length(OPY2)-1));
OPZ2 = OPZ2(2:(length(OPZ2)-1));


OT3 = OT3(2:(length(OT3)-1));
OPX3 = OPX3(2:(length(OPX3)-1));
OPY3 = OPY3(2:(length(OPY3)-1));
OPZ3 = OPZ3(2:(length(OPZ3)-1));


FT1 = FT1(2:(length(FT1)-1));
FPX1 = FPX1(2:(length(FPX1)-1));
FPY1 = FPY1(2:(length(FPY1)-1));
FPZ1 = FPZ1(2:(length(FPZ1)-1));


FT2 = FT2(2:(length(FT2)-1));
FPX2 = FPX2(2:(length(FPX2)-1));
```

```matlab
FPY2 = FPY2(2:(length(FPY2)-1));
FPZ2 = FPZ2(2:(length(FPZ2)-1));


FT3 = FT3(2:(length(FT3)-1));
FPX3 = FPX3(2:(length(FPX3)-1));
FPY3 = FPY3(2:(length(FPY3)-1));
FPZ3 = FPZ3(2:(length(FPZ3)-1));


IV = zeros(1,15);

for i = 1:15

    BIV1(i) = BVX1(i);
    BIV2(i) = BVX2(i);
    BIV3(i) = BVX3(i);

    OIV1(i) = OVX1(i);
    OIV2(i) = OVX2(i);
    OIV3(i) = OVX3(i);

    FIV1(i) = FVX1(i);
    FIV2(i) = FVX2(i);
    FIV3(i) = FVX3(i);

end

BTH1 = mean(BIV1) + 3 * std(BIV1);
BTH2 = mean(BIV2) + 3 * std(BIV2);
BTH3 = mean(BIV3) + 3 * std(BIV3);


OTH1 = mean(OIV1) + 3 * std(OIV1);
OTH2 = mean(OIV2) + 3 * std(OIV2);
OTH3 = mean(OIV3) + 3 * std(OIV3);


FTH1 = mean(FIV1) + 3 * std(FIV1);
FTH2 = mean(FIV2) + 3 * std(FIV2);
FTH3 = mean(FIV3) + 3 * std(FIV3);


minframes = 20;

i = 1;
j = 0;

while j < minframes

    if BVX1(i) >= BTH1
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;
```

```
    end

B1SE = i - (minframes);
[MH, B1EE] = max(BPZ1);
i = 1;
j = 0;

while j < minframes

    if BVX2(i) >= BTH2
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

B2SE = i - (minframes);
[MH, B2EE] = max(BPZ2);

i = 1;
j = 0;

while j < minframes

    if BVX3(i) >= BTH3
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

B3SE = i - (minframes);
[MH, B3EE] = max(BPZ3);

i = 1;
j = 0;

while j < minframes

    if OVX1(i) >= OTH1
        j = j + 1;

    else
        j = 0;
```

```
        end

    i = i + 1;

end

O1SE = i - (minframes);
[MH, O1EE] = max(OPZ1);

i = 1;
j = 0;

while j < minframes

    if OVX2(i) >= OTH2
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

O2SE = i - (minframes);
[MH, O2EE] = max(OPZ2);

i = 1;
j = 0;

while j < minframes

    if OVX3(i) >= OTH3
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

O3SE = i - (minframes);
[MH, O3EE] = max(OPZ3);

i = 1;
j = 0;

while j < minframes
```

```
    if FVX1(i) >= FTH1
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

F1SE = i - (minframes);
[MH, F1EE] = max(FPZ1);

i = 1;
j = 0;

while j < minframes

    if FVX2(i) >= FTH2
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

F2SE = i - (minframes);
[MH, F2EE] = max(FPZ2);

i = 1;
j = 0;

while j < minframes

    if FVX3(i) >= FTH3
        j = j + 1;

    else
        j = 0;

    end

    i = i + 1;

end

F3SE = i - (minframes);
[MH, F3EE] = max(FPZ3);
```

```
for i = B1SE:B1EE

    BTc1(i-B1SE+1) = BT1(i);

    BPXc1(i-B1SE+1) = BPX1(i);
    BPYc1(i-B1SE+1) = BPY1(i);
    BPZc1(i-B1SE+1) = BPZ1(i);

    BVXc1(i-B1SE+1) = BVX1(i);
    BVYc1(i-B1SE+1) = BVY1(i);
    BVZc1(i-B1SE+1) = BVZ1(i);

end

BPXc1 = transpose(BPXc1);
BPYc1 = transpose(BPYc1);
BPZc1 = transpose(BPZc1);

BVXc1 = transpose(BVXc1);
BVYc1 = transpose(BVYc1);
BVZc1 = transpose(BVZc1);

for i = B2SE:B2EE

    BTc2(i-B2SE+1) = BT2(i);

    BPXc2(i-B2SE+1) = BPX2(i);
    BPYc2(i-B2SE+1) = BPY2(i);
    BPZc2(i-B2SE+1) = BPZ2(i);

    BVXc2(i-B2SE+1) = BVX2(i);
    BVYc2(i-B2SE+1) = BVY2(i);
    BVZc2(i-B2SE+1) = BVZ2(i);

end

BPXc2 = transpose(BPXc2);
BPYc2 = transpose(BPYc2);
BPZc2 = transpose(BPZc2);

BVXc2 = transpose(BVXc2);
BVYc2 = transpose(BVYc2);
BVZc2 = transpose(BVZc2);

for i = B3SE:B3EE

    BTc3(i-B3SE+1) = BT3(i);

    BPXc3(i-B3SE+1) = BPX3(i);
    BPYc3(i-B3SE+1) = BPY3(i);
    BPZc3(i-B3SE+1) = BPZ3(i);

    BVXc3(i-B3SE+1) = BVX3(i);
    BVYc3(i-B3SE+1) = BVY3(i);
```

```matlab
        BVZc3(i-B3SE+1) = BVZ3(i);

    end


BPXc3 = transpose(BPXc3);
BPYc3 = transpose(BPYc3);
BPZc3 = transpose(BPZc3);


BVXc3 = transpose(BVXc3);
BVYc3 = transpose(BVYc3);
BVZc3 = transpose(BVZc3);


B1MD = BTc1(length(BTc1))-BTc1(1);
B1ST = BTc1(1);


BTp1 = (BTc1-B1ST)/B1MD*100;
BTp1 = transpose(BTp1);


B2MD = BTc2(length(BTc2))-BTc2(1);
B2ST = BTc2(1);


BTp2 = (BTc2-B2ST)/B2MD*100;
BTp2 = transpose(BTp2);


B3MD = BTc3(length(BTc3))-BTc3(1);
B3ST = BTc3(1);


BTp3 = (BTc3-B3ST)/B3MD*100;
BTp3 = transpose(BTp3);


for i = O1SE:O1EE

    OTc1(i-O1SE+1) = OT1(i);

    OPXc1(i-O1SE+1) = OPX1(i);
    OPYc1(i-O1SE+1) = OPY1(i);
    OPZc1(i-O1SE+1) = OPZ1(i);

    OVXc1(i-O1SE+1) = OVX1(i);
    OVYc1(i-O1SE+1) = OVY1(i);
    OVZc1(i-O1SE+1) = OVZ1(i);

    end


OPXc1 = transpose(OPXc1);
OPYc1 = transpose(OPYc1);
OPZc1 = transpose(OPZc1);


OVXc1 = transpose(OVXc1);
OVYc1 = transpose(OVYc1);
OVZc1 = transpose(OVZc1);


for i = O2SE:O2EE

    OTc2(i-O2SE+1) = OT2(i);
```

```matlab
        OPXc2(i-O2SE+1) = OPX2(i);
        OPYc2(i-O2SE+1) = OPY2(i);
        OPZc2(i-O2SE+1) = OPZ2(i);

        OVXc2(i-O2SE+1) = OVX2(i);
        OVYc2(i-O2SE+1) = OVY2(i);
        OVZc2(i-O2SE+1) = OVZ2(i);

    end

OPXc2 = transpose(OPXc2);
OPYc2 = transpose(OPYc2);
OPZc2 = transpose(OPZc2);

OVXc2 = transpose(OVXc2);
OVYc2 = transpose(OVYc2);
OVZc2 = transpose(OVZc2);


for i = O3SE:O3EE

    OTc3(i-O3SE+1) = OT3(i);

    OPXc3(i-O3SE+1) = OPX3(i);
    OPYc3(i-O3SE+1) = OPY3(i);
    OPZc3(i-O3SE+1) = OPZ3(i);

    OVXc3(i-O3SE+1) = OVX3(i);
    OVYc3(i-O3SE+1) = OVY3(i);
    OVZc3(i-O3SE+1) = OVZ3(i);

    end

OPXc3 = transpose(OPXc3);
OPYc3 = transpose(OPYc3);
OPZc3 = transpose(OPZc3);

OVXc3 = transpose(OVXc3);
OVYc3 = transpose(OVYc3);
OVZc3 = transpose(OVZc3);


O1MD = OTc1(length(OTc1))-OTc1(1);
O1ST = OTc1(1);

OTp1 = (OTc1-O1ST)/O1MD*100;

O2MD = OTc2(length(OTc2))-OTc2(1);
O2ST = OTc2(1);

OTp2 = (OTc2-O2ST)/O2MD*100;

O3MD = OTc3(length(OTc3))-OTc3(1);
O3ST = OTc3(1);
```

```matlab
OTp3 = (OTc3-O3ST)/O3MD*100;

for i = F1SE:F1EE

    FTc1(i-F1SE+1) = FT1(i);

    FPXc1(i-F1SE+1) = FPX1(i);
    FPYc1(i-F1SE+1) = FPY1(i);
    FPZc1(i-F1SE+1) = FPZ1(i);

    FVXc1(i-F1SE+1) = FVX1(i);
    FVYc1(i-F1SE+1) = FVY1(i);
    FVZc1(i-F1SE+1) = FVZ1(i);

end

FPXc1 = transpose(FPXc1);
FPYc1 = transpose(FPYc1);
FPZc1 = transpose(FPZc1);

FVXc1 = transpose(FVXc1);
FVYc1 = transpose(FVYc1);
FVZc1 = transpose(FVZc1);

for i = F2SE:F2EE

    FTc2(i-F2SE+1) = FT2(i);

    FPXc2(i-F2SE+1) = FPX2(i);
    FPYc2(i-F2SE+1) = FPY2(i);
    FPZc2(i-F2SE+1) = FPZ2(i);

    FVXc2(i-F2SE+1) = FVX2(i);
    FVYc2(i-F2SE+1) = FVY2(i);
    FVZc2(i-F2SE+1) = FVZ2(i);

end

FPXc2 = transpose(FPXc2);
FPYc2 = transpose(FPYc2);
FPZc2 = transpose(FPZc2);

FVXc2 = transpose(FVXc2);
FVYc2 = transpose(FVYc2);
FVZc2 = transpose(FVZc2);

for i = F3SE:F3EE

    FTc3(i-F3SE+1) = FT3(i);

    FPXc3(i-F3SE+1) = FPX3(i);
    FPYc3(i-F3SE+1) = FPY3(i);
    FPZc3(i-F3SE+1) = FPZ3(i);
```

```
        FVXc3(i-F3SE+1) = FVX3(i);
        FVYc3(i-F3SE+1) = FVY3(i);
        FVZc3(i-F3SE+1) = FVZ3(i);


end


FPXc3 = transpose(FPXc3);
FPYc3 = transpose(FPYc3);
FPZc3 = transpose(FPZc3);


FVXc3 = transpose(FVXc3);
FVYc3 = transpose(FVYc3);
FVZc3 = transpose(FVZc3);



F1MD = FTc1(length(FTc1))-FTc1(1);
F1ST = FTc1(1);


FTp1 = (FTc1-F1ST)/F1MD*100;
FTp1 = transpose(FTp1);


F2MD = FTc2(length(FTc2))-FTc2(1);
F2ST = FTc2(1);


FTp2 = (FTc2-F2ST)/F2MD*100;
FTp2 = transpose(FTp2);


F3MD = FTc3(length(FTc3))-FTc3(1);
F3ST = FTc3(1);


FTp3 = (FTc3-F3ST)/F3MD*100;


STDTime = 0.5:0.25:99.5;


BPXt1 = timeseries(BPXc1,BTp1);
BPXt1 = resample(BPXt1,STDTime);
BPXr1 = BPXt1.Data;


BPYt1 = timeseries(BPYc1,BTp1);
BPYt1 = resample(BPYt1,STDTime);
BPYr1 = BPYt1.Data;


BPZt1 = timeseries(BPZc1,BTp1);
BPZt1 = resample(BPZt1,STDTime);
BPZr1 = BPZt1.Data;


BPXt2 = timeseries(BPXc2,BTp2);
BPXt2 = resample(BPXt2,STDTime);
BPXr2 = BPXt2.Data;


BPYt2 = timeseries(BPYc2,BTp2);
BPYt2 = resample(BPYt2,STDTime);
BPYr2 = BPYt2.Data;


BPZt2 = timeseries(BPZc2,BTp2);
```

```matlab
BPZt2 = resample(BPZt2,STDTime);
BPZr2 = BPZt2.Data;


BPXt3 = timeseries(BPXc3,BTp3);
BPXt3 = resample(BPXt3,STDTime);
BPXr3 = BPXt3.Data;


BPYt3 = timeseries(BPYc3,BTp3);
BPYt3 = resample(BPYt3,STDTime);
BPYr3 = BPYt3.Data;


BPZt3 = timeseries(BPZc3,BTp3);
BPZt3 = resample(BPZt3,STDTime);
BPZr3 = BPZt3.Data;


figure(1),
grid on
hold on
plot3(BPXr1,BPYr1,BPZr1,'r')
plot3(BPXr2,BPYr2,BPZr2,'k')
plot3(BPXr3,BPYr3,BPZr3,'b')
title('\fontsize{18}Centre of Mass Trajectory at
Baseline','color',[.7 .4 .6])
xlabel('X-Direction')
ylabel('Y-Direction')
zlabel('Z-Direction')
legend('Trial 1','Trial 2','Trial 3')
daspect([1 1 1])
hold off


OPXt1 = timeseries(OPXc1,OTp1);
OPXt1 = resample(OPXt1,STDTime);
OPXr1 = OPXt1.Data;


OPYt1 = timeseries(OPYc1,OTp1);
OPYt1 = resample(OPYt1,STDTime);
OPYr1 = OPYt1.Data;


OPZt1 = timeseries(OPZc1,OTp1);
OPZt1 = resample(OPZt1,STDTime);
OPZr1 = OPZt1.Data;


OPXt2 = timeseries(OPXc2,OTp2);
OPXt2 = resample(OPXt2,STDTime);
OPXr2 = OPXt2.Data;


OPYt2 = timeseries(OPYc2,OTp2);
OPYt2 = resample(OPYt2,STDTime);
OPYr2 = OPYt2.Data;


OPZt2 = timeseries(OPZc2,OTp2);
OPZt2 = resample(OPZt2,STDTime);
OPZr2 = OPZt2.Data;


OPXt3 = timeseries(OPXc3,OTp3);
OPXt3 = resample(OPXt3,STDTime);
OPXr3 = OPXt3.Data;
```

```matlab
OPYt3 = timeseries(OPYc3,OTp3);
OPYt3 = resample(OPYt3,STDTime);
OPYr3 = OPYt3.Data;

