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ABSTRACT

POSTURAL COORDINATION DURING QUIET STANCE AND SUPRAPOSTURAL ACTIVITY

by Dean Loren Smith

Coordination of joints has not been well studied during quiet stance or non-locomotive suprapostural activity. This dissertation consists of three experiments examining multi-segmental postural coordination. Experiment 1, tested the effect of vision and support surface on multi-segmental postural kinematics and joint angles during upright quiet stance. Eight participants stood still on four surfaces (flat, foam surface, foam roller, wood beam) with eyes open and closed. Postural motion was recorded by an electromagnetic tracking device from the head, trunk, sacrum, hip, knee and ankle. Overall postural (head) sway and joint motion was influenced by both surface of support and vision. More sway and sagittal joint rotation occurred under non-visual and non-flat conditions. An ankle strategy as opposed to a hip strategy is primary in maintaining voluntary, upright balance on non-flat surfaces.

In experiments 2 and 3, surface of support (hard surface vs. foam roller) and suprapostural task (head-tracking frequency) were manipulated simultaneously. Twelve different participants in each experiment stood on each surface with hands behind their back looking at a computer monitor in front of them. They were instructed to maintain balance while tracking a simulated oscillating (fore-aft) computer target with their head at different frequencies. In Experiment 2, a rest was given between trials (frequencies), whereas no rest was given between trials in Experiment 3. The effects of discrete (rest), and changing frequency modulation (no rest) on postural dynamics were then determined. Results demonstrate that people use a continuum of coordination strategies to accomplish head-tracking at different frequencies. On both surfaces, a predominantly anti-phase, hip-ankle relationship was seen with only gradual postural transitions observed. Dynamic standing tasks exhibit many similarities in postural coordination whether performed at a singular frequency or by modulating frequency. However, continuous motion without rest may confer postural stability benefits when compared to discrete frequency oscillation.

The results imply that models of postural control should be explicitly multi-segmental, that postural transitions are gradual during suprapostural activity, and that modulating postural frequency may confer stability benefits. Most importantly, the data strongly argue that there is a need to examine postural control and coordination without mechanical perturbation.

POSTURAL COORDINATION DURING QUIET STANCE
AND SUPRAPOSTURAL ACTIVITY

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Postural Coordination During Quiet Stance
and Suprapostural Activity

To stand upright, humans have to actively regulate the movement of their joints. People typically regulate their movement by generating torques around their ankles, hips or a combination of joints; such patterns are referred to as coordination strategies. Coordination strategies not only enable people to remain upright, but also accomplish various goal directed activities, such as bending over to reach for an object or reading text from afar. Coordination strategies have often been studied in the context of either performing suprapostural, goal-directed actions or responding to external perturbations (e.g., push on the back or sudden movement of the support surface). However, with the exception of Kuo et al. (1998) who studied shank and hip coordination, these coordination strategies have not been examined during quiet stance, that is, in the absence of an explicit suprapostural task or external perturbation.

In order to study goal-directed postures, several distinctions need to be made (Figure A). First, posture is maintained either in the presence or absence of an external perturbation. Posture can be viewed in service of an explicit task (suprapostural activity) or simply to maintain balance. Second, in the absence of external perturbation, quiet stance may be viewed as a maintenance posture that is critical for standing upright (Type 1 Posture, Figure A). For this reason, the failure to examine postural coordination during quiet stance is a serious omission. One goal of this investigation will be to describe coordination strategies that are used during quiet stance, uncontaminated by the effects of suprapostural tasks or external perturbations. A second purpose is to examine the stability of these observed coordination patterns while performing a suprapostural activity (Type 4 Posture, Figure A), in which participants move their head anterior and posterior at different frequencies in response to an optical display, while simultaneously standing on one of two different surfaces. The dynamic properties of the postural coordination patterns are revealed in the emergence of new coordination patterns resulting from changes in oscillatory frequency and support surface characteristics.

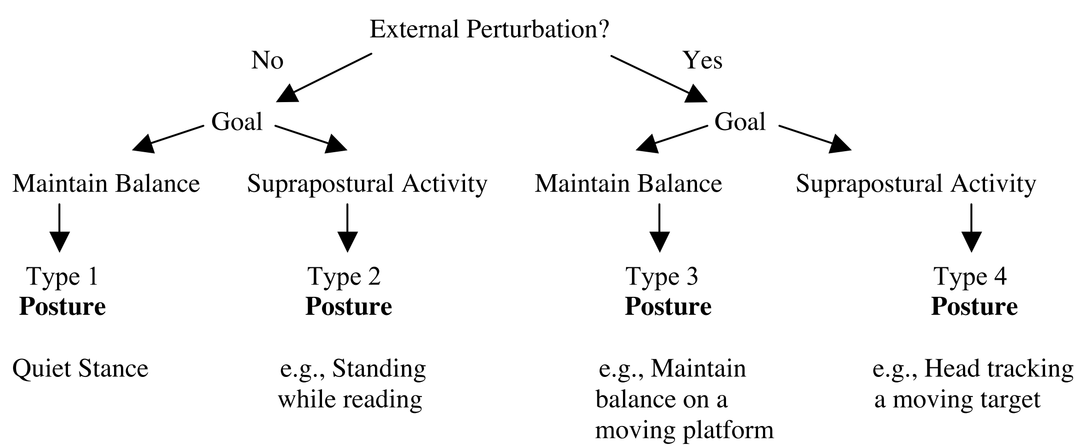


Figure A. Taxonomy of non-locomotive postures. An external perturbation is defined as a sudden change in conditions that displaces the body posture away from equilibrium (Horak, Henry, & Shumway-Cook, 1997).

Upright bipedal stance is an essential posture through which we interact with our environment. Standing requires muscular activity because of the inherent instability of the human body in a vertical position. This instability is caused in part because of the multi-segmental nature of our bodies. To stabilize the body, the activity of muscles, joints, and limb segments must be coordinated. For example, while standing, the ability to track a moving visual target with your head requires dynamic stabilization of the trunk, head, and lower extremities. The independent entities (e.g., joints, muscles) that can be regulated while maintaining upright stance constitute multiple degrees of freedom (DOF). Successful coordination of the existing DOF allows for the achievement of everyday activities, such as reading and eating. Coordination, then, can be defined as the strategy for reducing the degrees of freedom involved in producing a movement, i.e., reducing the number of independent variables to be controlled (Bernstein, 1967). For the purposes of this study, coordination will be described macroscopically in terms of the patterning of the body and limbs with respect to each other and to the environment (Turvey, 1990).

What specific multi-segmental coordination strategies are used to maintain posture? Nashner & McCollum (1985) describe the various types of strategies: hip, ankle, knee and mixed (e.g. hip and ankle). These strategies were characterized from observations of neuromuscular activation (EMG) and platform posturography during surface perturbation (Nashner & McCollum, 1985). The ankle strategy involves activity of the tibialis anterior and gastrocnemius muscles to cause dorsiflexion/plantarflexion, generating torques and rotation about the ankle with relatively little motion at the hip and knee (Horak & Kuo, 2000). This strategy is used primarily on flat surfaces, in response to small and slow perturbations (translation of support surface) that are directed in the anterior or posterior directions (Horak & Kuo, 2000; Horak & Nashner, 1986; Nashner & McCollum, 1985). The hip strategy is used when ankle responses are constrained (e.g., on a beam) which limits available ankle torque. The hip strategy enables the person to respond to rapid or large amplitude perturbations by creating torques around the hip joint (Horak & Nashner, 1986). The hip strategy most recently has been described as a form of *mixed* strategy, consisting of flexing the trunk at the hip joints in addition to antiphase rotations of the ankle and neck (Horak & Kuo, 2000; Shumway-Cook & Woollacott, 2001).

Postural coordination has been well described during surface perturbations as outlined above (Type 3 Postures, Figure A). However, the majority of studies have focused on describing the macroscopic patterns of coordination resulting from external postural perturbations. When the body is subjected to perturbations, effective coordination strategies are required to maintain equilibrium of the multi-segmental body. Coordination strategies can be characterized by their different muscle synergies, movement patterns, joint torques, and contact forces (Horak et al., 1997). These postural strategies are important components of effective stability during stance (Horak et al., 1997) and represent the behavioral mechanisms used to maintain control over posture.

The vast majority of studies describing Type 1 posture have recorded postural sway as center of pressure (COP) and center of mass (COM) movement (Blaszczyk, Bacik, & Juras, 2003; Cherng, Lee, & Su, 2003; Murray, Seireg, & Sepic, 1975; Winter, 1990; Winter, Patla, Ishac, & Gage, 2003). In particular, COP has been widely used because: a) it is relatively easy to measure; b) patients with a variety of neurological disorders exhibit greater sway compared to normals (Horak & Macpherson, 1996; Shumway-Cook & Woollacott, 2001); c) sensory manipulations such as closing the eyes increases sway and; d) sway has been proposed among other variables as useful for detecting balance disorders and/or risk of falling (Maki, Holliday, & Topper, 1991). However, while COP and COM measures provide kinetic and kinematic information about postural motion, they do not inform us about the multi-segmental kinematics and joint angles required for a complete model of quiet standing (Winter et al., 2003). Because so many studies have concentrated on measuring the displacement of COP and COM, the investigation of multi-segmental coordination under quiet stance conditions has been largely ignored.

Some studies have looked at the kinematics of Type 1 Posture. However, despite the complexity of motion and the existence of multiple possible modes of behavior, only limited regional analyses (e.g. hip and ankle, head and hip segments) of quiet stance postures typify the literature. Kuo et al. (1998) studied coordination of shank and hip during quiet stance by disrupting visual and somatosensory information. They found increased shank angular motion in the absence of vision, and increased use of a hip strategy under platform sway-referenced conditions but not under earth-referenced conditions in the sagittal plane. Sway-referencing refers to the manipulation of a movable platform that rotates about an axis aligned with ankle motion in the sagittal plane such that the platform matches the subject's ankle position, whereas earth-referenced refers to the platform being fixed (i.e., not movable) to the earth. Two other studies have looked at the coordination of head and hip during quiet stance in the Romberg position (Accornero, Capozza, Rinalduzzi, & Manfredi, 1997; Mesure, Amblard, & Cremieux, 1997). These studies found lateral head-hip strategies suggesting the existence of multi-segment coordination even during quiet stance.

Studies that have examined more than one segment during quiet posture (but not coordination per se) suggest the potential for multi-joint coordination. For example, Day et al. (1993) found that the ankle was dominant for movement in the frontal plane while standing with narrow stance widths (<8cm), but for all other conditions, most angular motion occurred between trunk and leg (Day et al., 1993). This finding of angular motion at several segments implied that the single-segment inverted pendulum model (sway at only one joint) of body sway is incomplete. Further, Blackburn et al. (2003) found movements at both hip and trunk during bilateral stance suggesting these two sources be considered separately during kinematic analysis. Together, the studies by Day et al. (1993), Blackburn et al. (2003) and Kuo et al. (1998) provide evidence for multi-joint postural coordination during quiet stance.

Our own preliminary investigation (Smith et al., 2002) indicates that hip, ankle, trunk and head segments all rotate in the sagittal plane during quiet stance on different support surfaces with eyes open or closed. Ankle rotational movement was largest on a narrow beam (Smith et al., 2002), exactly opposite to the predictions of a perturbation model (cf. Horak & Nashner, 1986) which predicts larger movement around the hip.

Therefore, not only is there considerable reason to believe that multi-segmental postural coordination exists during quiet stance, but preliminary evidence also suggests that this coordination may appear different in form compared to results obtained from a perturbation model.

Adopting a multi-segmental approach allows for the measurement of postural coordination. This multi-segmental approach can not only identify the amount of sway but also the behavioral mechanisms (e.g., coordination) responsible for the production of sway. Most importantly however, the multi-segmental mechanisms involved in postural coordination represent a new direction in the evaluation and treatment (e.g., modification of postural behavior) of various clinical disorders. Deterioration of the various components of the postural control system due to age, trauma, disease or deconditioning could result in changes in the coordination of posture. For example, patients with low back pain tend to exhibit an “en-bloc” or rigid global pattern of coordination in which movement stems from as few parts of the body as possible. These coordination changes cannot be adequately described using traditional univariate measures such as COP or COM (cf. Kuo et al., 1998), but can be addressed by the multi-segmental approaches described herein.

Experiment 1 was designed to characterize the postural coordination and joint rotations associated with maintaining upright balance on each of four different surfaces of varying stability. Although previous research has described postural control during quiet stance, specific multi-segmental coordination strategies have not been identified. This experiment determines whether visual information affects the type of postural mode used to maintain stance. It functions as the baseline experiment for which the postural kinematics can be compared during experiments 2 and 3. By measuring the coordination among body segments during quiet stance, this experiment sought to answer three questions:

1) Does multi-segmental coordination exist during quiet, unperturbed stance?
2) Will the coordination modes or “strategies” (e.g. hip-ankle strategy) used by people to maintain standing equilibrium without perturbation be qualitatively different from strategies obtained on surfaces using a perturbation paradigm?
3) Does vision influence postural modes during unperturbed stance, or does it only affect the magnitude of response (e.g., increased sway)?

The need to conduct this experiment comes from our lack of knowledge regarding what coordination modes exist for upright non-perturbed posture and determining the extent to which stability (operationalized by changing support surface) and vision (eyes open versus eyes closed) affect such modes. If multi-segmental coordination is being used, then future work could evaluate the effects of suprapostural activities on the emergence of multi-segmental coordination.

Experiment 1 – Postural Kinematics and Coordination During Quiet Stance

Method

Participants

Eight right-handed students (2 males, 6 females) from Miami University between the ages of 18-35 (mean ± *SD*: age 26.6 ± 3.7 years, height 1.69 ± 0.03 m, mass 70 ± 19 kg) volunteered to participate in the experiment. All participants had normal or corrected-to-normal vision. Participants had no history of vestibular/inner ear dysfunction and no history of recurrent dizziness, falling, or vertigo or other condition that would impair the ability to achieve standing balance. Participants all reported being able to perform normal activities of daily living such as standing, sitting, and sit-stand activities. No participant had recent trauma within the 6 months prior to data collection. All participants read and signed an informed consent document approved by the Miami University Institutional Review Board. They were not informed of the aims of the study. Finally, participants received $8 for completing the posture session.

Apparatus

Participants were asked to maintain balance on each of four surfaces (see Figure 1), a wide plank (.59 m wide x .49m length x .015m thick), a narrow wood beam (1.33 m x .085m x .085m thick), a foam surface (.61m x .50 m, 0.085m thick), and a standard rehabilitation half-biofoam roller (.90m x .15m x 0.08m thick). All surfaces were raised 0.076m from the laboratory floor.

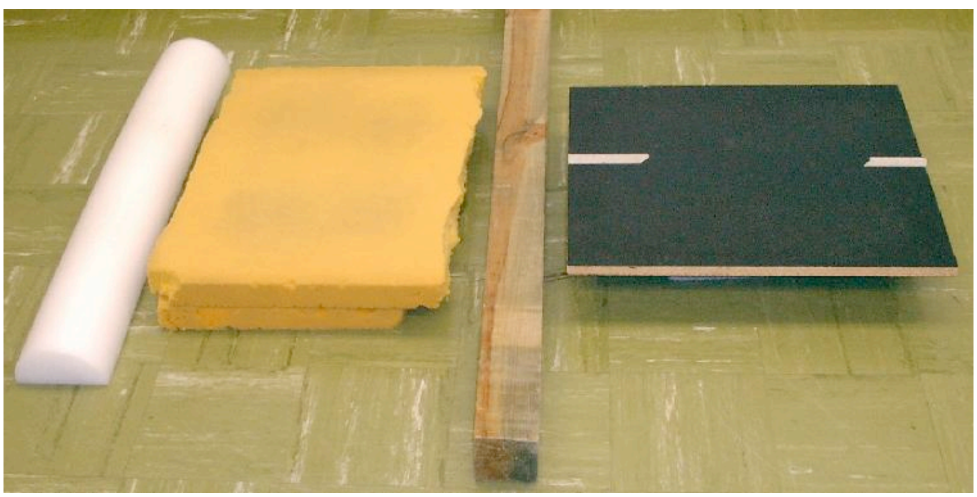


Figure (1). Support surfaces used in the experiment. From left to right: foam roller, foam surface, hard beam, flat surface.