OPZt3 = timeseries(OPZc3,OTp3);
OPZt3 = resample(OPZt3,STDTime);
OPZr3 = OPZt3.Data;

figure(2),
grid on
hold on
plot3(OPXr1,OPYr1,OPZr1,'r')
plot3(OPXr2,OPYr2,OPZr2,'k')
plot3(OPXr3,OPYr3,OPZr3,'b')
title('\fontsize{18}Centre of Mass Trajectory at
Outcome','color',[.7 .4 .6])
xlabel('X-Direction')
ylabel('Y-Direction')
zlabel('Z-Direction')
legend('Trial 1','Trial 2','Trial 3')
daspect([1 1 1])
hold off

FPXt1 = timeseries(FPXc1,FTp1);
FPXt1 = resample(FPXt1,STDTime);
FPXr1 = FPXt1.Data;

FPYt1 = timeseries(FPYc1,FTp1);
FPYt1 = resample(FPYt1,STDTime);
FPYr1 = FPYt1.Data;

FPZt1 = timeseries(FPZc1,FTp1);
FPZt1 = resample(FPZt1,STDTime);
FPZr1 = FPZt1.Data;

FPXt2 = timeseries(FPXc2,FTp2);
FPXt2 = resample(FPXt2,STDTime);
FPXr2 = FPXt2.Data;

FPYt2 = timeseries(FPYc2,FTp2);
FPYt2 = resample(FPYt2,STDTime);
FPYr2 = FPYt2.Data;

FPZt2 = timeseries(FPZc2,FTp2);
FPZt2 = resample(FPZt2,STDTime);
FPZr2 = FPZt2.Data;

FPXt3 = timeseries(FPXc3,FTp3);
FPXt3 = resample(FPXt3,STDTime);
FPXr3 = FPXt3.Data;

FPYt3 = timeseries(FPYc3,FTp3);
FPYt3 = resample(FPYt3,STDTime);
FPYr3 = FPYt3.Data;
```

```matlab
FPZt3 = timeseries(FPZc3,FTp3);
FPZt3 = resample(FPZt3,STDTime);
FPZr3 = FPZt3.Data;


figure(3),
grid on
hold on
plot3(FPXr1,FPYr1,FPZr1,'r')
plot3(FPXr2,FPYr2,FPZr2,'k')
plot3(FPXr3,FPYr3,FPZr3,'b')
title('\fontsize{18}Centre of Mass Trajectory at Follow
Up','color',[.7 .4 .6])
xlabel('X-Direction')
ylabel('Y-Direction')
zlabel('Z-Direction')
legend('Trial 1','Trial 2','Trial 3')
daspect([1 1 1])
hold off


BVXt1 = timeseries(BVXc1,BTp1);
BVXt1 = resample(BVXt1,STDTime);
BVXr1 = BVXt1.Data;


BVYt1 = timeseries(BVYc1,BTp1);
BVYt1 = resample(BVYt1,STDTime);
BVYr1 = BVYt1.Data;


BVZt1 = timeseries(BVZc1,BTp1);
BVZt1 = resample(BVZt1,STDTime);
BVZr1 = BVZt1.Data;


BVXt2 = timeseries(BVXc2,BTp2);
BVXt2 = resample(BVXt2,STDTime);
BVXr2 = BVXt2.Data;


BVYt2 = timeseries(BVYc2,BTp2);
BVYt2 = resample(BVYt2,STDTime);
BVYr2 = BVYt2.Data;


BVZt2 = timeseries(BVZc2,BTp2);
BVZt2 = resample(BVZt2,STDTime);
BVZr2 = BVZt2.Data;


BVXt3 = timeseries(BVXc3,BTp3);
BVXt3 = resample(BVXt3,STDTime);
BVXr3 = BVXt3.Data;


BVYt3 = timeseries(BVYc3,BTp3);
BVYt3 = resample(BVYt3,STDTime);
BVYr3 = BVYt3.Data;


BVZt3 = timeseries(BVZc3,BTp3);
BVZt3 = resample(BVZt3,STDTime);
BVZr3 = BVZt3.Data;


OVXt1 = timeseries(OVXc1,OTp1);
OVXt1 = resample(OVXt1,STDTime);
```

```
        OVXr1 = OVXt1.Data;

        OVYt1 = timeseries(OVYc1,OTp1);
        OVYt1 = resample(OVYt1,STDTime);
        OVYr1 = OVYt1.Data;

        OVZt1 = timeseries(OVZc1,OTp1);
        OVZt1 = resample(OVZt1,STDTime);
        OVZr1 = OVZt1.Data;

        OVXt2 = timeseries(OVXc2,OTp2);
        OVXt2 = resample(OVXt2,STDTime);
        OVXr2 = OVXt2.Data;

        OVYt2 = timeseries(OVYc2,OTp2);
        OVYt2 = resample(OVYt2,STDTime);
        OVYr2 = OVYt2.Data;

        OVZt2 = timeseries(OVZc2,OTp2);
        OVZt2 = resample(OVZt2,STDTime);
        OVZr2 = OVZt2.Data;

        OVXt3 = timeseries(OVXc3,OTp3);
        OVXt3 = resample(OVXt3,STDTime);
        OVXr3 = OVXt3.Data;

        OVYt3 = timeseries(OVYc3,OTp3);
        OVYt3 = resample(OVYt3,STDTime);
        OVYr3 = OVYt3.Data;

        OVZt3 = timeseries(OVZc3,OTp3);
        OVZt3 = resample(OVZt3,STDTime);
        OVZr3 = OVZt3.Data;

        FVXt1 = timeseries(FVXc1,FTp1);
        FVXt1 = resample(FVXt1,STDTime);
        FVXr1 = FVXt1.Data;

        FVYt1 = timeseries(FVYc1,FTp1);
        FVYt1 = resample(FVYt1,STDTime);
        FVYr1 = FVYt1.Data;

        FVZt1 = timeseries(FVZc1,FTp1);
        FVZt1 = resample(FVZt1,STDTime);
        FVZr1 = FVZt1.Data;

        FVXt2 = timeseries(FVXc2,FTp2);
        FVXt2 = resample(FVXt2,STDTime);
        FVXr2 = FVXt2.Data;

        FVYt2 = timeseries(FVYc2,FTp2);
        FVYt2 = resample(FVYt2,STDTime);
        FVYr2 = FVYt2.Data;

        FVZt2 = timeseries(FVZc2,FTp2);
        FVZt2 = resample(FVZt2,STDTime);
```

```matlab
FVZr2 = FVZt2.Data;

FVXt3 = timeseries(FVXc3,FTp3);
FVXt3 = resample(FVXt3,STDTime);
FVXr3 = FVXt3.Data;

FVYt3 = timeseries(FVYc3,FTp3);
FVYt3 = resample(FVYt3,STDTime);
FVYr3 = FVYt3.Data;

FVZt3 = timeseries(FVZc3,FTp3);
FVZt3 = resample(FVZt3,STDTime);
FVZr3 = FVZt3.Data;

figure(4),

subplot(3,1,1)
hold on
grid on
plot(STDTime,BVXr1, 'r')
plot(STDTime,BVYr1, 'k')
plot(STDTime,BVZr1, 'b')
title('Trial 1')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,2)
hold on
grid on
plot(STDTime,BVXr2, 'r')
plot(STDTime,BVYr2, 'k')
plot(STDTime,BVZr2, 'b')
title('Trial 2')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,3)
hold on
grid on
plot(STDTime,BVXr3, 'r')
plot(STDTime,BVYr3, 'k')
plot(STDTime,BVZr3, 'b')
title('Trial 3')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')
hold off

figure(5),

subplot(3,1,1)
hold on
grid on
plot(STDTime,OVXr1, 'r')
plot(STDTime,OVYr1, 'k')
```

```
plot(STDTime,OVZr1, 'b')
title('Trial 1')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,2)
hold on
grid on
plot(STDTime,OVXr2, 'r')
plot(STDTime,OVYr2, 'k')
plot(STDTime,OVZr2, 'b')
title('Trial 2')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,3)
hold on
grid on
plot(STDTime,OVXr3, 'r')
plot(STDTime,OVYr3, 'k')
plot(STDTime,OVZr3, 'b')
title('Trial 3')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')
hold off

figure(6),

subplot(3,1,1)
hold on
grid on
plot(STDTime,FVXr1, 'r')
plot(STDTime,FVYr1, 'k')
plot(STDTime,FVZr1, 'b')
title('Trial 1')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,2)
hold on
grid on
plot(STDTime,FVXr2, 'r')
plot(STDTime,FVYr2, 'k')
plot(STDTime,FVZr2, 'b')
title('Trial 2')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,3)
hold on
grid on
plot(STDTime,FVXr3, 'r')
plot(STDTime,FVYr3, 'k')
```

```matlab
plot(STDTime,FVZr3, 'b')
title('Trial 3')
xlabel('Time [%]')
ylabel('Centre of Mass Velocity [mm/s]')
legend('X-Direction', 'Y-Direction', 'Z-Direction')
hold off


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Creating Matrices of Velocities for
% Each Assessment Stage and Direction
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

BXVM = transpose([BVXr1 BVXr2 BVXr3]);
BYVM = transpose([BVYr1 BVYr2 BVYr3]);
BZVM = transpose([BVZr1 BVZr2 BVZr3]);


OXVM = transpose([OVXr1 OVXr2 OVXr3]);
OYVM = transpose([OVYr1 OVYr2 OVYr3]);
OZVM = transpose([OVZr1 OVZr2 OVZr3]);


FXVM = transpose([FVXr1 FVXr2 FVXr3]);
FYVM = transpose([FVYr1 FVYr2 FVYr3]);
FZVM = transpose([FVZr1 FVZr2 FVZr3]);


SDBXV = std(BXVM);
SDBYV = std(BYVM);
SDBZV = std(BZVM);


SDOXV = std(OXVM);
SDOYV = std(OYVM);
SDOZV = std(OZVM);


SDFXV = std(FXVM);
SDFYV = std(FYVM);
SDFZV = std(FZVM);
figure(7),

subplot(3,1,1)
hold on
grid on
plot(STDTime,SDBXV, 'r')
plot(STDTime,SDBYV, 'k')
plot(STDTime,SDBZV, 'b')
title('Baseline')
xlabel('Time [%]')
ylabel('Standard Deviation Between Trials')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,2)
hold on
grid on
plot(STDTime,SDOXV, 'r')
plot(STDTime,SDOYV, 'k')
plot(STDTime,SDOZV, 'b')
title('Outcome')
xlabel('Time [%]')
```

```matlab
ylabel('Standard Deviation Between Trials')
legend('X-Direction', 'Y-Direction', 'Z-Direction')

subplot(3,1,3)
hold on
grid on
plot(STDTime,SDFXV, 'r')
plot(STDTime,SDFYV, 'k')
plot(STDTime,SDFZV, 'b')
title('Follow Up')
xlabel('Time [%]')
ylabel('Standard Deviation Between Trials')
legend('X-Direction', 'Y-Direction', 'Z-Direction')
hold off

TSDBX = trapz(STDTime,SDBXV);
TSDBY = trapz(STDTime,SDBYV);
TSDBZ = trapz(STDTime,SDBZV);

TSDOX = trapz(STDTime,SDOXV);
TSDOY = trapz(STDTime,SDOYV);
TSDOZ = trapz(STDTime,SDOZV);

TSDFX = trapz(STDTime,SDFXV);
TSDFY = trapz(STDTime,SDFYV);
TSDFZ = trapz(STDTime,SDFZV);

TSDX = [TSDBX TSDOX TSDFX];
TSDY = [TSDBY TSDOY TSDFY];
TSDZ = [TSDBZ TSDOZ TSDFZ];