Postural motion was recorded using an electro-magnetic tracking system (ETS, Flock of Birds; Ascension, Inc.). This system detects motion in six degrees of freedom (3 axes of translation and 3 axes of rotation). A centrally located emitter (controlled by an electronics unit) created a low-intensity magnetic field of known strength, extent and orientation. The emitter was located behind the participant on a custom-built, non-metallic tripod. Receivers ("birds") move within this field. Three orthogonal coils are contained within both the emitter and the receivers. The signal from the receiver is processed by the electronics unit and the orientation and position of the sensor relative to the emitter is obtained. The receivers have a root-mean-square position accuracy of 2.5 mm/0.5º and a resolution of 0.76 mm/0.1º (at .3m) within a 1.22 m operating range (Flock of Birds; Ascension, Inc.).

Task

Participants stood on one of the four different surfaces with their hands resting comfortably behind their back. Participants were instructed to attempt to stand motionless and to maintain balance. On half of the trials participants closed their eyes. With the eyes closed, participants were instructed to keep their head positioned as if looking straight ahead. For the eyes open trials, the participants were told to keep their eyes focused within a rectangular space depicted on a wall, 3.23 m directly in front of them (9.8º x 12.4º visual angle) at eye level. The rectangular space consisted of a random pattern of contact paper, the purpose of which was to provide participants a scene to look at. The feet were placed slightly less than shoulder width apart, with the toes angled slightly outward. Foot position was marked on the floor to insure consistent foot placement within and between trials.

Design and Procedure

Participants were recruited via campus-wide advertising. Upon entering the laboratory, participants received a brief description of the experiment and provided their written consent to participate. Verbal instructions were the same as above. Segmental motion of the foot, leg, thigh, sacrum, C7, and head was assessed during each postural trial. Data collection of postural motion began when the participant stated that he/she was ready. Four trials were conducted for each surface per person. Half of the trials were with eyes open and half were with eyes closed. Each surface and eye condition was replicated once to yield 16 total trials per person (4 surfaces x 2 eye conditions x 2 replications).

Participants were encouraged to move around and to relax between trials. The participants were given a 30 second rest between trials to prevent fatigue and to minimize any chance of adverse effects of standing still (e.g., neurologic syncope). Each trial lasted 30 seconds. The 16 trials comprised one block. A pseudo-random order was chosen for each block of trials. Each block of trials began and ended with two trials on the hard surface. Alternating trials were completed with eyes open or eyes closed. With the exception of trials on the hard surface, all 4 trials on each of the other surfaces were completed before moving on to the subsequent surface. An electronic switch (event marker) was synchronized with the Motion Monitor (see below) that delivered an analog signal to the data collection computer when pressed. Compensatory events that occurred during the performance of a trial were recorded in the data set by pressing the event marker for the length of the event. Compensatory events as defined in this study included removing the hands from the back, opening the eyes (observed by experimenter) during an eyes-closed trial and/or lifting either foot from the support surface. Following the procedure by Riemann et al. (2003) an incomplete trial was designated as those in which more than 3 compensatory events occurred. Participants were given 1 retest trial for each incomplete trial. All data collection for each participant occurred in one session that lasted approximately 40 minutes. After completion of the study, participants were debriefed and received their monetary compensation.

Because of the number of abbreviations and terms used in the following studies, Appendix A has been included. This appendix provides a summary of the abbreviations used in the following sections along with a glossary of terms.

Data Acquisition and Analysis

Data from the birds was sampled at a rate of 75 Hz for each 30 second trial and stored on a computer for future analysis. Six "birds" were employed (Figure 2A) at the following 6 sites: the head (external occipital protuberance); C7 spinous process (vertebra prominens); S1 tubercle; mid-lateral right thigh; anterior right leg (mid shaft); right dorsum of foot. The birds were secured to the anatomical landmarks using specially designed Velcro cuffs with molded plastic receptacles to lock the sensor into place (Figure 2B, Innovative Sports Training, Inc., Chicago, IL, USA). Both hips, right knee and ankle joint centers were determined by manually digitizing (using a custom stylus) two points on opposite sides of each joint and calculating the mid point. In addition, the T12 spinous process and the right second phalanx (foot) were also digitized. The digitized points served as reference coordinates for the above body segments. Use of these reference coordinates permitted calculations of joint rotations and joint positions.

A

B

Figure (2). The Experimental setup is seen on the left (A). Sensors, emitter, visual pattern (shown in background) and computer (used in Experiments 2 and 3) are shown. Sensor (bird) is shown secured to the custom designed body bands (B) and is placed over the appropriate anatomical landmark.

Kinematic variables in three dimensions were assessed using Motion Monitor software (Innovative Sports Training, Inc., Chicago, IL, USA). The Motion Monitor software filtered the data using a lowpass, Butterworth filter with a 10Hz cutoff frequency. Angular measurements were formed on the basis of projection angles in the sagittal plane and correspond to standard goniometric measurements as described in Norkin & White (1995). For example, ankle motion was operationally defined as occurring between the foot and the leg, knee motion as occurring between the thigh and the leg, and hip motion occurring between the thigh and pelvis.

Specifically, the following dependent variables were included (see Appendix A for definitions and computational procedures): a) postural sway as measured by antero-posterior (AP) and medio-lateral (ML) head translation variability; b) total angular range of motion (ROM) and angular standard deviation for the neck, trunk, hip, knee and ankle in the sagittal plane. Further, a composite measure of inter-joint coordination was introduced, the inter-joint coordination ratio. The inter-joint coordination ratio was obtained by dividing the standard deviation of one joint's angular motion (e.g. hip joint) by the standard deviation of another joint's angular motion (e.g. ankle joint). This provides a unitary number that represents the relative movement pattern between two joints. Postural strategies were determined kinematically by coordination ratios. For example, a hip/ankle coordination ratio >1 would mean more (variable) movement occurred about the hip joint and would be defined as a hip strategy. A hip/ankle coordination ratio ~1 defines a kinematically equivalent hip and ankle strategy and a ratio <1 defines an ankle strategy.

Results and Discussion

Recall that there were three proposed aims for this study (under 'Aims and Hypotheses'). The existence of multi-segmental coordination during quiet, unperturbed stance will be addressed by the analysis of joint angles and inter-joint coordination ratios. The second and third aims dealing specifically with strategies will be addressed by the analysis of inter-joint coordination ratios.

In this experiment, the main objective was to determine intersegmental kinematic relationships during upright quiet standing posture. No participant had an incomplete trial as defined above. Out of the 128 total trials (16 trials per person – 4 trials per each of the 4 surfaces) in this experiment, 3 trials were not recorded by the flock of birds system due to run-time errors. Five participants had no error trials, and 3 participants had 1 error trial each under 3 different conditions. To eliminate cells with no data in the analysis, and since each condition was replicated, the replicated data point for each of these 3 trials served as the value for that condition.

Recall that previous research (cf. Shumway-Cook & Woollacott, 2001) had found postural sway to increase with eyes closed and while standing on altered support surfaces. It was expected that these same challenges would also influence multi-segmental postural coordination. In order to verify the increased sway predictions, AP and ML head sway variability measures were examined during quiet stance under each condition. The standard deviation of the AP and ML head translation positions for each 30 second trial was calculated and formed the basic unit of postural sway analysis. The standard deviations for the two replication trials for each individual were then averaged together to form the individual mean standard deviation (IMSD) for each experimental condition. Postural sway analysis of variance (ANOVA) results for the AP direction are presented in Table 1, and the ANOVA results for ML head sway are presented in Table 2. The interested reader can find all of the IMSD values in Appendix 1. The IMSD values were averaged across participants to obtain group mean standard deviations for each experimental condition. The group means (GMSD) are given in Figures 3 and 4. Differences among the group means for the various conditions were investigated. Note that the IMSD and GMSD measures reported hereafter also have their own variability. IMSD values constituted the cell entries for the ANOVA's. The statistical analysis was conducted with a 2x4 factor, within subjects ANOVA with the 2 factors being visual condition (eyes open, closed) and support surface (flat surface, foam roller, hard beam, foam surface) with alpha equal to 0.01.

Table 1. ANOVA table for AP head sway

Source	Sum of Squares	df	Mean Square	F
Eyes	0.0017	1	0.0017	16.687 *
Surface	0.0029	3	0.0010	13.188 *
EyesxSurface	0.0016	3	0.0005	7.677 *
Subjects				
EyesxS	0.0007	7	0.0001	
SurfacexS	0.0015	21	0.0001	
EyesxSurfacexS	0.0015	21	0.0001	
Total		63		

* denotes p<0.01

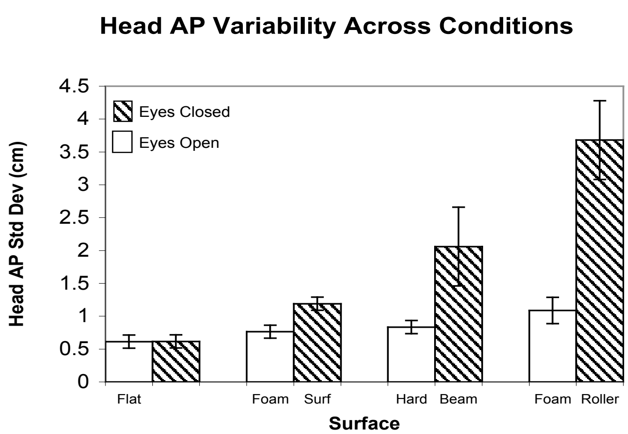


Figure (3). GMSDs (± SE) for AP head translation variability. Planned comparisons revealed no significant differences between any surfaces with eyes open. There was a significant difference between eyes open and closed conditions on the foam roller (p<.01).

Table 2. ANOVA table for ML head sway

Source	Sum of Squares	df	Mean Square	F	
Eyes	0.000271	1	0.000271	12.17	*
Surface	0.000708	3	0.000236	9.523	*
EyesxSurface	0.000201	3	0.000067	2.472	
Subjects					
EyesxS	0.000156	7	0.000022		
SurfacexS	0.000520	21	0.000025		
EyesxSurfacexS	0.000570	21	0.000027		
Total		63			

* denotes p<0.01

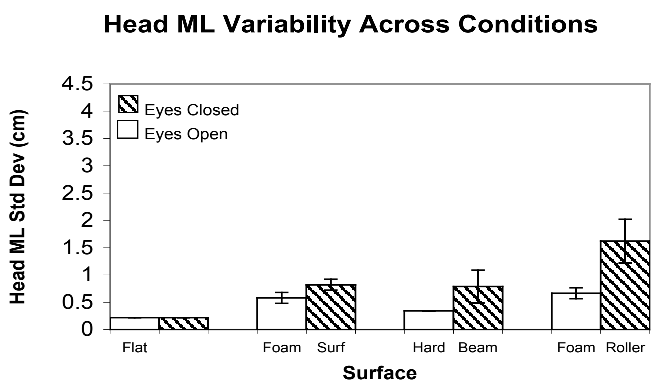


Figure (4). GMSDs (± SE) for ML head translation variability. Planned comparisons were conducted only within a surface to examine for the effect of eyes. A significant difference between eyes open and eyes closed existed for the foam roller (p<.01).

When participants were asked to stand quietly on four different surfaces under eyes open or closed conditions, their body sway (as measured by AP and ML head sway) was lowest on a flat surface and higher on the other surfaces during eyes closed conditions. For AP head sway, a main effect of surface showed that the most sway occurred on the foam roller and the least sway on the flat surface (Figure 3). A main effect of eye condition demonstrated that with the eyes closed, more AP sway occurred compared to eyes open (Figure 3). Main effects of surface and eye condition also existed for the ML condition showing remarkable similarity to the pattern of results for the AP condition. With eyes closed ML sway was greater than with eyes open (Figure 4). Also, more sway was noted on foam surfaces versus flat surfaces and on narrower surfaces versus wide surfaces (Figures 3 and 4).

The interaction of eye and surface conditions for AP head sway demonstrates that eyes closed yielded a relatively larger sway on narrower surfaces compared to wider surfaces. This finding is consistent with previous studies that have shown that motion increases with eyes closed (cf. Shumway-Cook & Woollacott, 2001) and on altered support surfaces (cf. Blackburn et al., 2003) during quiet stance. Further, these results show almost the same pattern for both ML and AP sway (with the exception of no interaction for ML sway) across both surface and visual conditions, suggesting similar control mechanisms.

The multi-segmental mechanisms by which people maintain normal voluntary control over posture, has received little attention. Of the studies that have been done (cf. Blackburn et al., 2003; Kuo et al., 1998), most have focused on limited regional analyses, leaving out the larger picture of how all major regions together contribute to equilibrium maintenance. Further, a more global examination across multiple joints provides a way to assess the coordination of these segments with respect to one another. To determine whether multi-segmental motion was present during stance as predicted, joint angular ROM and angular standard deviation values in the sagittal plane were computed. Individual and group mean values for ROM (IMROM, GMROM) and angular standard deviations (IMSD, GMSD) were calculated in the same way as described above for AP and ML head sway (see also Appendix A). Group descriptive statistics for each joint (GMROM and GMSD) are presented in Table 7. An ANOVA was performed for each joint, using IMROM and IMSD data. The ANOVA summary tables are presented for the hip and ankle joints (Tables 3-6). To be consistent with the literature, only hip and ankle ANOVA results are presented here; ANOVA summary tables for the other joints are found in Appendix 1.

Table 3. Hip ROM

Source	Sum of Squares	df	Mean Square	F
Eyes	490.88	1	490.88	17.528 *
Surface	1093.37	3	364.46	13.628 *
EyesxSurface	565.16	3	188.39	6.846 *
Subjects				
EyesxS	196.04	7	28.01	
SurfacexS	561.61	21	26.74	
EyesxSurfacexS	577.84	21	27.52	
Total		63		

* denotes p<0.01

Table 4. Hip Angular Variability

Source	Sum of Squares	df	Mean Square	F
Eyes	25.25	1	25.25	18.832 *
Surface	51.03	3	17.01	12.456 *
EyesxSurface	32.61	3	10.87	7.396 *
Subjects				
EyesxS	9.39	7	1.34	
SurfacexS	28.68	21	1.37	
EyesxSurfacexS	30.87	21	1.47	
Total		63		

* denotes p<0.01

Table 5. Ankle ROM

Source	Sum of Squares	df	Mean Square	F
Eyes	2961.16	1	2961.16	17.262 *
Surface	9330.35	3	3110.12	12.03 *
EyesxSurface	2896.72	3	965.58	4.966 *
Subjects				
EyesxS	1200.79	7	171.54	
SurfacexS	5429.28	21	258.54	
EyesxSurfacexS	4083.43	21	194.45	
Total		63		

* denotes p<0.01

Table 6. Ankle Angular Variability

Source	Sum of Squares	df	Mean Square	F
Eyes	83.30	1	83.30	14.752 *
Surface	348.59	3	116.20	16.333 *
EyesxSurface	109.96	3	36.65	7.057 *
Subjects				
EyesxS	39.53	7	5.65	
SurfacexS	149.40	21	7.11	
EyesxSurfacexS	109.07	21	5.19	
Total		63		