figure(8),
hold on
plot([0 6 12], TSDX, 'ro-')
plot([0 6 12], TSDY, 'ko-')
plot([0 6 12], TSDZ, 'bo-')
title('\fontsize{18}Total Standard Deviation Between Trials at
Baseline, Outcome and Follow Up','color',[.7 .4 .6])
xlabel('Time [Weeks]')
ylabel('Total Standard Deviation')
legend('X-Direction', 'Y-Direction', 'Z-Direction')
```

12.2. Incomplete Data Sets
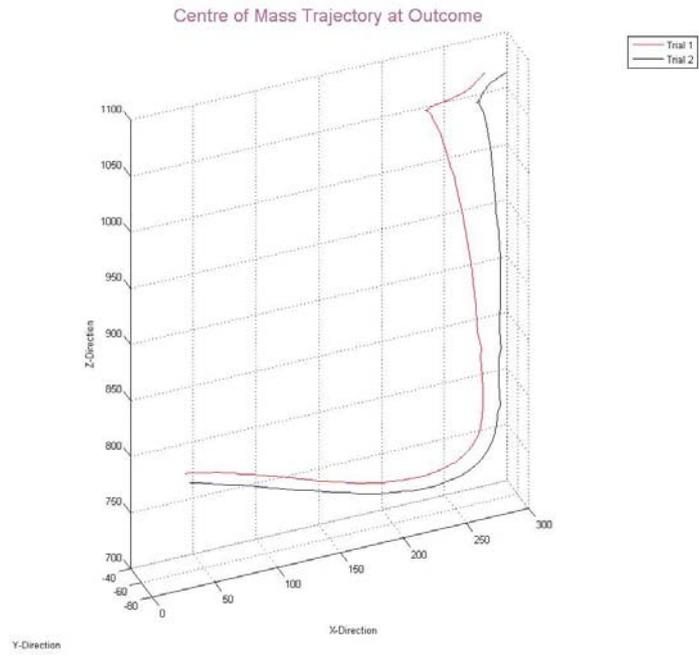
12.2.1. Subject LL03

Subject LL03
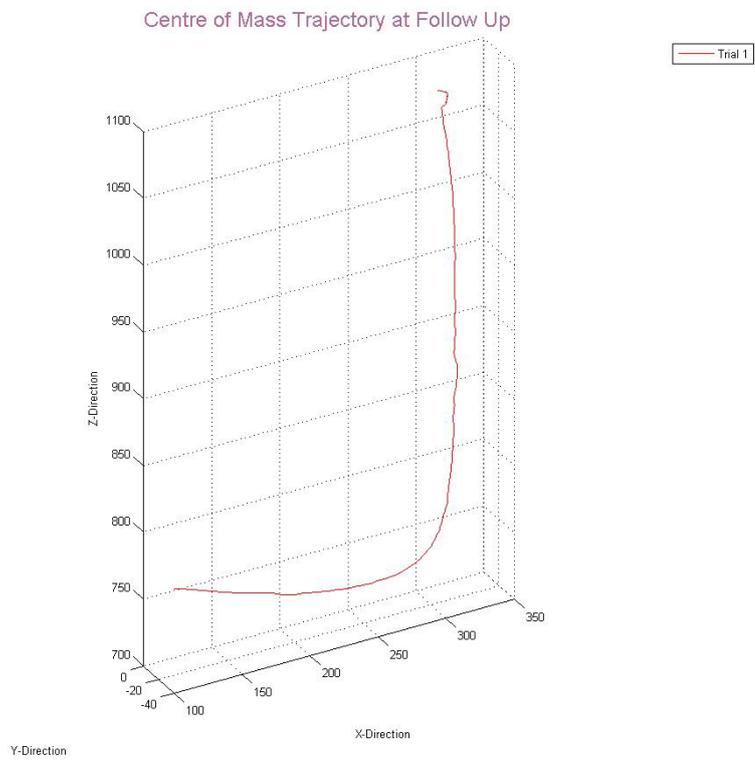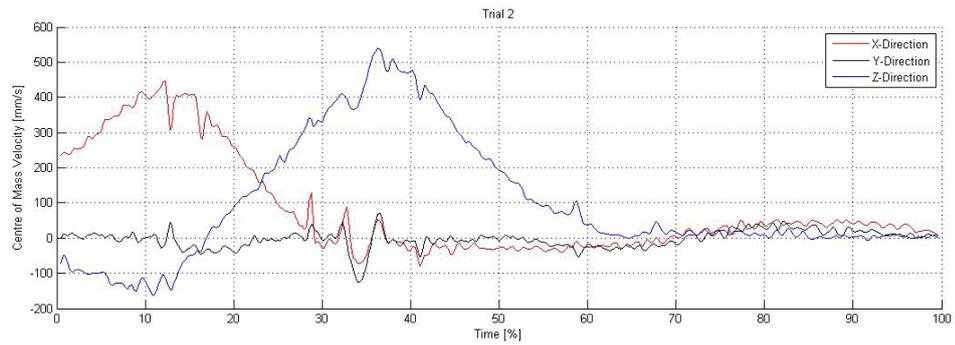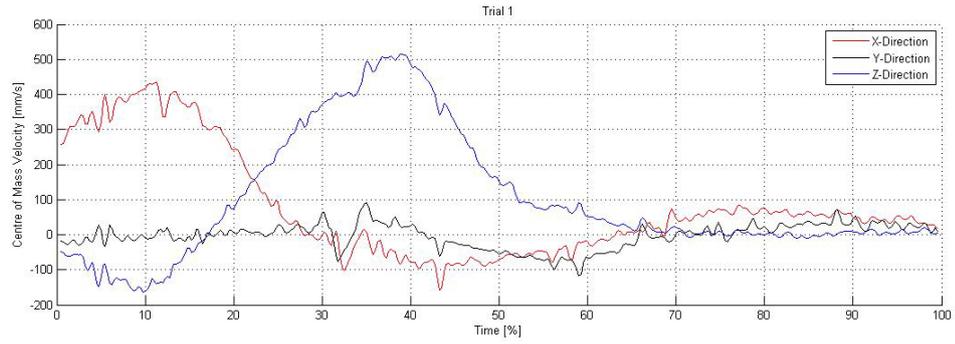
Velocity Profiles at Outcome, Subject LL03
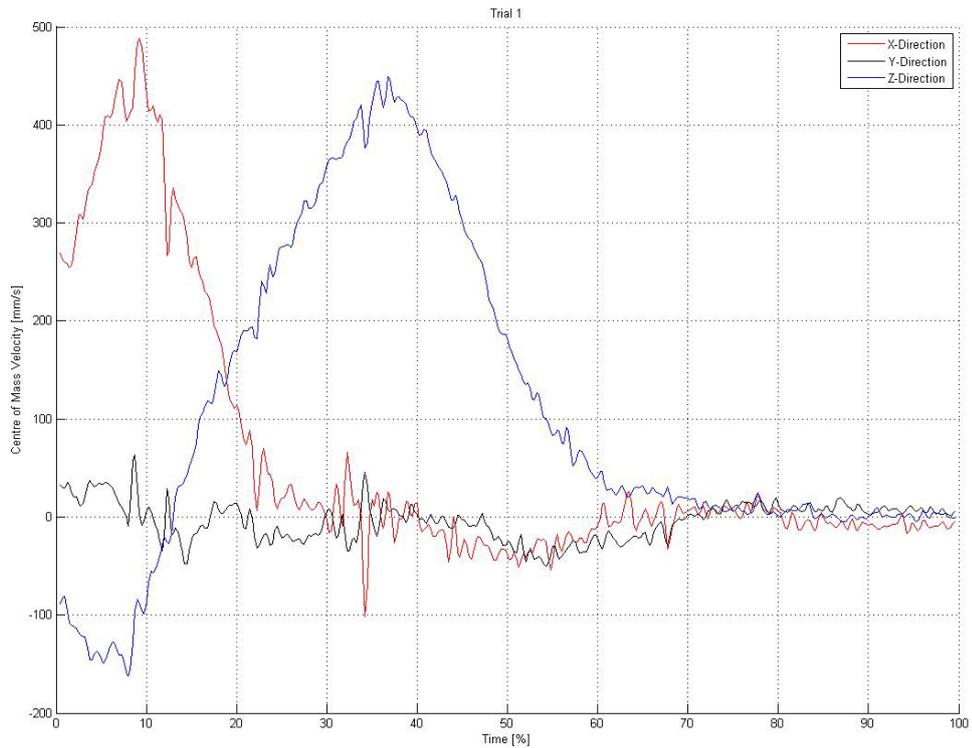
Velocity Profiles at Follow Up, Subject LL03
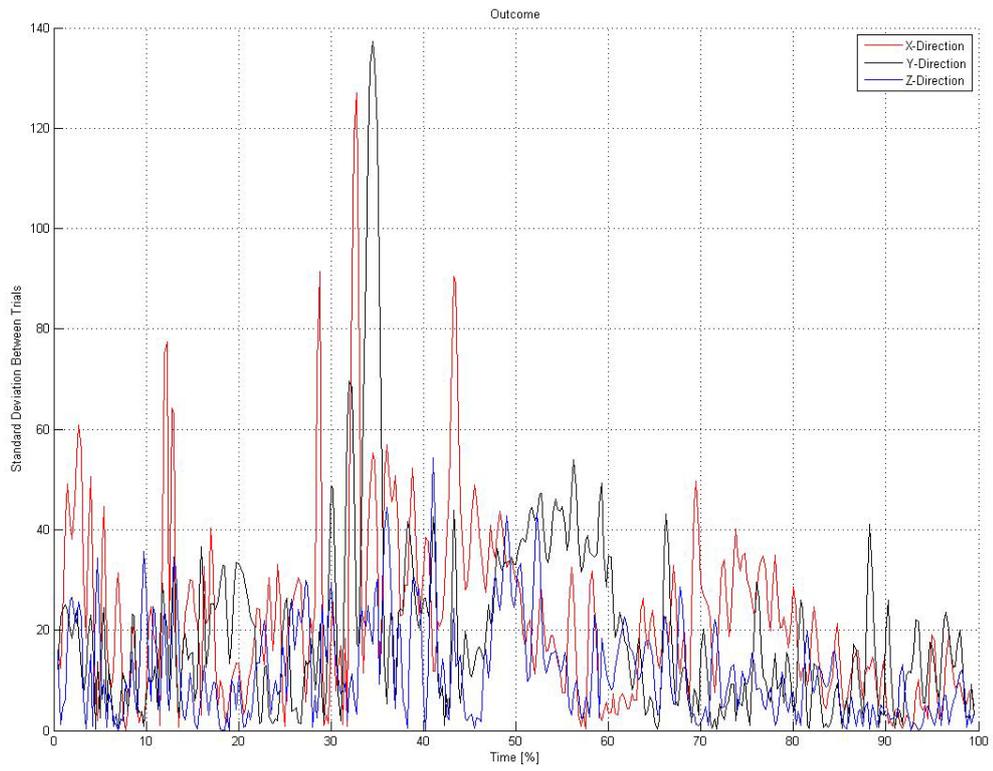