* denotes p<0.01

Table 7. Summary Table for GMROM and Angular GMSD for Flexion/Extension

	HSEO	HSEC	FSEO	FSEC	HBEO	HBEC	FBEO	FBEC
Cervical GMROM	2.09 (.50)	1.70 (.30)	2.03 (.52)	2.39 (.51)	1.81 (.28)	8.35 (3.30)	5.18 (2.19)	17.18 (4.32)
Trunk GMROM	1.07 (.16)	1.37 (.11)	1.10 (.15)	1.40 (.14)	1.50 (.14)	5.86 (2.01)	4.95 (2.65)	12.05 (2.11)
Hip GMROM	.88 (.18)	.97 (.11)	1.17 (.15)	1.53 (.20)	1.18 (.13)	8.28 (3.01)	3.95 (1.93)	18.6 (3.67)
Knee GMROM	1.99 (.24)	2.07 (.19)	2.97 (.37)	4.19 (.39)	3.06 (.42)	11.10 (3.84)	5.16 (1.59)	17.0 (4.32)
Ankle GMROM	1.39 (.15)	1.42 (.14)	4.60 (.57)	7.82 (.87)	4.30 (.87)	21.40 (8.92)	16.0 (2.43)	50.1 (11.09)
Cervical GMSD	.54 (.12)	.46 (.08)	.52 (.15)	.58 (.12)	.45 (.08)	1.80 (.71)	1.13 (.41)	4.14 (1.17)
Trunk GMSD	.25 (.03)	.34 (.03)	.25 (.04)	.32 (.03)	.34 (.03)	1.3 (.48)	.88 (.32)	2.51 (.47)
Hip GMSD	.20 (.04)	.22 (.03)	.27 (.03)	.36 (.06)	.29 (.03)	1.66 (.62)	.67 (.20)	4.22 (.98)
Knee GMSD	.52 (.07)	.54 (.05)	.74 (.10)	1.02 (.11)	.74 (.12)	1.77 (.49)	1.06 (.22)	3.00 (.73)
Ankle GMSD	.35 (.04)	.36 (.04)	1.15 (.17)	1.79 (.17)	1.04 (.23)	2.84 (.99)	3.14 (.43)	9.82 (2.17)

Note. Values refer to degrees of sagittal rotation (± SE). Abbreviations: HS (Hard Flat Surface), FB (Biofoam Roller), FS (Foam Surface), HB (Hard Beam), EO (Eyes Open), EC (Eyes Closed)

The experiment provided precise measures of multi-segmental postural kinematics and joint angles during upright quiet stance. These measures fulfilled the present requirements to investigate coordination, and additionally provided preliminary data to meet the need for such measures as voiced in the literature (Winter et al., 2003). Averaged across all surface and eye conditions, absolute ankle ROM was greatest and trunk ROM was least (ankle, 13.38º > knee, 5.95º > cervical, 5.09º > hip, 4.57º > trunk, 3.66º). The order of angular GMSD values was almost the same (ankle, 2.56 > cervical spine, 1.20 > knee, 1.17 > hip, 0.99 > trunk, 0.77). Visual inspection of Table 7 revealed that all joint angles and joint variability changed across conditions. A statistical analysis revealed that while hip and ankle angular variability was affected by all conditions (including a significant interaction between surface and eye condition), knee angular variability and cervical angular variability were influenced only by surface (Appendix 1). Both main effects influenced trunk angular variability (Appedix 1). These results provide initial evidence that each segment played a unique role in accomplishing the task of maintaining balance and trying to stand quietly. In addition, the results have provided justification for examining each of the involved joints. Thus, even standing quietly involves multi-segmental motion.

The kinematic profile of two joints (hip and ankle) was of particular interest because of their proposed function in motor strategies as described in the postural perturbation literature. Statistically significant main effects were seen for eye and surface conditions for both joints. For the hip, a main effect of surface resulted with the least angular movement (ROM and angular variability) on the flat surface and the most on the foam roller. A significant main effect of eye condition demonstrated that hip angular movement (ROM and angular variability) was greatest with eyes closed and least with eyes open. This pattern of significant main effects was identical for the ankle. Both ROM and angular variability for both hip and ankle joints exhibited an interaction of eye condition with surface type (Tables 3-6) showing that maintaining posture with eyes closed produced relatively larger joint rotation on narrower surfaces compared to wider surfaces. The interactions are the same as those found for AP head sway.

In order to corroborate and extend the above findings, coordination was assessed by means of inter-joint coordination ratios as outlined in the methods section. The angular standard deviation of one joint for each 30 second trial was divided by the angular standard deviation of the second joint for the same 30 second trial and this formed the basic variability ratio. The variability ratios for the two replication trials for each individual were then averaged together to form the individual mean variability ratio (IMVR) for a given experimental condition. The IMVR values comprised the data for the ANOVA calculations. Group mean inter-joint coordination results (GMVR) for hip and ankle, flexion/extension are presented in Figure 5. The ANOVA summary table for the hip/ankle variability ratios is presented in Table 8. Appendix 1 provides inter-joint coordination ratios and ANOVA summary tables for the other segments across experimental conditions.

Table 8. ANOVA table for hip/ankle variability ratio's

Source	Sum of Squares	df	Mean Square	F	
Eyes	0.132000	1	0.132000	2.075	
Surface	2.414000	3	0.805000	5.097	*
EyesxSurface	0.186000	3	0.062160	1.738	
Subjects					
EyesxS	0.444000	7	0.063390		
SurfacexS	3.316000	21	0.158000		
EyesxSurfacexS	0.751000	21	0.035760		
Total		63			

* denotes p<0.01

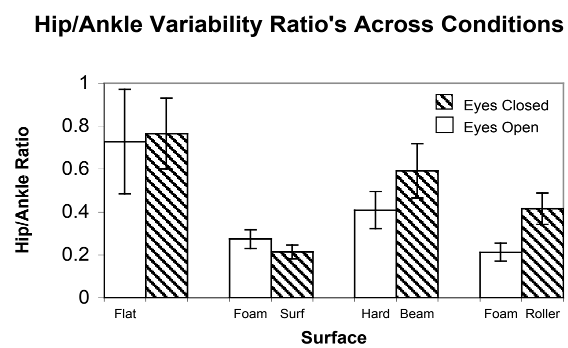


Figure (5). Group mean hip/ankle variability ratios (± SE). Planned comparisons revealed that coordination ratios were significantly higher for the hard beam than the foam surface. Note the relatively greater ankle variability on the narrow/foam surfaces.

Nashner and McCollum (1985) hypothesized two forms of discrete postural strategies that could control the position of the center of mass (CoM) in the sagittal plane. The strategies included the ankle strategy, which operates as a single-segment inverted pendulum about the ankle, and the hip strategy, which operates as a double-segment inverted pendulum with anti-phase motion about the hip and ankle. It was further suggested (Nashner & McCollum, 1985) that a hip strategy should be observed when the effectiveness of ankle torque is reduced such as on compliant or shortened surfaces. Experimental observation using a perturbation model (e.g. platform translation) was consistent with the hypothesis and demonstrated that ankle strategies were produced with flat surface translation, while hip strategy was produced by backward translation on a narrow beam (10cm, Horak & Nashner, 1986).

Our current kinematic results show an effect opposite to that obtained and predicted with a perturbation induced postural model (Horak & Nashner, 1986; Nashner & McCollum, 1985). Specifically, on the more compliant and narrow support surfaces, more movement was produced about the ankle (Figure 5) as opposed to the hip, which would be predicted by the perturbation model. In addition to an increase in ankle joint range of motion, the angular GMSD of motion was also greater under the same conditions, confirming the effect. Hip/ankle ratios determined the relative amounts of movement at each joint. Note that these ratios provide a measure of relative motion only, not providing a temporal relationship. The hip/ankle ratios, show that the largest relative amount of hip movement occurred on the flat surface (see Figure 5), exactly opposite the prediction using perturbation. The inter-joint coordination ratio was recently introduced to the literature by Smith et al. (2002) to fill a need to examine the multi-segment postural coordination during quiet stance in this study. Since then, it has been successful in differentiating postural strategies not only in this study, but also for stance while performing a visual reading task (Smart, Mobley, Otten, Smith, & Amin, 2004). Interestingly, in this study, having eyes closed did not statistically affect the type of coordination mode (ratio) used by participants. Thus, a change in coordination mode cannot simply be due to any factor that generally increases postural instability (e.g., increased head sway) such as having eyes closed. Rather, it appears that specific factors (e.g., surface) influence the emergence of new coordination modes.