Standard Deviation Profiles, Subject LL39

12.2.2. Subject LL09

Centre of Mass Trajectory at Baseline

Subject LL09

Centre of Mass Trajectory at Outcome
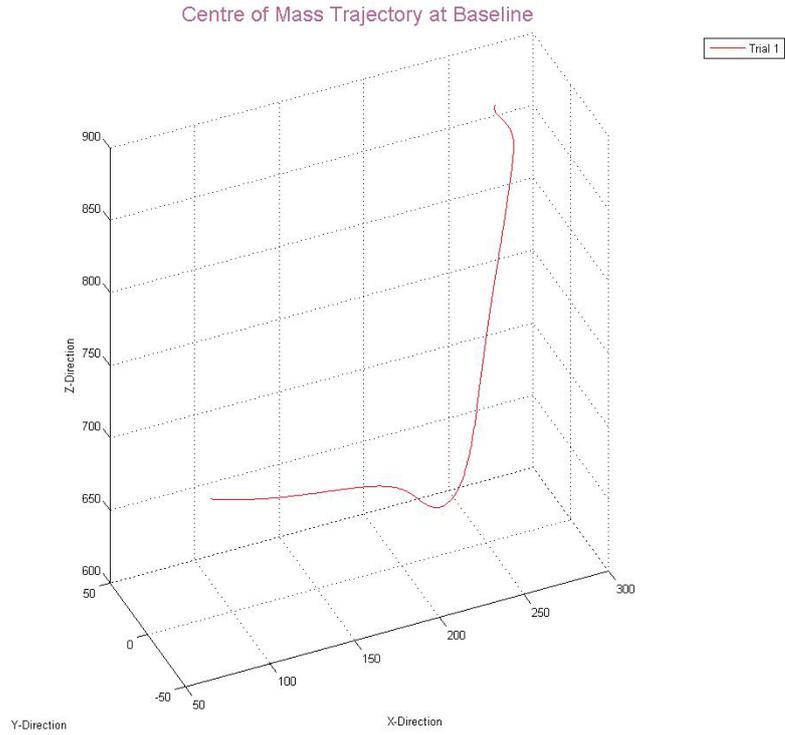
Subject LL09

Subject LL09
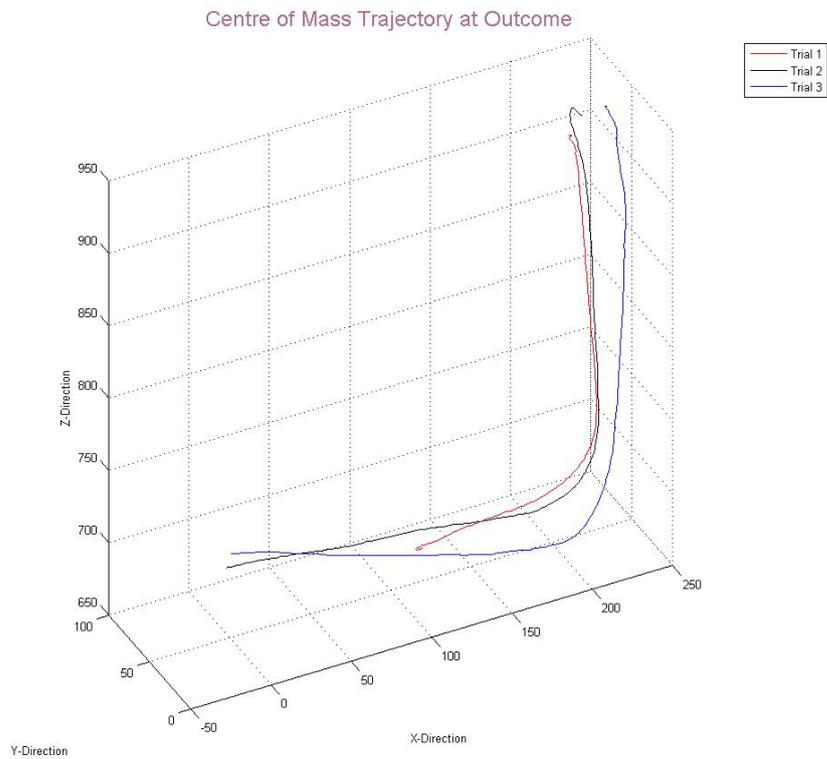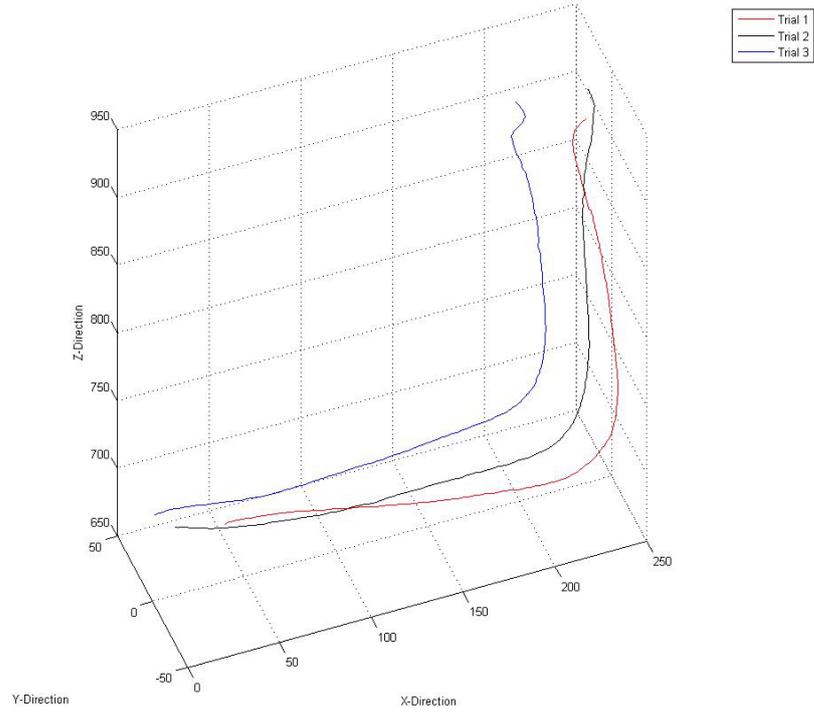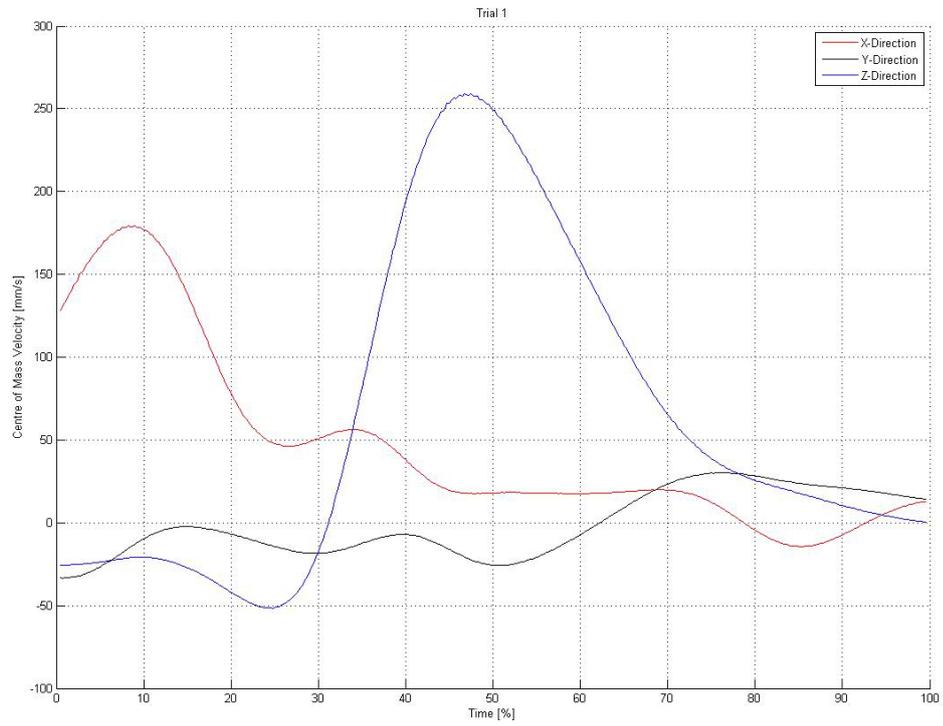
Velocity Profiles at Baseline, Subject LL09
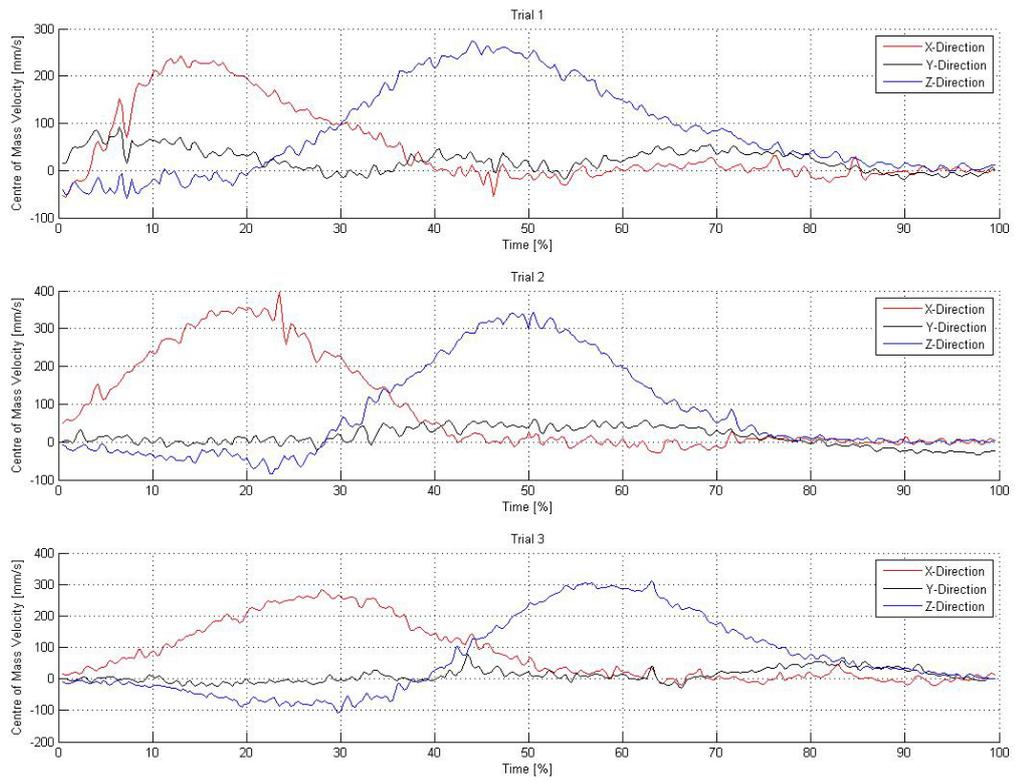
Velocity Profiles at Outcome, Subject LL09
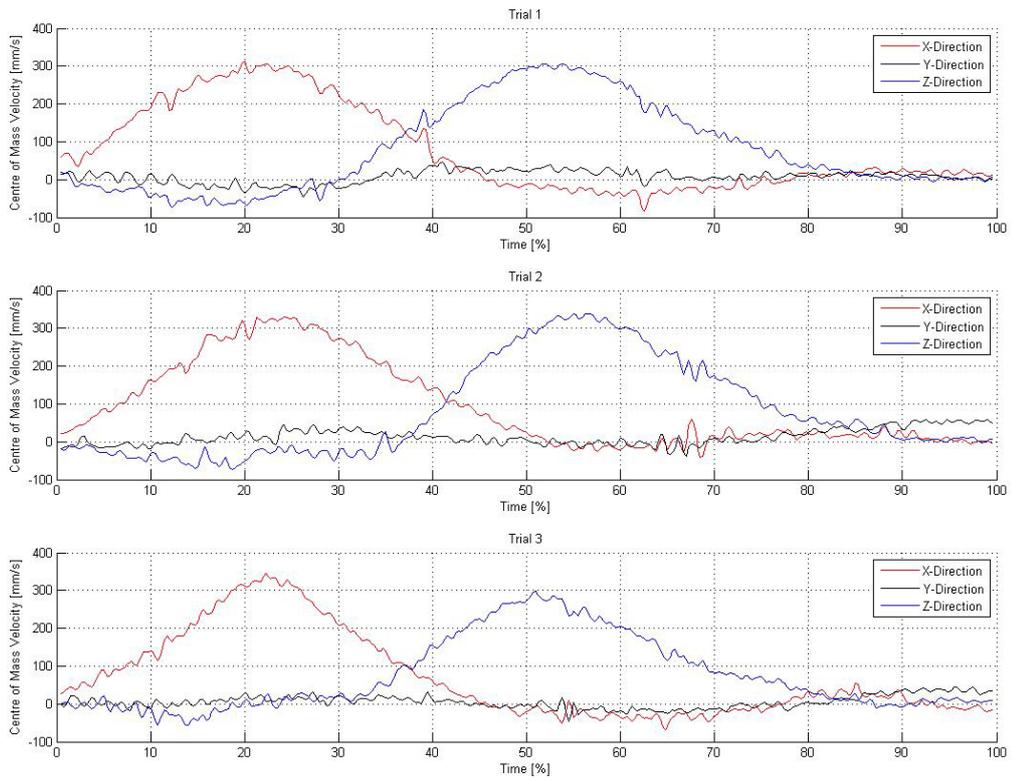
Velocity Profiles at Follow Up, Subject LL09
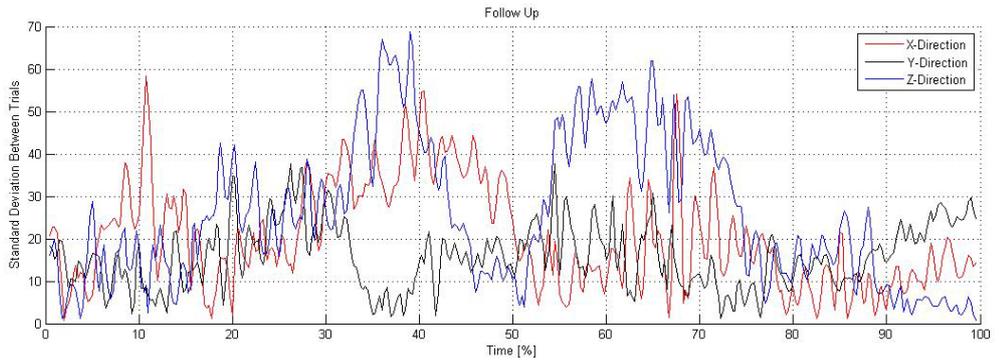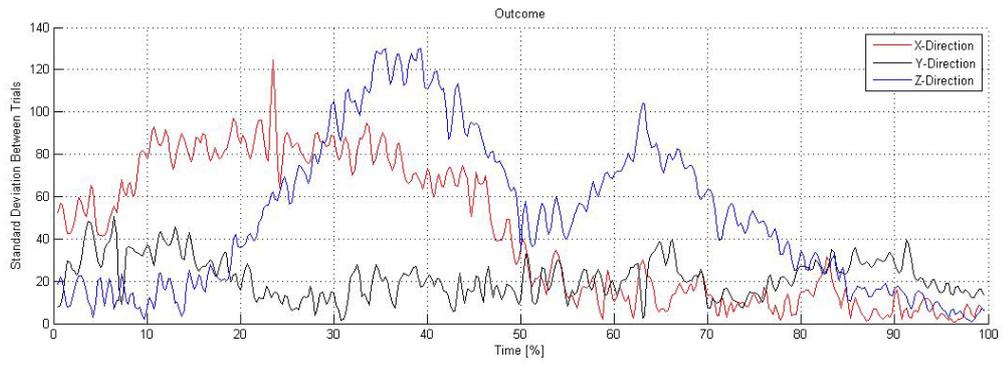
Standard Deviation Profiles, Subject LL09

12.2.3. Subject LL10
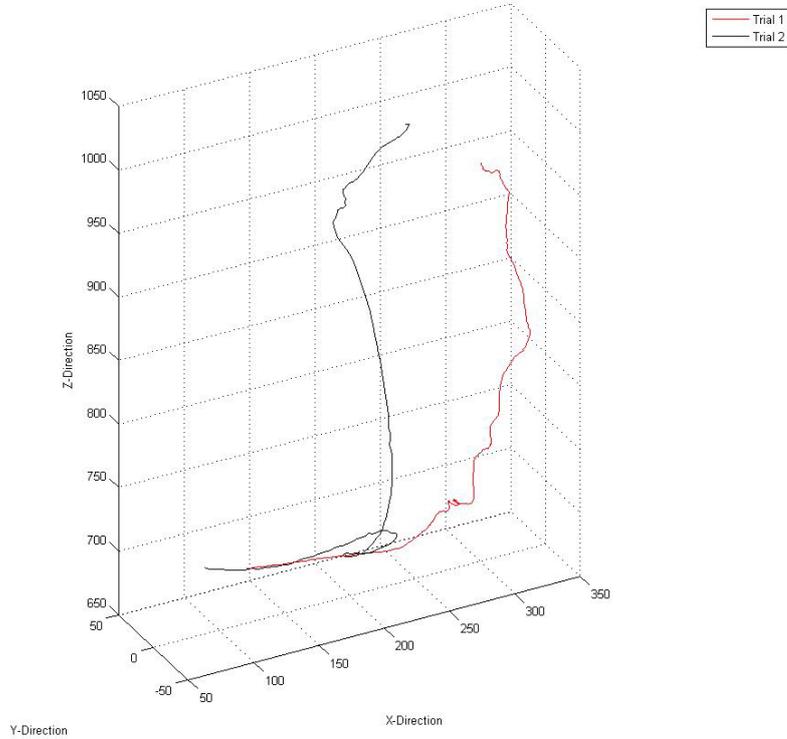