This study has shown differences in responses other than those predicted by externally generated perturbation studies. In attempting to explain why there were differences, it is important to note that postural perturbations can be generated internally, externally or by a combination of both. For example, fast voluntary arm movements are an internal source of equilibrium disturbance, while unexpected platform translation is an external disturbance. Likewise, postural responses to perturbations can be classified as compensatory (reactive) and anticipatory (proactive) (Horak et al., 1997; Maki & McIlroy, 1997). Anticipatory responses occur in anticipation of internally generated destabilizing forces and are initiated by the subject. Even predictability of an upcoming external perturbation is insufficient by itself to produce anticipatory postural adjustments (Latash, 1998). Compensatory responses deal with actual perturbations to balance and are often reactionary to external forces that displace the body's center of gravity (Latash, 1998).

In this experiment, participants mostly dealt with internally generated disturbances or maintenance postures. Perturbation induced models of postural control predict that on non-flat surfaces, participants use primarily a hip strategy (cf., Horak & Nashner, 1986) because ankle torque is insufficient to recover balance. However, the present results show clearly that across 3 non-flat surfaces, the ankle as opposed to the hip is primary in maintaining voluntary, upright balance. Apparently, since large and/or fast disturbances in equilibrium were not experienced, the ankle was able to provide sufficient torque upon each surface to maintain balance. The first experiment thus supports the hypothesis that maintenance and compensatory behaviors are in fact, not identical. Therefore, the pattern of joint coordination that emerges during natural stance situations seems to differ from those produced in perturbation environments.

Many clinical balance and mobility training programs (cf. Rose, 2003) operate under the assumption that a hip strategy is used on narrow surfaces. While this assertion is correct under conditions of external perturbation or through self-movement, the present results find that quiet stance on altered support surfaces can be maintained primarily under ankle control. Thus, quiet standing on non-flat and narrow support surfaces may be a good way to train patients to use an ankle strategy. In addition, the present results imply that reactions to perturbation reveal only one aspect of the postural control system and we should also consider mechanisms related to control of stability and steady-state positions (Horak et al., 1997). Since responses to perturbation do not account for the mechanisms implicated in steady-state stance posture, or anticipatory postural coordination with voluntary movements (Horak et al., 1997), further studies should be directed towards these efforts.

Experiment 2 – Suprapostural Head Tracking with Between Trials Frequency Manipulation

Overview

Experiment 1 demonstrated that multi-segmental coordination strategies exist during quiet stance, uncontaminated by the effects of suprapostural tasks or external perturbations. However, due to the absence of an explicit task or change in task, the stability of these coordination patterns and the change from one pattern to another remain to be examined. While a few studies have investigated postural coordination during suprapostural tasks they have tended to focus on unique factors (e.g., oscillation frequency and support surface) leading to an abrupt change (transition) in postural coordination (cf. Bardy, Marin, Stoffregen, & Bootsma, 1999; Bardy, Oullier, Bootsma, & Stoffregen, 2002; Marin, Bardy, Baumberger, Fluckiger, & Stoffregen, 1999). Support surface and oscillation frequency (OF) have each been shown to impact postural coordination. However, their combined effects on the stability of coordination patterns along with their effects on the accomplishment of suprapostural activities are still poorly known.

Although coordination changed under different surface constraints in the first experiment, dynamic properties (e.g., postural transitions, hysteresis) of coordination and postural control were not examined. The nature of the system's coordination dynamics are revealed around *transitions* (spontaneous changes in coordination pattern under the influence of some parameter, e.g. frequency of motion) (Zanone & Kelso, 1994). The factors that influence the onset and extent of such transitions are essential to postural stability (Zanone & Kelso, 1994). Previous investigations have found that postural transitions have occurred by manipulating oscillation frequency during a head-tracking task (Bardy et al., 2002). Since support surface and oscillation frequency have each been shown to impact postural coordination, the subsequent experiments were designed to determine their combined effects. Experiments 2 and 3 manipulated the suprapostural task (tracking a visual target at different frequencies) that the person engaged while standing on different surfaces in order to examine the emergence of distinct postural strategies and the interactions between support surface and task performance. Specifically these experiments test the effect of frequency of postural motion on coordination on different surfaces of support.

Experiment 2 examines the effect of head tracking frequency on postural coordination when trials are presented one at a time with a short rest between trials. This experiment was designed to find the frequency at which postural transitions (e.g., switching from in phase to antiphase coordination) occurred and whether or not the type of support surface influenced strategy selection and/or head tracking performance. The motivation behind this experiment lies in the notion that adding a combined visual/motor task to the system should induce clearly demonstrable and differential patterns of coordination as a function of frequency and support surface (cf., Bardy et al., 1999; Bardy et al., 2002). But, given the results of the first experiment, will the support surface alone bring about dynamical changes in postural coordination, or will there be an interaction of surface and task that shape the underlying dynamics? In other words, will multiple constraints lead to changes in postural control or will a single constraint primarily influence control?

Based on Bardy et al.'s work (1999; 2002), it is hypothesized that postural transitions which occur at ~0.50 Hz (e.g., from in-phase to anti-phase hip/ankle relations) will occur at lower frequencies on an unstable support surface. The premise here is that in-phase hip/ankle relations are stable at low frequencies, but less stable at higher frequencies resulting in a transition to the anti-phase mode (supposedly a more stable attractor at higher frequencies) (Bardy et al., 2002). This hypothesis was derived from Bardy et al. (1999) who found that artificially creating a high COM (and hence challenging postural stability) while head tracking a visual stimulus, resulted in a transition to anti-phase hip/ankle relations at lower amplitude displacements compared to a normal COM condition. Since Experiment 2 involves having the eyes open during all trials, the choice was made to use the two surfaces that produced the two most extreme coordination modes (hard surface and foam roller) from the first experiment.

Recently, two predominant methods have been used to examine the coordination of bodily segments during dynamic posture. Researchers have relied on generating movement of the body through either self-produced motion to accomplish a task (e.g. head tracking) or by response to an external force (e.g. moving platform). Two studies in particular have looked at postural coordination in response to a moving platform. Both Buchanan and Horak (2001) and Ko et al. (2003) reported similar kinematic experimental findings that gradual change in postural strategies occur with change in frequency of a sinusoidally moving platform. Small joint angular movements (with high variability) were found at low platform frequencies while coordination between joint (ankle, knee and hip) motion stabilized (i.e. standard deviation of joint relative phase decreased) with increasing platform frequencies (Buchanan & Horak, 2001; Ko et al., 2003). Ko et al. (2003) observed a change from a more in phase to an anti-phase ankle-hip (relative phase) relationship above .73 Hz, with continued stable antiphase relations above .73 Hz, whereas Buchanan and Horak (1999) found only in-phase relations with similar frequencies.

Using the head tracking method on the other hand, Bardy et. al (Bardy et al., 1999; Bardy et al., 2002) reported an abrupt transition in coordination strategy occurring at about .5 Hz with in-phase hip-ankle relations at lower frequencies and anti-phase relations above .5 Hz. It is noteworthy that the Ko et al. (2003) and Bardy et al. (1999; 2002) studies found similar phase relations (e.g. switch from in phase to anti-phase with increasing frequency) despite the fact that they used completely different experimental methods (e.g. compensatory vs. volitional behavior). However, the Buchanan and Horak study found only in-phase relations during the range of platform translation frequencies (1999). Therefore, the two methods of examining postural coordination mentioned above have not yielded converging evidence for: a) abrupt transitions in postural coordination, nor; b) a consistent pattern of phase relations between the hip and ankle with respect to changes in motion frequency. Thus, the possibility exists that perturbation by moving platform produces different patterns of coordination compared to those produced during a suprapostural task.

Experiment 2 was designed to determine the stability of coordination modes while performing a suprapostural activity and standing on one of two different surfaces. Although previous research has described the separate effects of oscillation frequency and support surface on head tracking performance, the combined effects of these factors are not well known. By measuring coordination among body segments, head motion and frequency characteristics of the joints, this experiment sought to examine two main questions:

1) Will the stability of postural coordination be influenced by an interaction between surface and oscillation frequency (OF)?
2) Will an abrupt change (transition) in postural coordination occur or will a gradual change predominate?