Subject LL10

Centre of Mass Trajectory at Outcome

Subject LL10

Trial 1

Trial 2
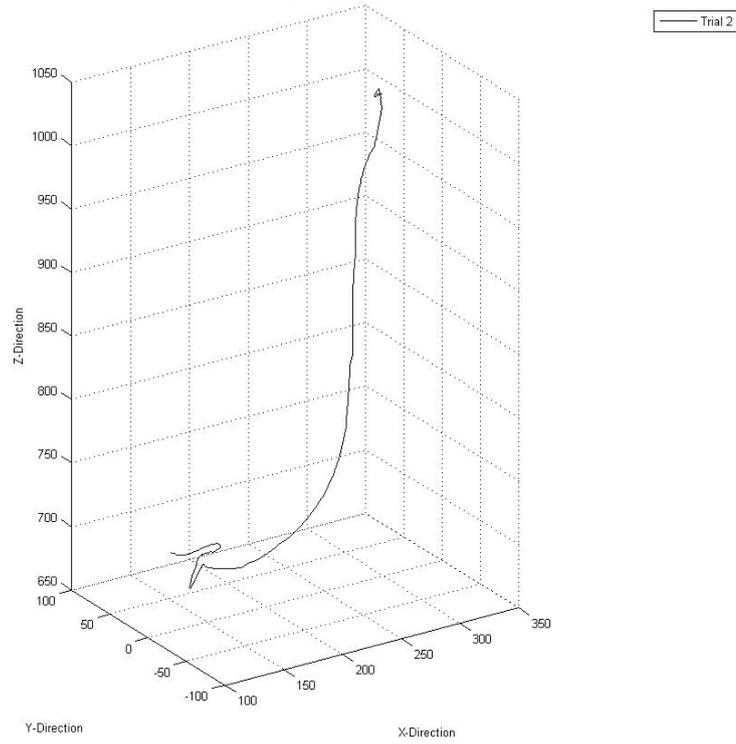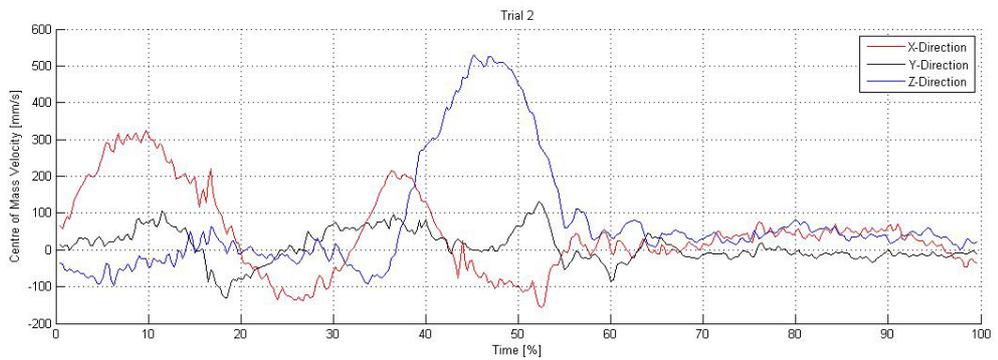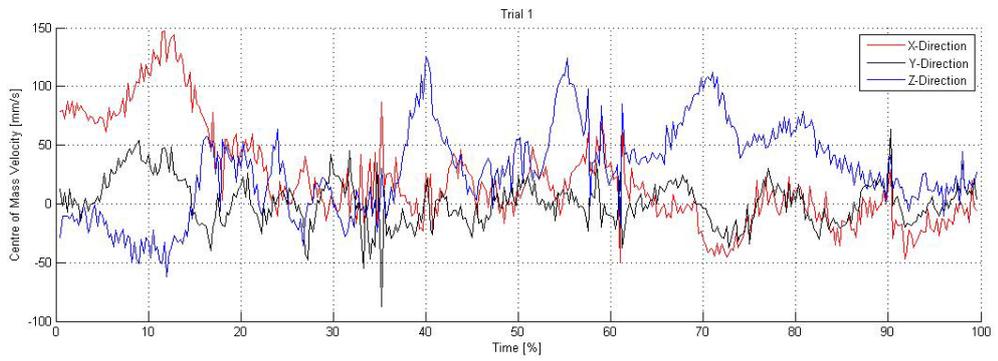
Velocity Profiles at Baseline, Subject LL10
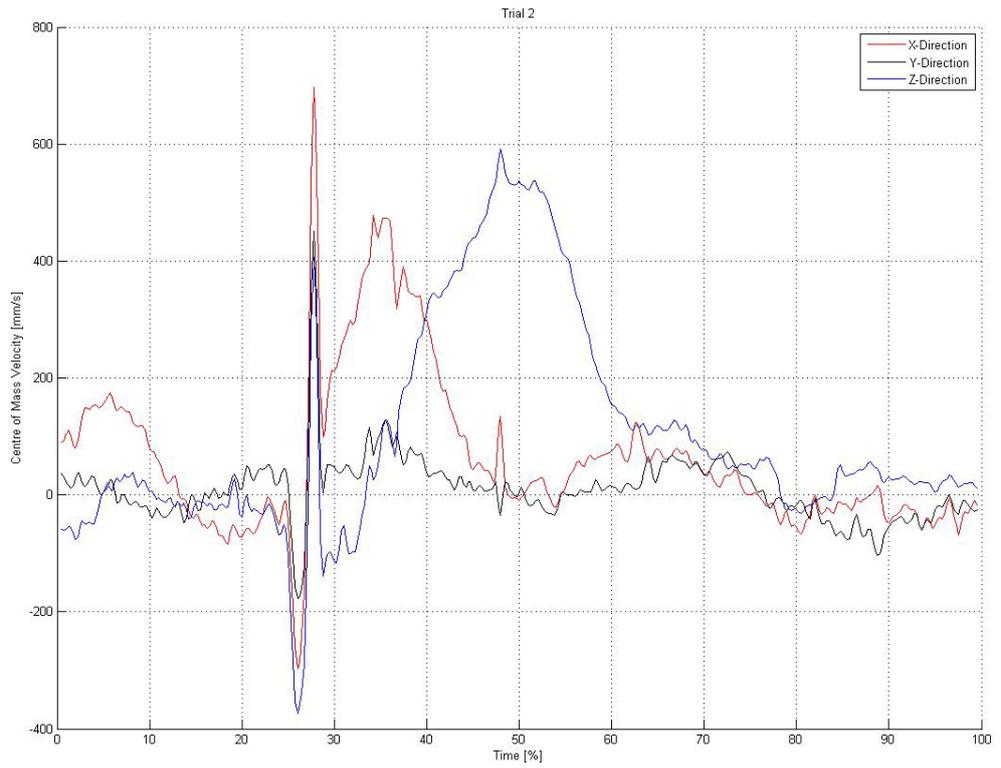
Velocity Profiles at Outcome, Subject LL10
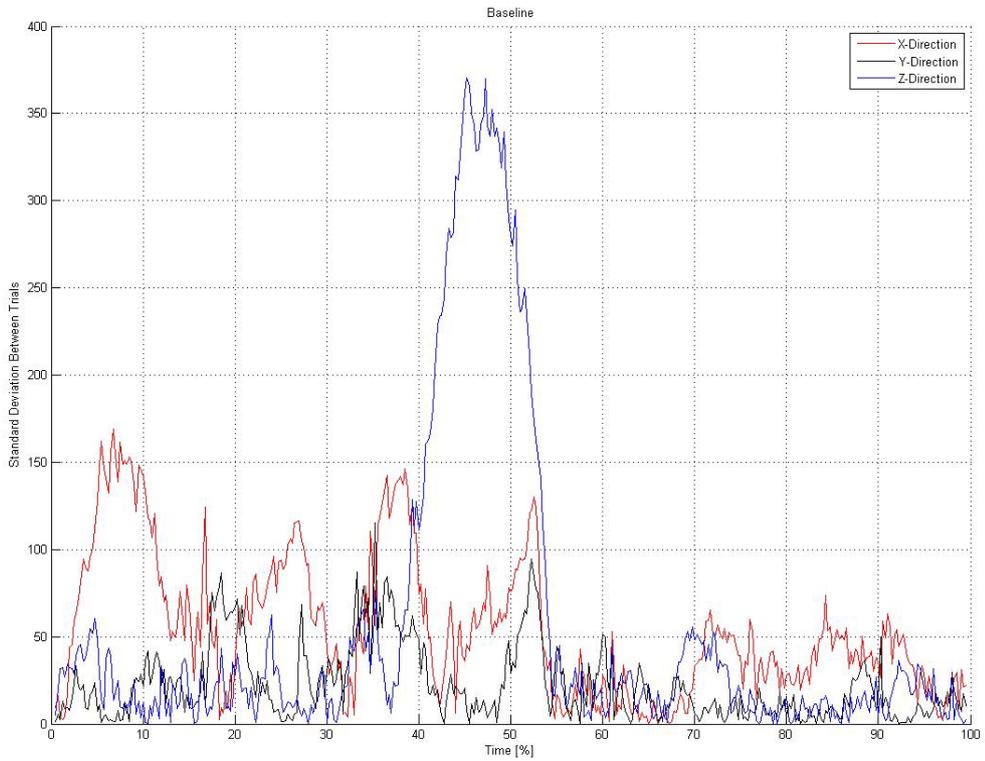
12.2.4. Subject LL12
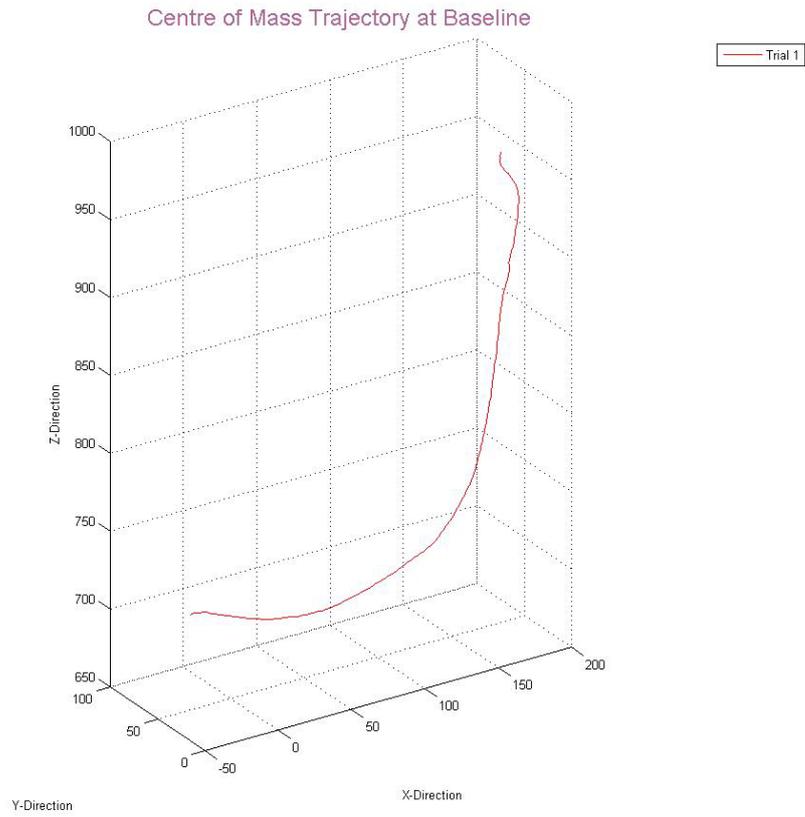
Subject LL10

Centre of Mass Trajectory at Outcome
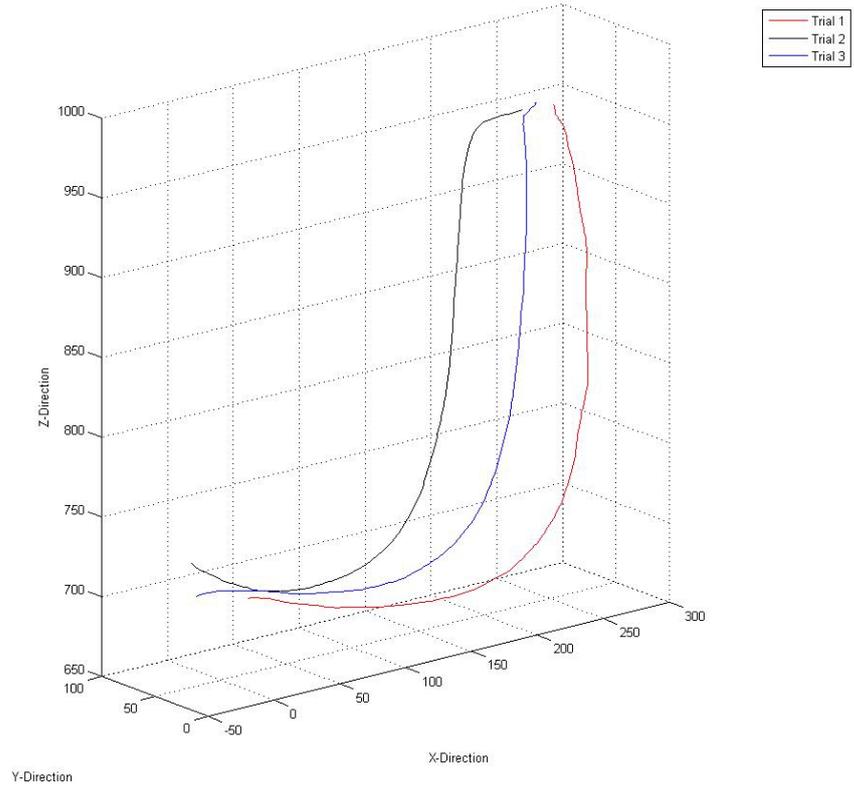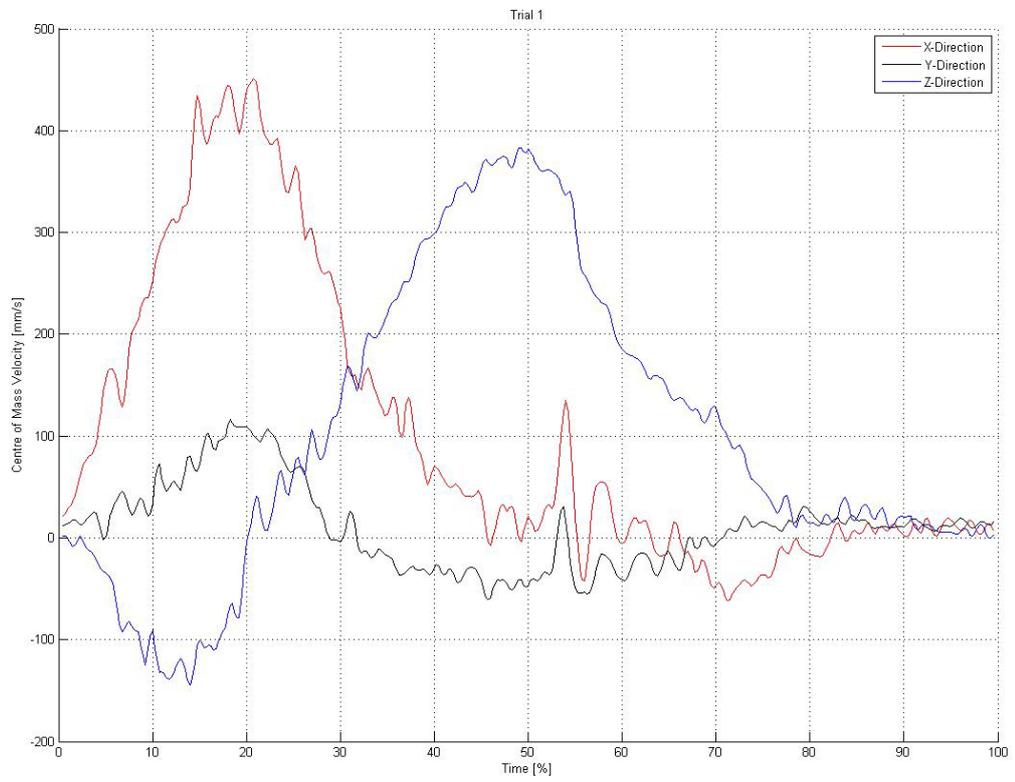
Subject LL10

Trial 1
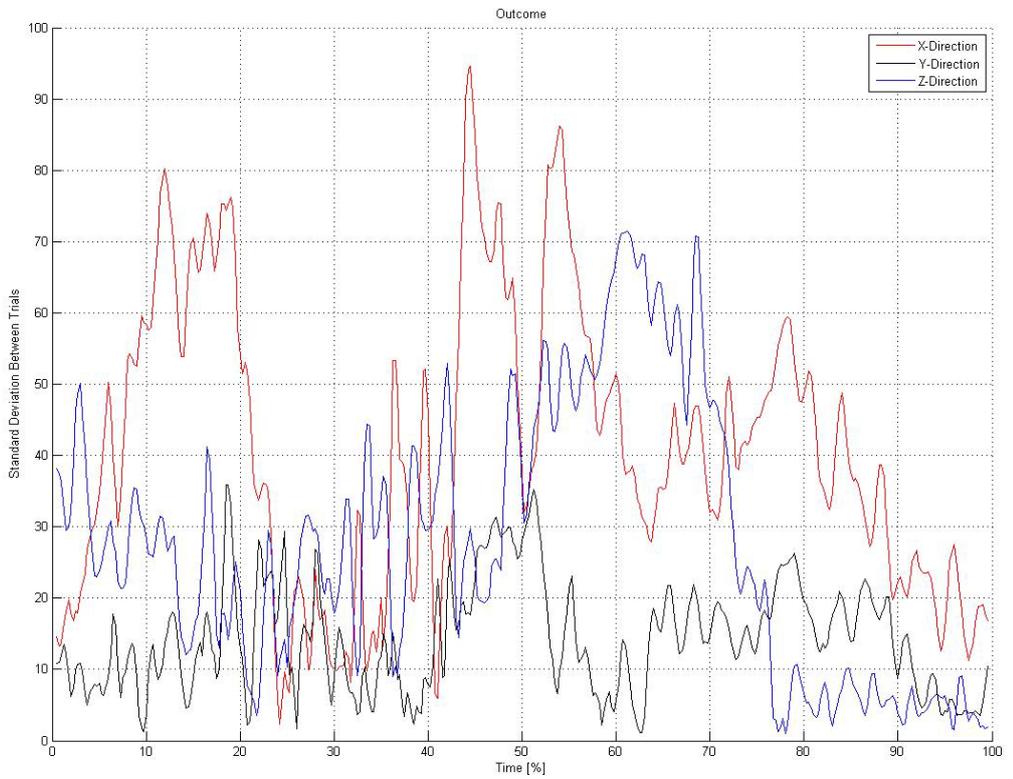
Velocity Profiles at Baseline, Subject LL10

Velocity Profiles at Outcome, Subject LL10

12.2.5. Subject LL24