Method

Participants

Twelve right-handed students (5 males, 7 females) from Miami University between the ages of 18-35 (mean ± *s*: age 23.2 ± 4.9 years, height 1.72 ± 0.1 m, mass 70 ± 15 kg) volunteered to participate in the experiment. These participants were different from those in Experiment 1. All other participant criteria from Experiment 1 applied to this experiment.

Task and Apparatus

Participants stood on one of two surfaces with their hands resting comfortably behind their back, while looking at a computer monitor located 1m in front of them at eye-height. The two surfaces were the wide plank and half-biofoam roller (see Figure 1) used in Experiment 1. Foot position and surface height were the same as in Experiment 1. Participants in this experiment were given a suprapostural task: they were instructed to maintain balance while tracking an oscillating (fore-aft) computer generated target with their head. Instructions were carefully given to oscillate "in phase" with the target (e.g. when the target moves forward (becomes smaller), move your head forward) and to "match" the amplitude produced by the target. Instructions also emphasized the need to remain oriented to the screen (display) and to use whatever movements necessary to remain on the surface and to track the forward-backward oscillations.

The target display was generated on a 15" computer monitor located 1 meter in front of the participant at eye height. Room lights were left on, but glare was minimized by using opaque shielding over sources of direct lighting. Displays contained 200 randomly positioned opaque dots (1 pixel) occupying a circle (Figure 6) in a coronal plane that oscillated in projected space with a simulated peak-to-peak amplitude of 20 cm. A screen resolution of 640 x 480 was used for the displays.

The following depth oscillation frequencies were generated by the custom program: 0.16 Hz, 0.23 Hz, 0.31 Hz, 0.47 Hz, 0.54 Hz, 0.63 Hz and 0.75 Hz. Each trial oscillation lasted 12 cycles. The frame rate of the monitor was 60 Hz. To produce the different oscillation frequencies, sixteen pictures per oscillation cycle were used for the highest frequencies (0.54 Hz, 0.63 Hz, 0.75 Hz), while 64 pictures per oscillation cycle were used for the lowest frequencies (0.16Hz, 0.23 Hz, 0.31 Hz, 0.47 Hz). Within each cycle length, pictures were presented for different numbers of frames to further manipulate frequency. As an example, for the 0.23 Hz frequency, each oscillation cycle required 256 pictures (64 pictures x 4 frames/cycle). Further, 256 pictures multiplied by 12 oscillation cycles yielded a total of 3072 pictures, which provided a presentation time of 51.2 seconds (3072 pics/60 pics/sec).

A custom Quick C program was written to display the stimuli. During each trial, the 200 dots were transformed by a scaling factor that moved the dots radially in time, mimicking contraction and expansion of the perceived circle. A custom switch was designed to start the computer display and begin the recording of postural motion (from the data collection computer) at the same time. Synchronization of the two computers permitted comparison of postural variables and target variables such as relative phase.

Figure (6). Dot pattern used for Experiments 2 and 3.

Design and Procedure

Participants in this experiment were required to actively track a continuously oscillating (fore-aft in depth) visual target while their segmental postural motion was assessed. Data collection and the presentation of the stimulus (target) began when the participant stated that he/she was ready. Different oscillation frequencies (OF) were used across trials, with a simulated fixed peak-to-peak movement amplitude of 20 cm. It was hypothesized that this method of varying target frequency between trials would provide sufficient control parameter regulation (cf. Bardy et al., 2002 for a discussion) so as to elicit the emergence of quantitatively different behavioral modes of coordination at the different frequencies. This method followed the psychophysical "method of limits". On each trial, a target at only one particular frequency was shown. The trials were arranged for sequences in which the frequency order (FO) was either increasing (up condition) or decreasing (down condition). In the increasing FO condition, the frequency was, 0.16Hz, 0.23 Hz, 0.31 Hz, 0.47 Hz, 0.54 Hz, 0.63 Hz and 0.75 Hz. In the decreasing FO condition, the order was reversed.

Each frequency order and surface condition was replicated to yield 56 trials (2 surfaces x 2 FO x 7 OF x 2 replications) for each participant in the experiment. A warm-up period of about 75 seconds using multiple frequencies was given prior to the first trial to familiarize participants with the task. Each trial lasted 12 oscillation cycles, giving 12 different stimulus durations ranging from 76.8 seconds (0.16 Hz) to 16 seconds (0.75 Hz). A complete FO (i.e., increasing or decreasing) composed of 7 OF comprised a block of trials. A 30 second rest break was allowed between trials to prevent fatigue, with a 5-minute rest break between blocks of trials. Blocks alternated between increasing and decreasing FO. Four pseudo-random orders of blocked trials were used. Participants completed all blocks of trials on one surface before completing the blocks on the other surface. Each participant was randomly selected for each pseudo-random order of blocks. Compensatory events were recorded using the same method as in Experiment 1. The time to complete all 56 trials was approximately an hour and a half.

Data Acquisition and Analysis

Dependent variables were arranged into 5 functional categories that corresponded to head motion with respect to the tracking task, overall postural sway, hip and ankle spectral analyses, phase relationships among target and joint motions and hip-ankle variability ratios. Postural motion was recorded using the same method as in Experiment 1.

1. Head motion with respect to the tracking task (suprapostural performance):
   a) peak-to-peak AP head translation
   b) spectral analysis of head AP translation
   c) AP head phase
2. Overall postural sway variables:
   a) ML head sway
   b) joint angular standard deviations

3. Spectral analysis of hip and ankle joint rotation
4. Phase relationships among the target and hip and ankle joints
   a) hip and ankle phase with respect to target
   b) hip-ankle relative phase (ϕ_{rel})
5. Hip-ankle variability ratios as described in the first experiment

Statistical analyses were conducted using a 2x2x7 design, within subjects analysis of variance (ANOVA) with the 3 factors being support surface (foam beam, hard beam), FO (increasing, decreasing) and OF (0.16-0.75Hz). FO was included as a variable to determine if hysteresis (property of a dynamic system) effects were present. Alpha was equal to 0.01.

Spectral Analyses

Since, the task in this experiment involved oscillating at certain frequencies, some frequency-domain characteristics were important to examine. Of particular interest were the frequency responses of the ankle, hip (assumed to be the two prime movement strategies) and head (as a measure of task performance) and how these responses may change as function of sensory condition (e.g. support surface) and imposed motor (frequency tracking) demands.

The raw position data of the measured ankle and hip joint flexion/extension rotation angles, as well as AP head translation were imported from Microsoft Excel 2000 (Office 2000; Microsoft Corporation, Seattle, WA) and frequency analyzed using Matlab 6.1 (Mathworks, Natick, MA). A modified method of McClenaghan et al. (1996) and later Cherng et al. (2003) was used to conduct a frequency analysis of the data. A fast Fourier transform (FFT) algorithm was used to estimate the frequency composition of the rotation and translation positional data of each respective segment and to compute the power spectra. The FFT was performed separately on the data for each trial (representing each target frequency) for a total of 56 separate FFT's per person. The following variables were derived from the frequency spectra: 1) the percent power at the target frequency; and 2) the ratio of total power (unitless measure) at frequencies above and below the target frequency. To calculate the power ratio, power was summed for a log band below the stimulus frequency and a comparable log band above the stimulus frequency. The lower log band was 12^1 harmonics wide, while the upper band was 12^2 harmonics wide. The thirteenth harmonic corresponded to the target frequency. This procedure was followed for all the OF conditions.

Phase Analysis

Individual joint phase and head phase was obtained from each FFT analysis of the angular position and translation position data mentioned above. Data collection began at the onset of a target oscillation cycle, which permitted the calculation of the phase lag between each bodily segment and target. Since phase angles are a circular variable, circular statistics were used to compute measures of central tendency. The procedures described by Sparto and Schor (2004) to determine the descriptive and inferential statistics for the phase variables were followed. Since the design was within subjects, the first-order mean phase angle and mean vector length for each individual for a given condition were first computed. Then, the second-order group means and standard deviations for phase angle and vector length were computed. Paired sample tests (Sparto & Schor, 2004; p. 146-147) were performed on the data that resulted from second-order analyses. A minimal number of specific F tests were performed on the phase data, and alpha was equal to .01. Hip-ankle relative phase was obtained by subtracting ankle phase from hip phase at the target frequency during a trial. Values of $\phi_{rel} \approx 180^{o}$ indicated that the hip and ankle joints were moving in opposite directions (anti-phase) while $\phi_{rel} \approx 0^{o}$ indicated movement in the same direction (in-phase).