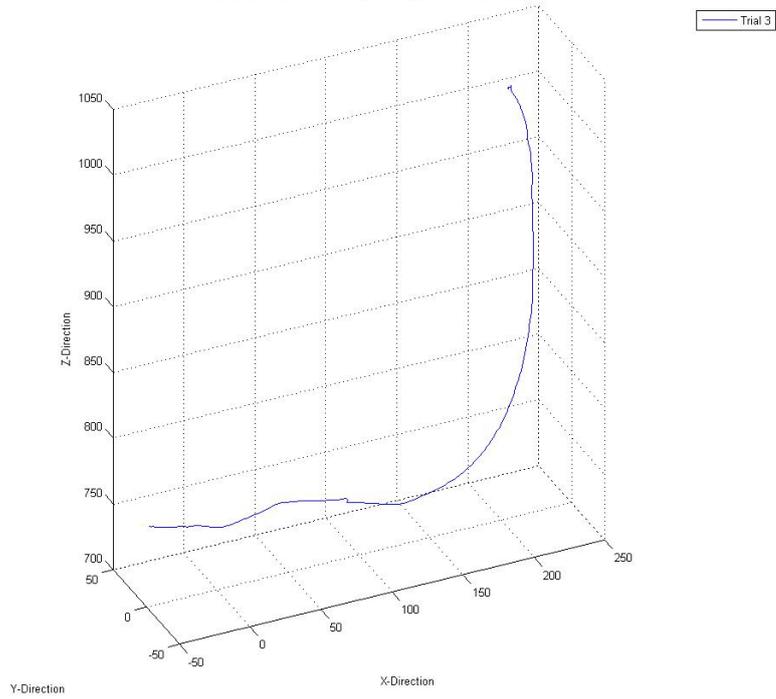
Subject LL24

Subject LL24

Subject LL24

Velocity Profiles at Baseline, Subject LL24
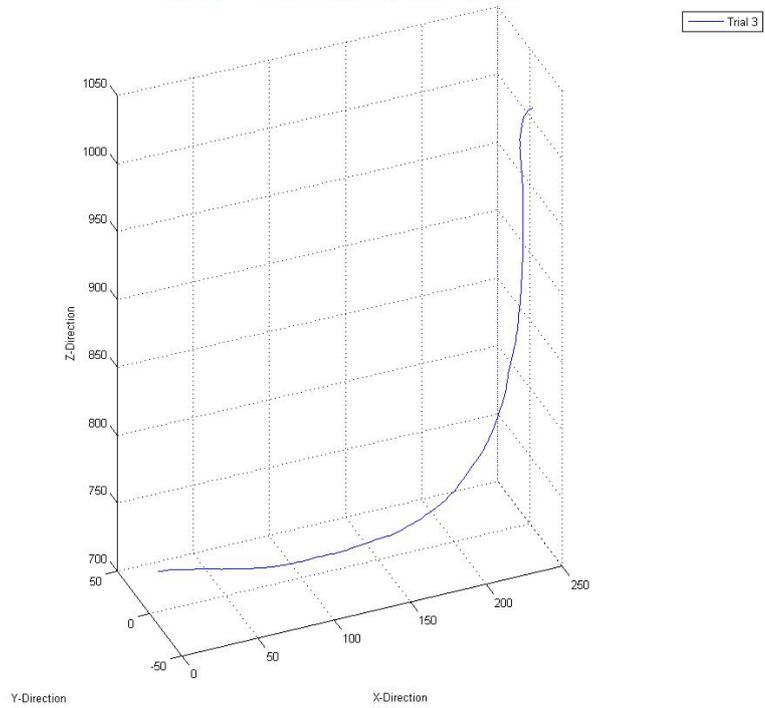
Velocity Profiles at Outcome, Subject LL24

Velocity Profiles at Follow Up, Subject LL24
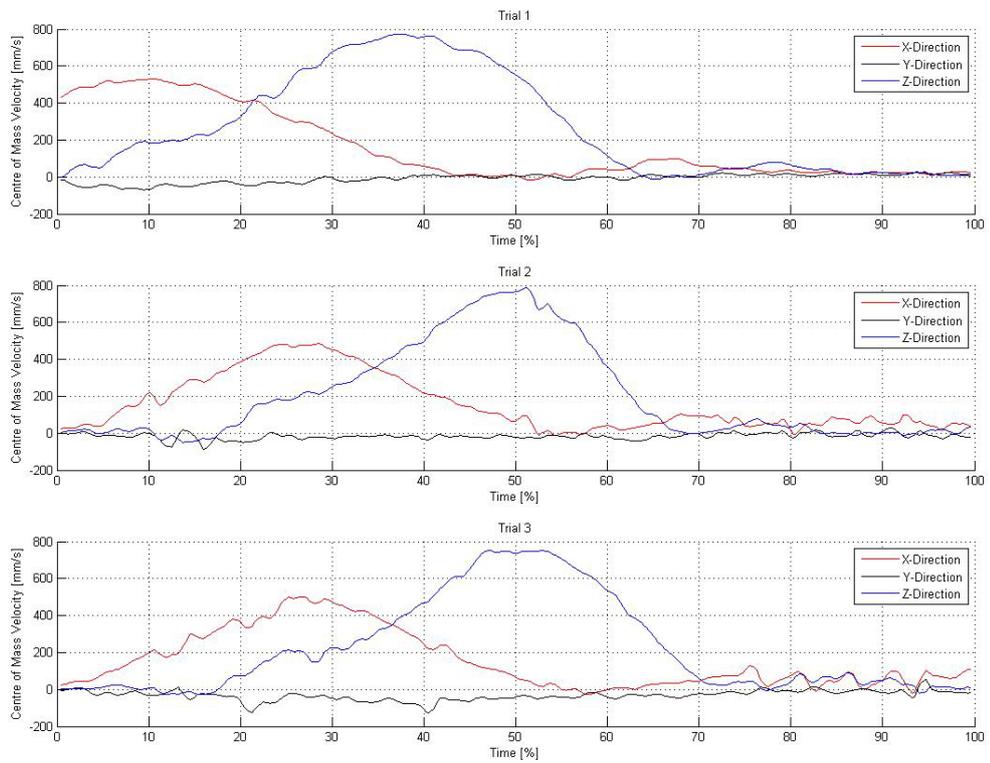
Page | 65
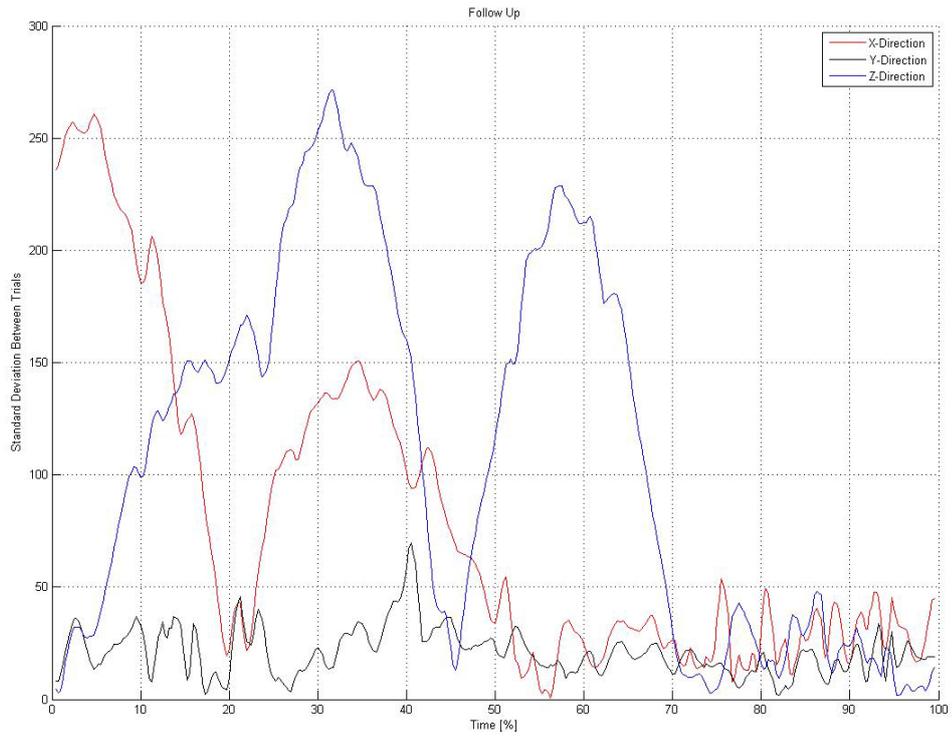
Standard Deviation Profiles, Subject LL24

12.2.6. Subject LL29
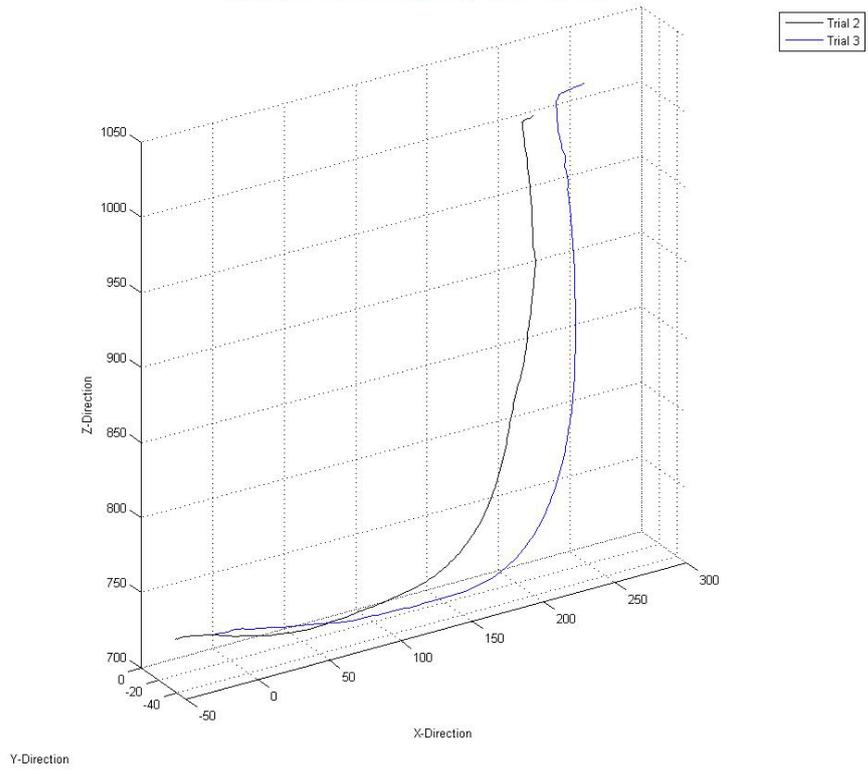
Subject LL29
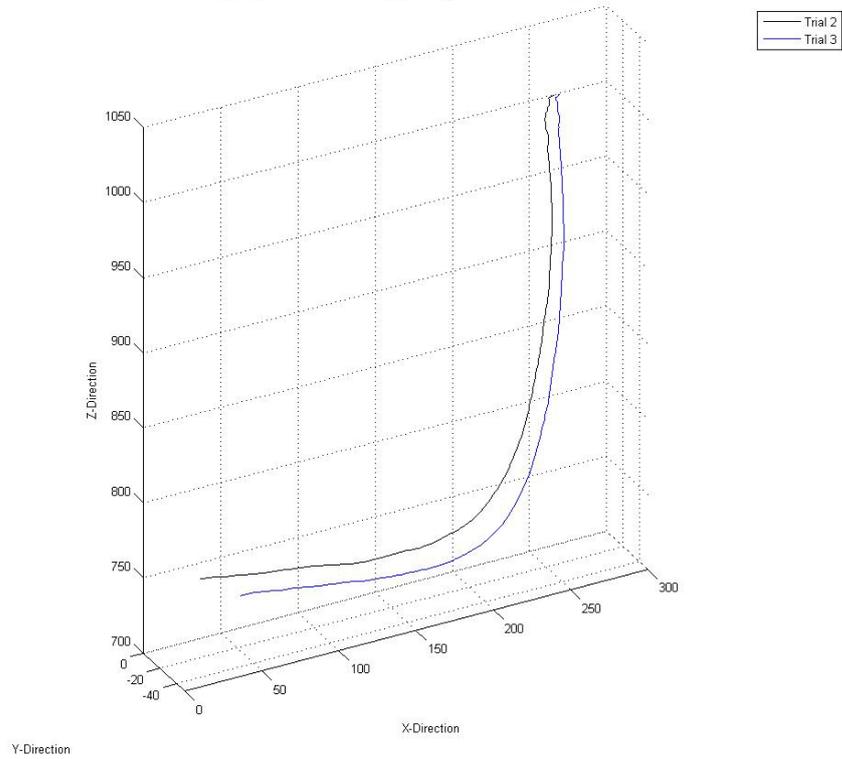
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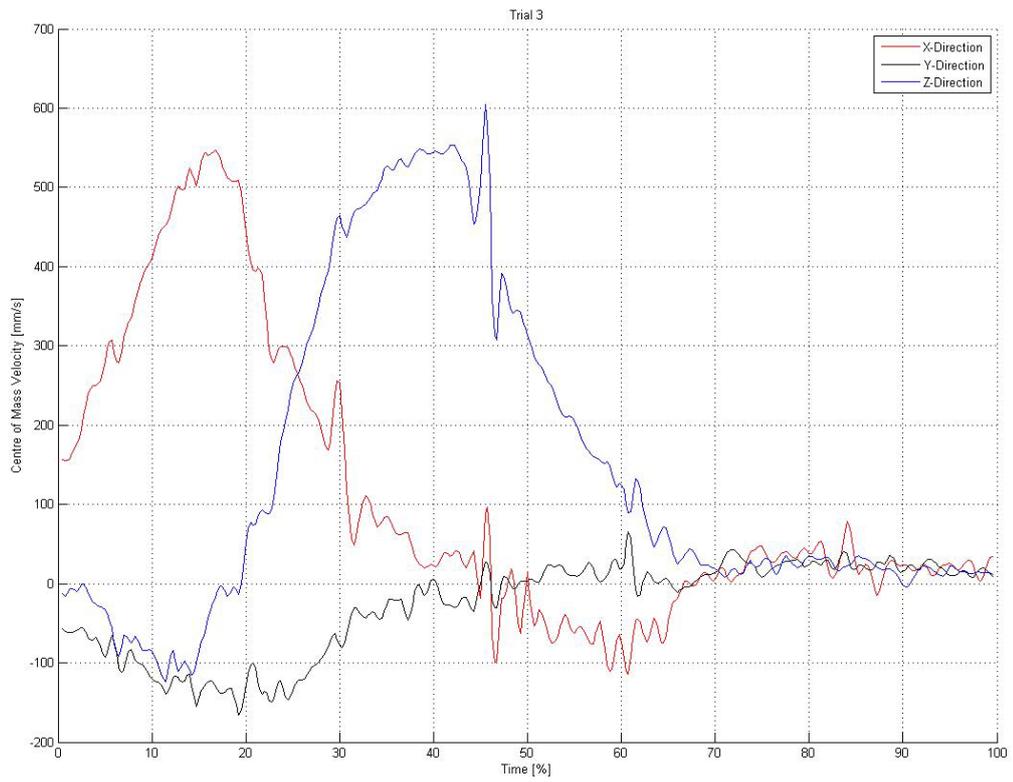
Subject LL29

Velocity Profiles at Baseline, Subject LL29
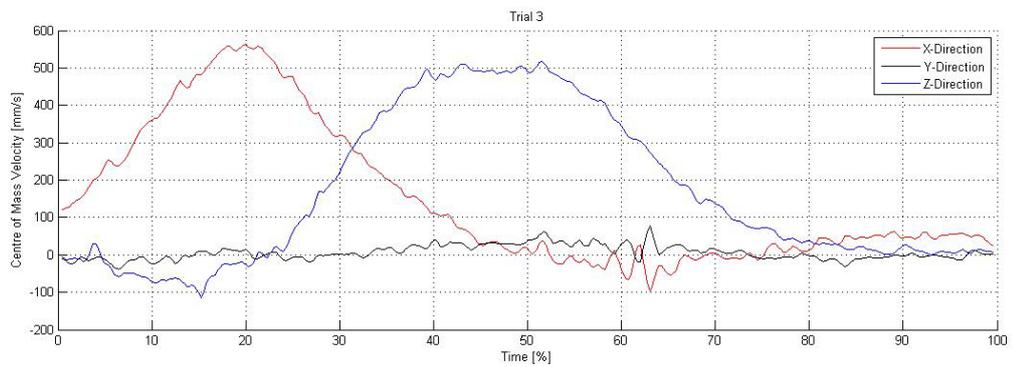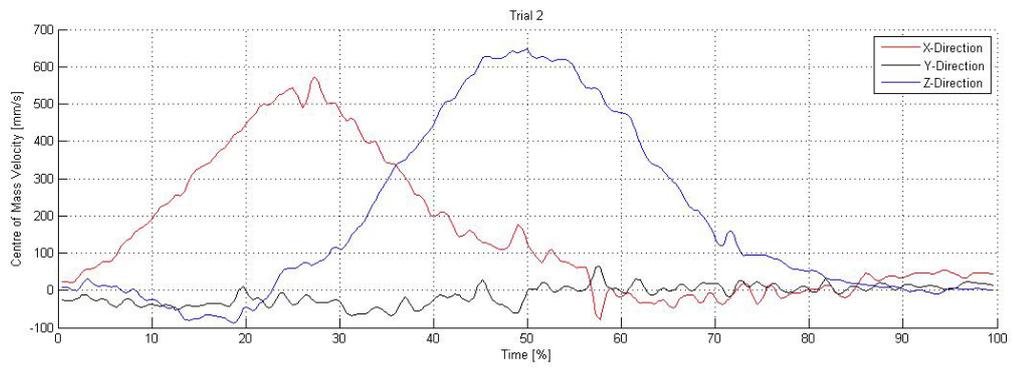
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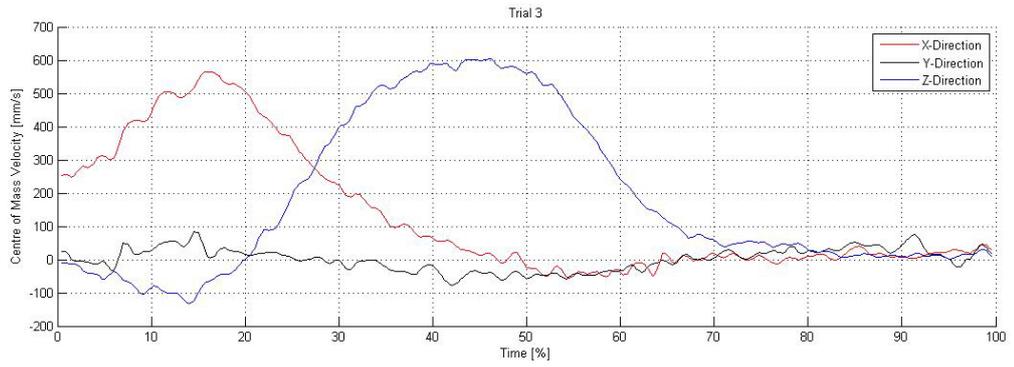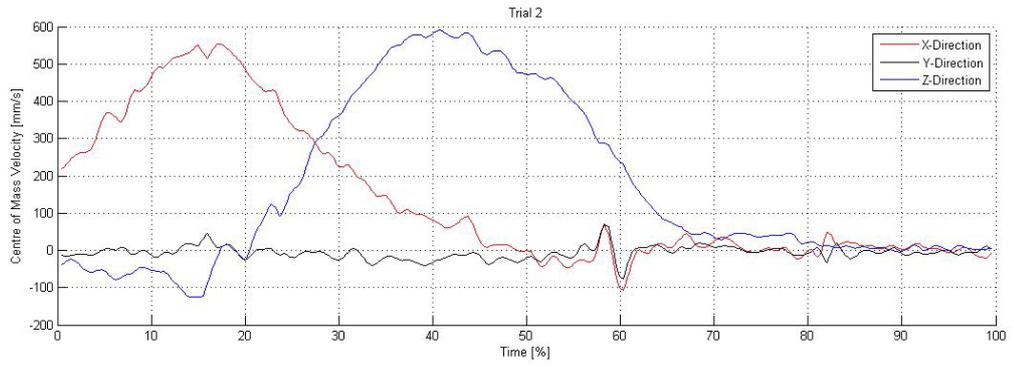
Velocity Profiles at Follow Up, Subject LL29

Standard Deviation Profiles, Subject LL29

Total Standard Deviation Between Trials at Outcome and Follow Up
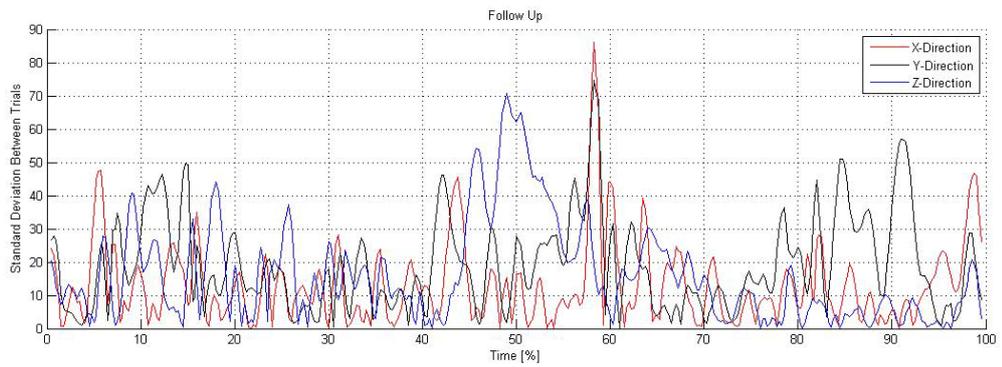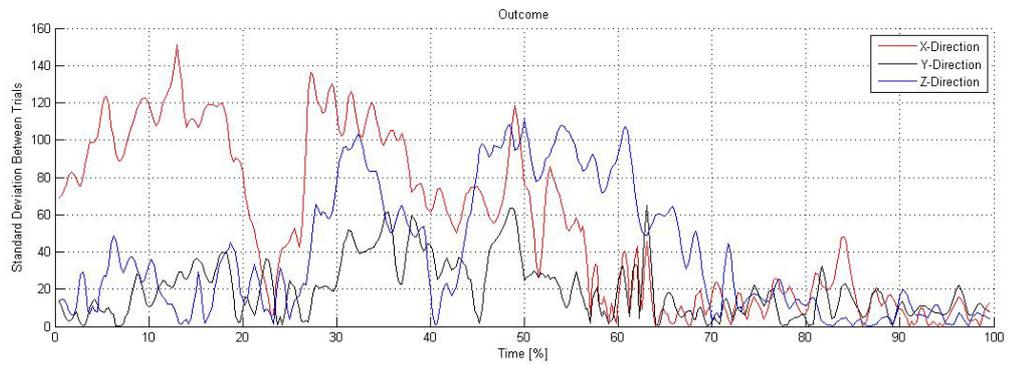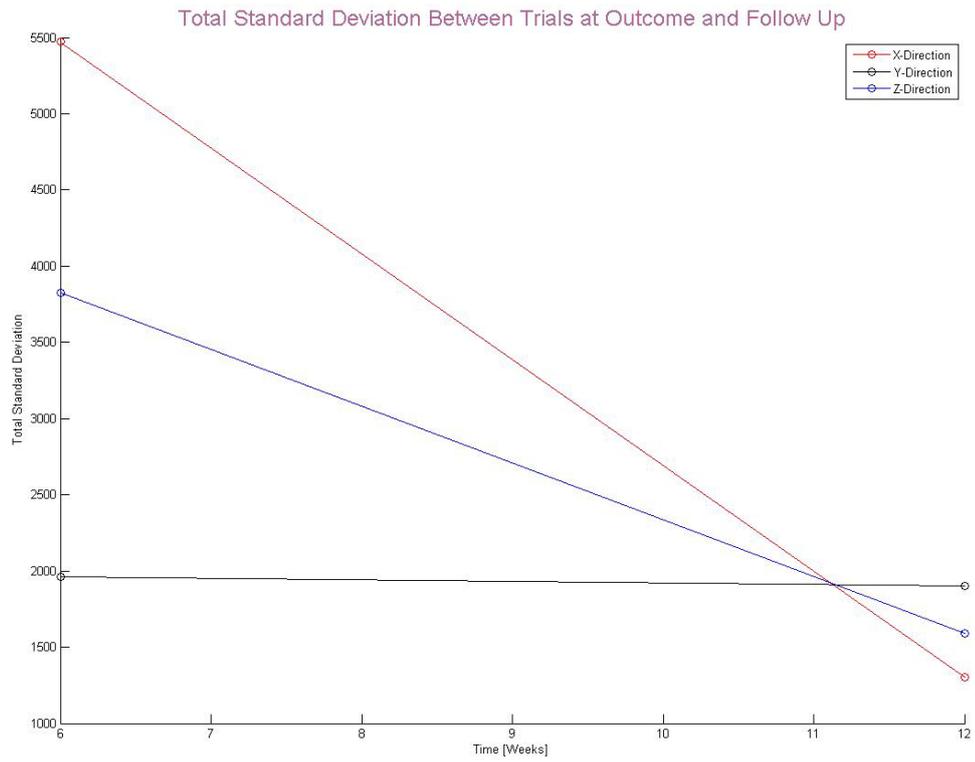
Subject LL29

12.2.7. Subject LL30

Centre of Mass Trajectory at Baseline
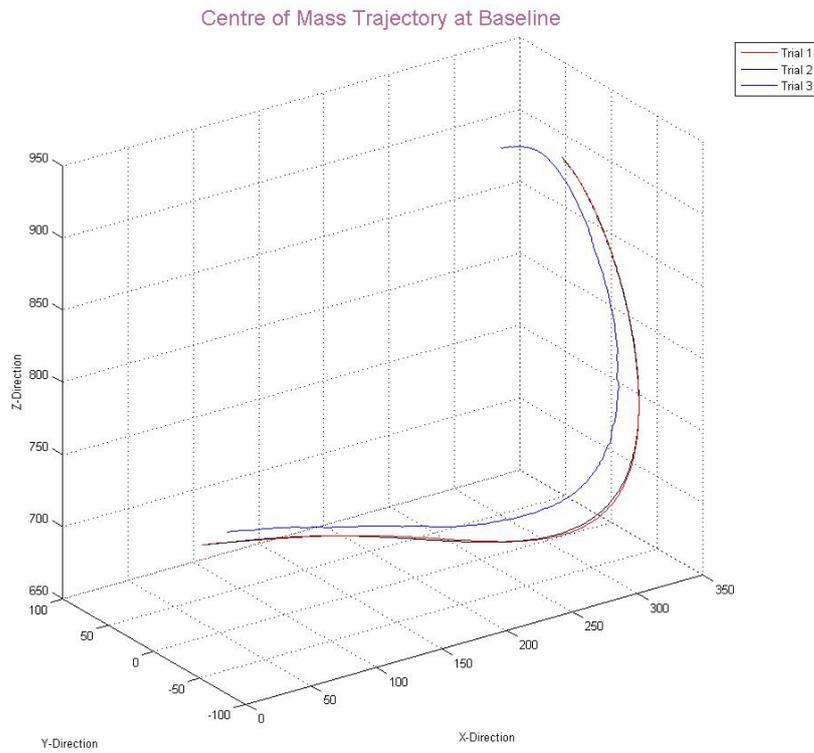
Subject LL30

Centre of Mass Trajectory at Follow Up
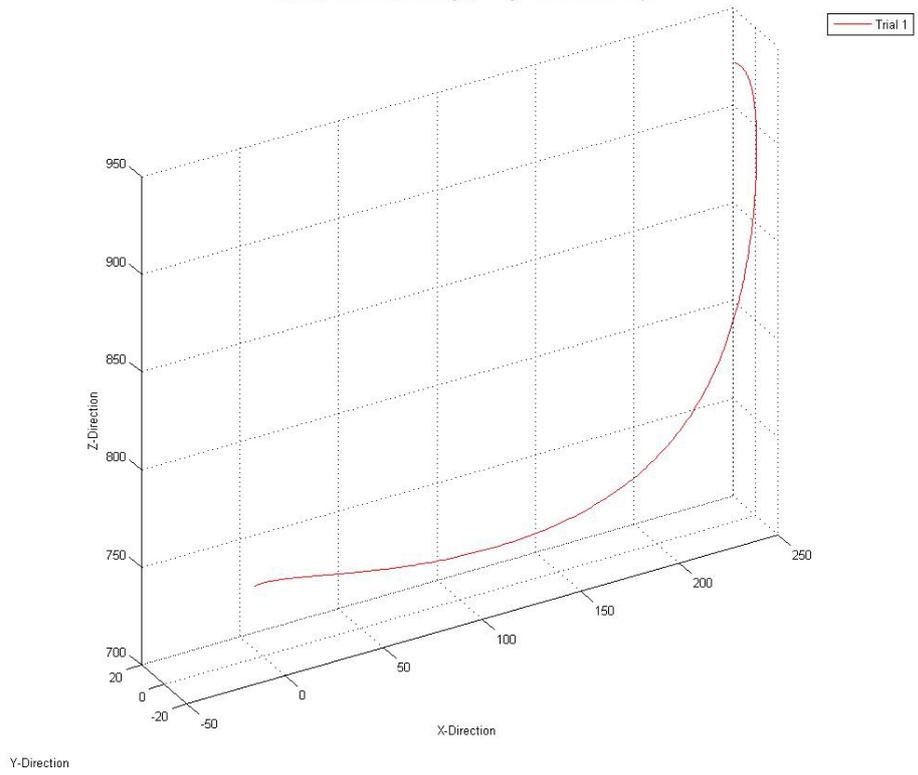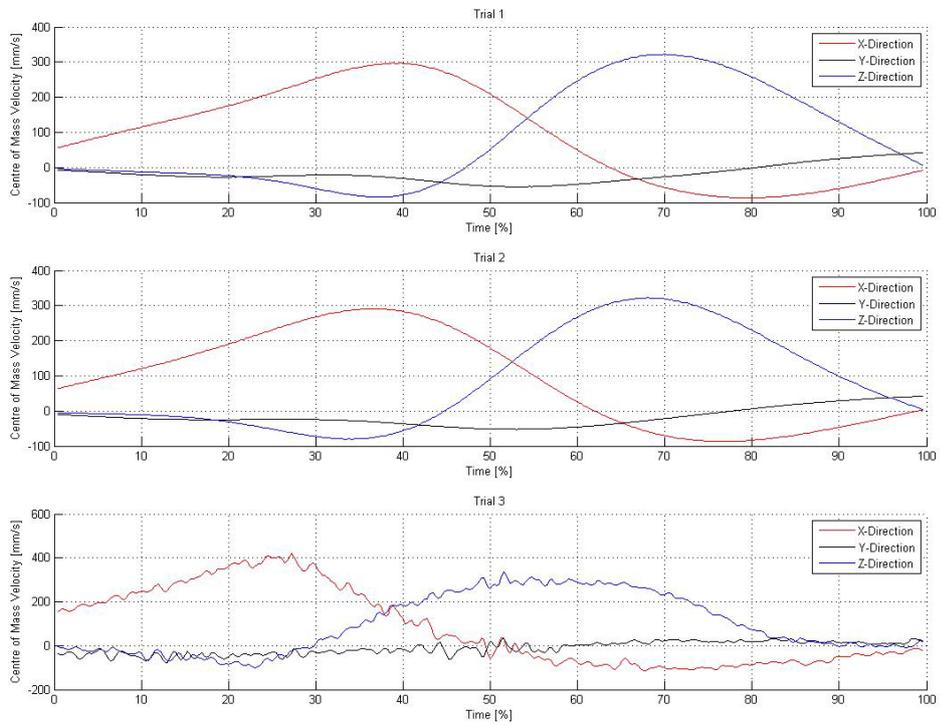
Subject LL30

Velocity Profiles at Baseline, Subject LL29
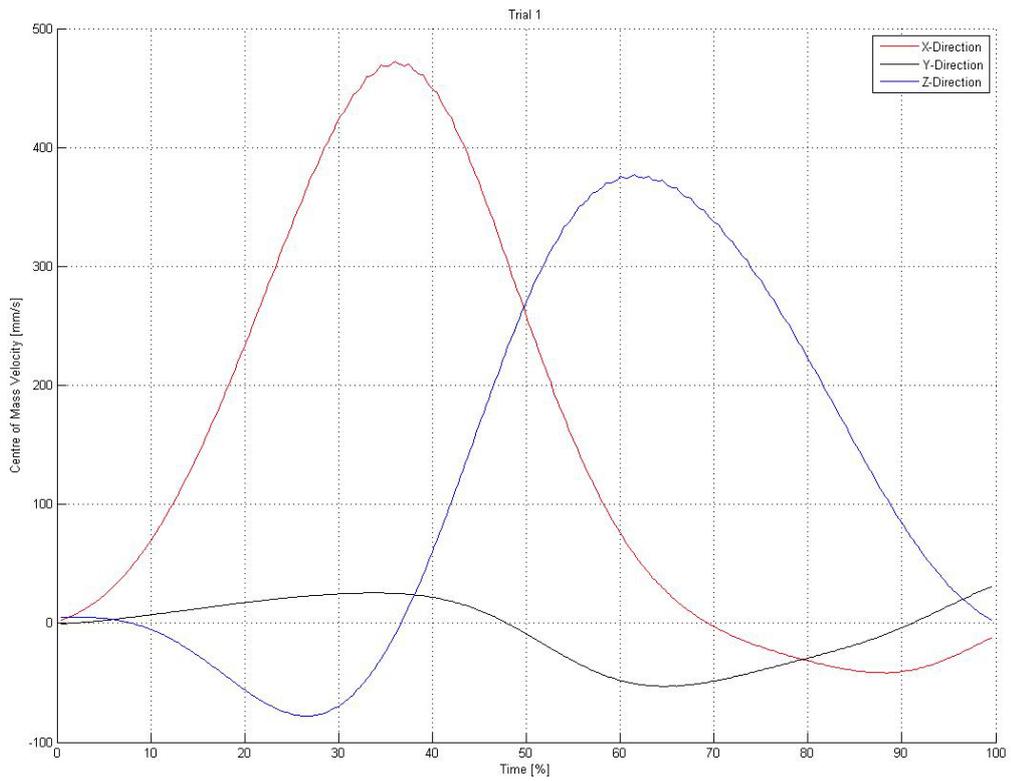
Velocity Profiles at Follow Up, Subject LL30
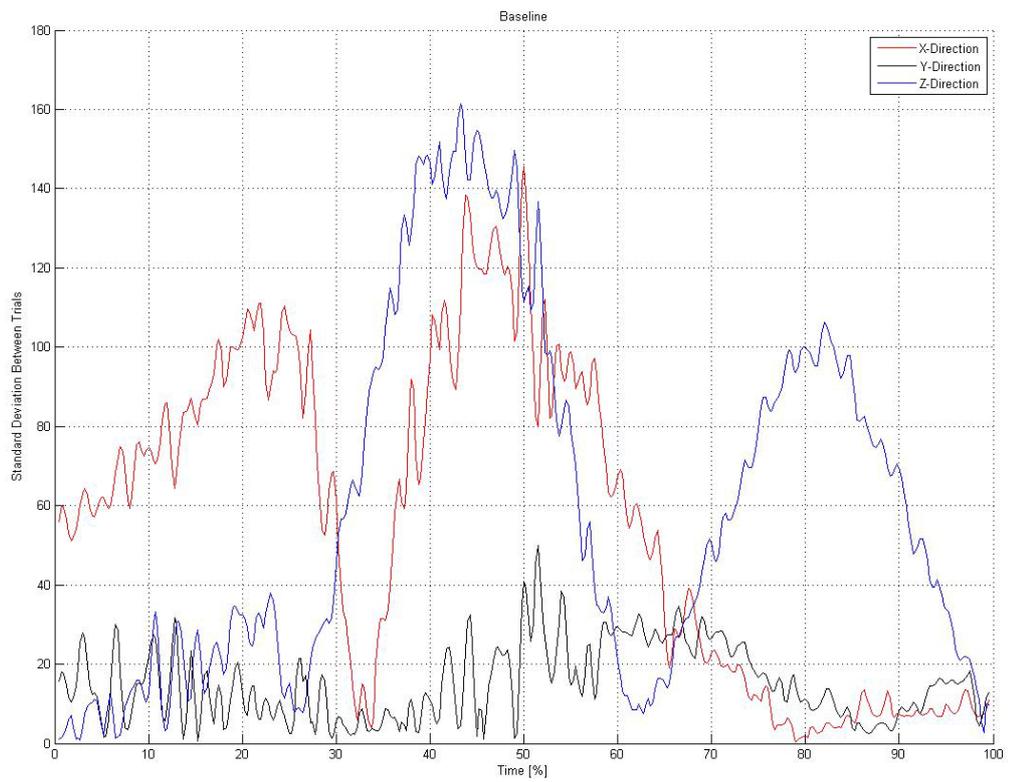
Standard Deviation Profiles, Subject LL30

12.2.8. Subject LL48

Subject LL48

Subject LL48

Centre of Mass Trajectory at Follow Up
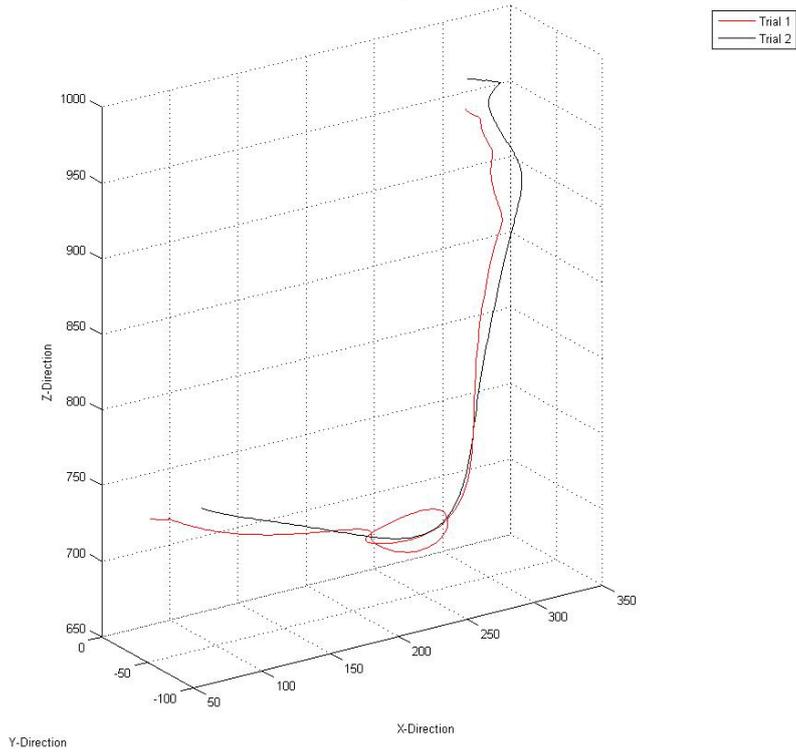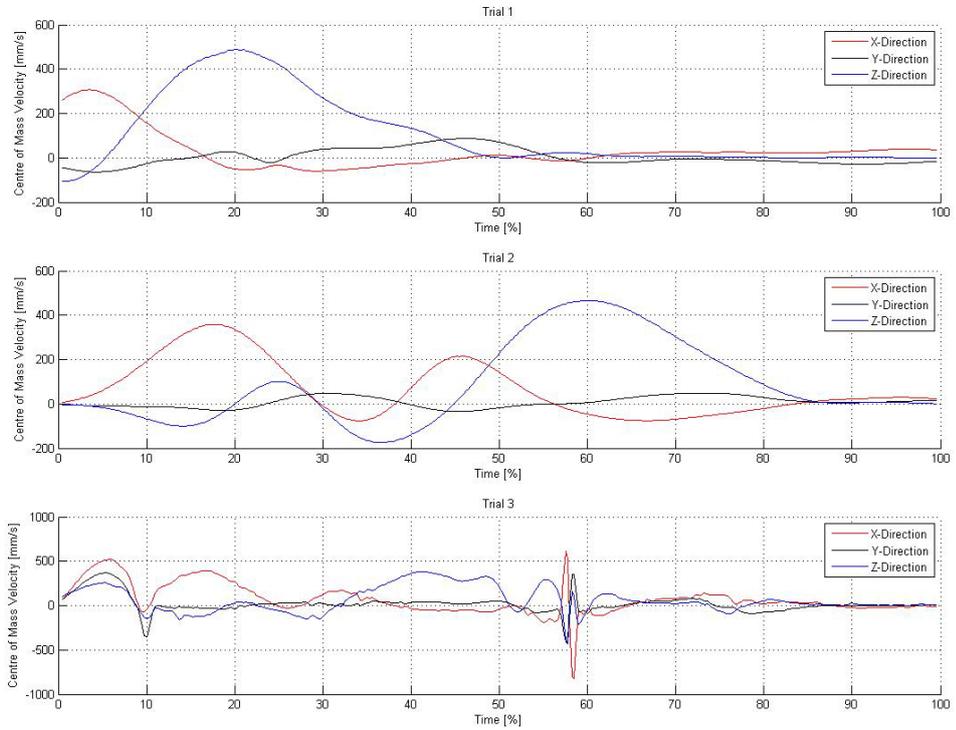
Subject LL48

Velocity Profiles at Baseline, Subject LL48
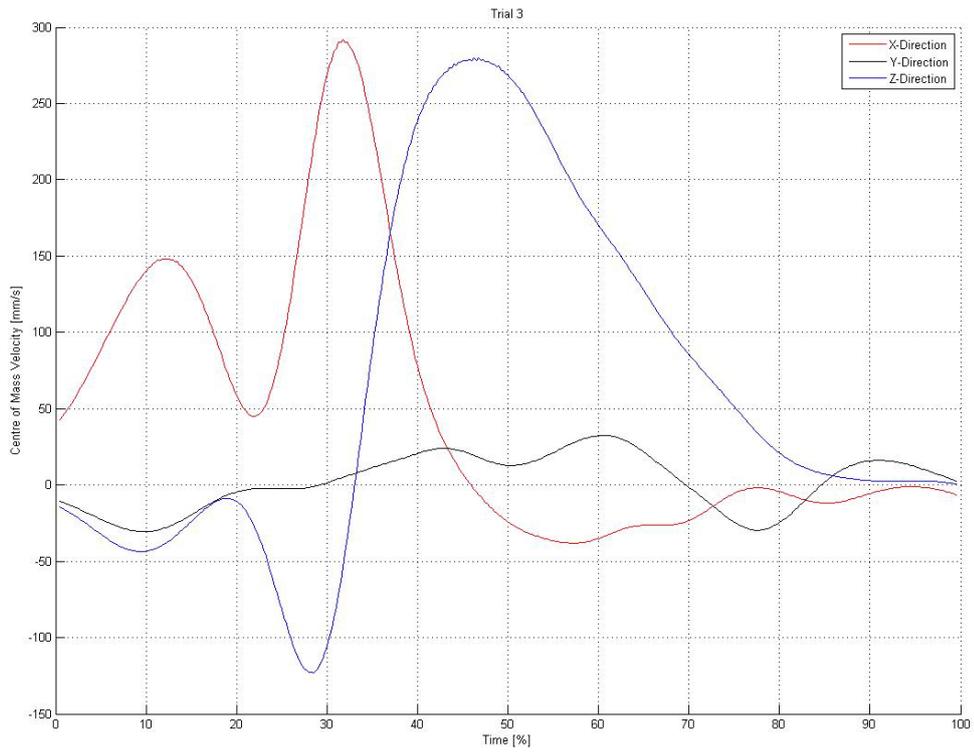
Velocity Profiles at Outcome, Subject LL48
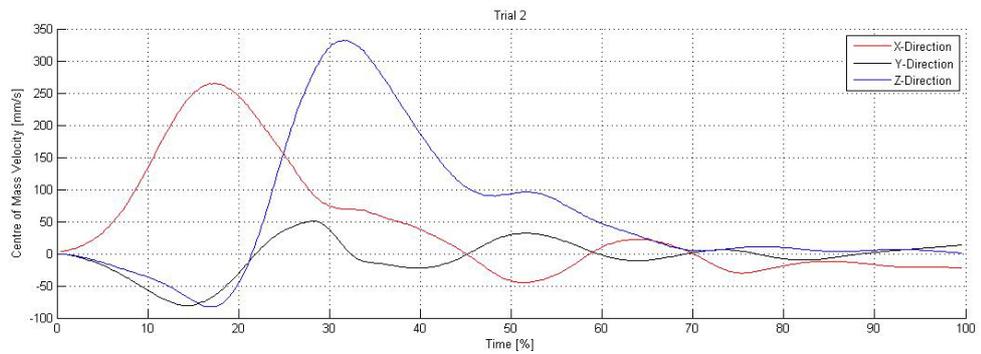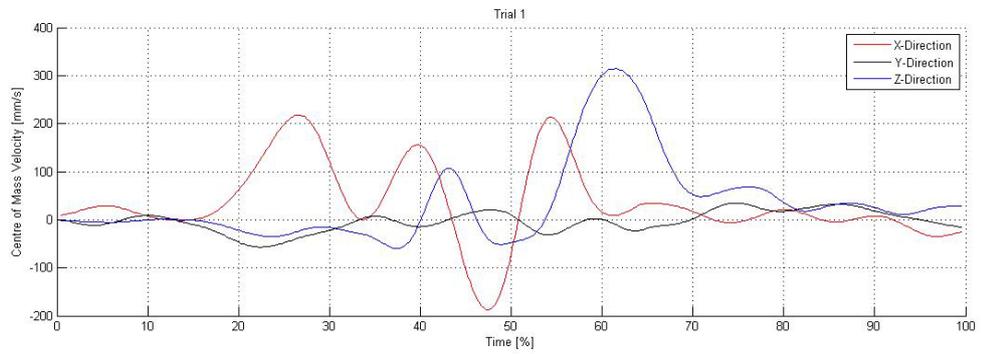
Velocity Profiles at Follow Up, Subject LL48
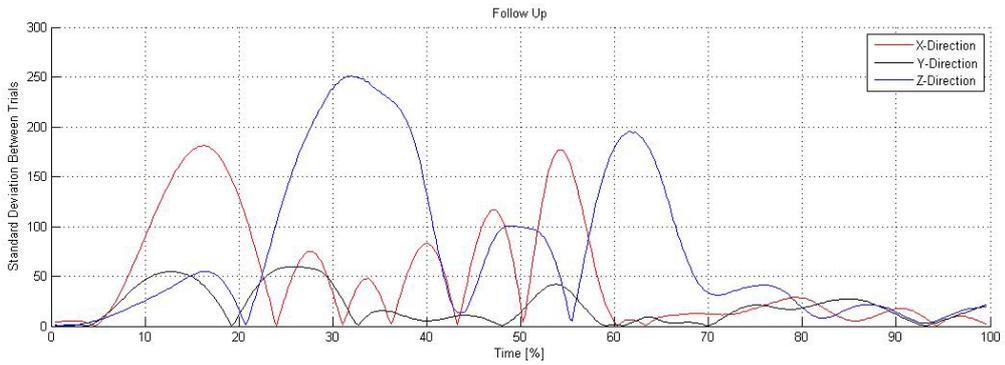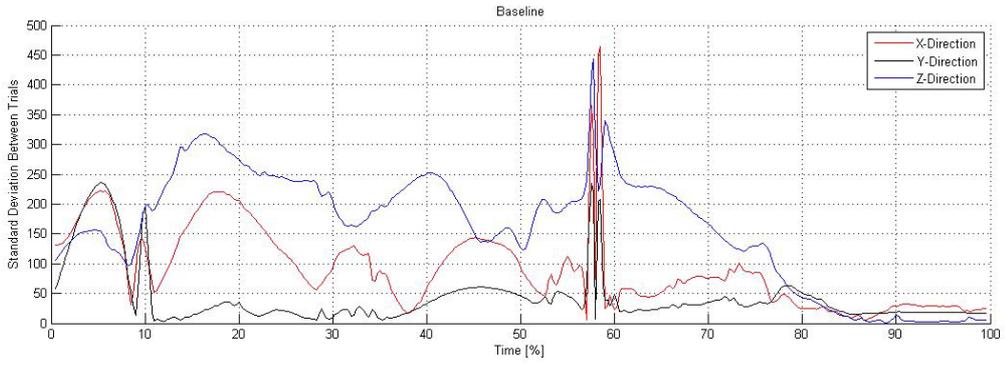
Standard Deviation Profiles, Subject LL48

Subject LL48