Results and Discussion

The main objective of this experiment was to test the hypothesis that postural strategies would vary in the face of both task and environmental constraints. The question of whether or not the stability of postural coordination will be influenced by an interaction between surface and OF will be addressed by the analysis of hip-ankle coordination ratios. The question of whether or not an abrupt change (transition) in postural coordination will occur will be addressed by examining hip-ankle relative phase.

No participant had an incomplete trial as defined earlier. Out of the 672 total trials (56 trials for each of 12 people) in this experiment, 11 trials were not recorded by the flock of birds system due to a run-time error. Five participants had no error trials, and the 11 error trials were spread across the other 7 participants in no apparent order. To eliminate cells with no data in the analysis, and since each condition was replicated, the other data point for each of these 11 trials served as the value for the missing condition.

Suprapostural performance

A. Peak-to-peak AP Head Translation

The aim of an individual participant was to maintain balance while tracking an oscillating (fore-aft) computer generated target with their head. They were instructed to oscillate "in phase" with the target and to "match" the amplitude produced by the target. To determine how well participants matched the target in terms of amplitude, peak-to-peak AP head translation distance (ROM) was examined. An AP head translation distance of 20 cm equates to perfect performance, while less translation meant poorer performance. The ROM for AP head translation for each trial was calculated and formed the basic unit of postural movement analysis. The ROM values for the two replication trials for each individual were then averaged together to form the individual mean ROM (IMROM) for each experimental condition. ANOVA results for AP head ROM are presented in Table 9. The interested reader can find all of the IMROM values in Appendix 2. The IMROM values were averaged across participants to obtain group mean ROM for each experimental condition. The group means (GMROM) are given in Figures 7 and 8. Differences among the group means for the various conditions were investigated. Note that IMROM and GMROM measures reported also have their own variability. The IMROM values constituted the cell entries for the ANOVA.

Table 9. ANOVA Table for AP Head ROM

Source	Sum of Squares	df	Mean Square	F
FO	0.00024	1	0.00024	0.389
OF	0.12800	6	0.02141	29.786 *
Surface	0.00498	1	0.00498	0.708
FOxOF	0.00483	6	0.00080	3.548 *
FOxSurface	0.00008	1	0.00008	0.230
OFxSurface	0.00460	6	0.00077	4.261 *
FOxOFxSurface	0.00159	6	0.00027	1.252
Subjects				
FOxS	0.00667	11	0.00061	
OFxS	0.04745	66	0.00072	
SurfacexS	0.07729	11	0.00703	
FOxOFxS	0.01497	66	0.00023	
FOxSurfacexS	0.00380	11	0.00035	
OFxSurfacexS	0.01187	66	0.00018	
FOxOFxSurfacexS	0.01400	66	0.00021	
Total		335		

* denotes p<0.01

Overall performance was good and consistent across both surfaces. A main effect of oscillation frequency showed that head translation was greatest at 0.16 Hz (M=17cm, SE=1.4cm) and least at 0.75 Hz (M=10.9cm, SE=0.8cm) (see Figure 7). Oscillation frequency was a particularly potent factor in determining translation distance. This makes sense as translation has been shown to decrease with decreased movement times that occur with high frequency motion (Bardy et al., 2002; Kay, Saltzman, Kelso, & Schoner, 1987), exhibiting a low pass filter effect.

No main effect of support surface was found. However, in combination with OF, surface did influence translation distance. This OF by surface interaction (Figure 7) demonstrates that head translation was greater on the flat surface compared to the foam roller, primarily during low OFs. This indicates that participants seemed unwilling (possibly because of perceived instability) to translate their heads as far during low frequencies on a more challenging surface than the flat surface. In addition, an OF by FO interaction showed that head translation was greater in the decreasing FO condition compared to the increasing FO condition, but this pattern reversed with OFs greater than .31 Hz (Figure 8). This effect seems to be due to the steeper slope of the decreasing FO curve compared to the flatter, increasing FO curve. Thus, AP head ROM over all OFs was greater when starting with high frequency, low amplitude movements. The interaction between FO and OF fulfilled one aspect of a hysteresis effect, namely that at the same OF, two values of AP head ROM existed for the two FOs. However, AP head ROM was not consistently impacted by the history of the oscillation movements, where the history of the system is another property of hysteresis (cf. Woollacott & Jensen, 1996). In this case, beginning with small ROM (e.g., decreasing FO) should produce a curve that is consistently smaller in ROM at every OF compared to beginning with larger ROM (e.g., increasing FO).

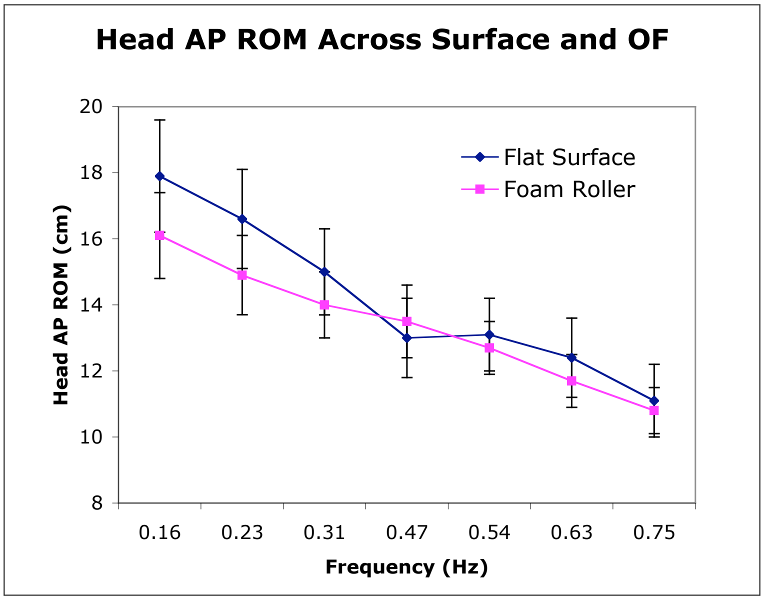


Figure (7). Mean head AP ROM across surface and OF (± SE).

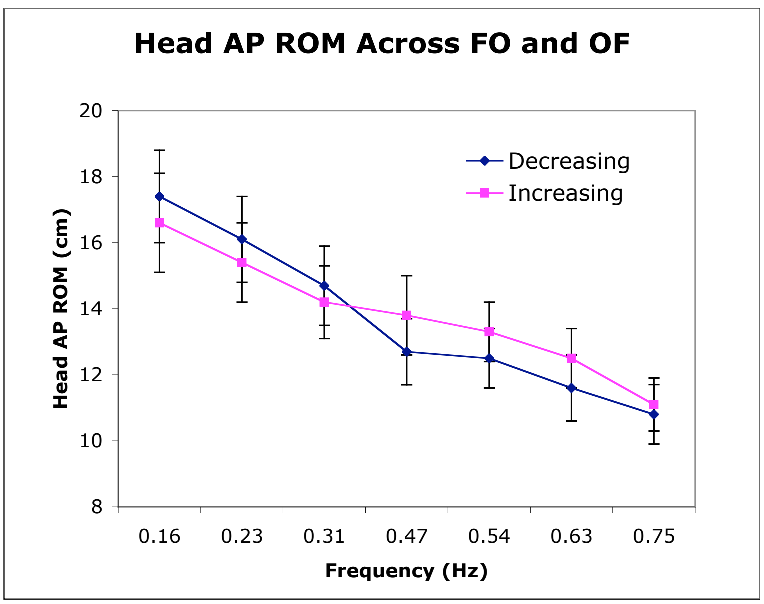


Figure (8). Mean head AP ROM (± SE) is plotted for increasing and decreasing FO conditions across OF.

B. Spectral analysis of AP Head Translation

Another measure of how well participants tracked the visual stimulus was to examine the frequency of their head tracking motions. A representative example of AP head motion across three OFs can be seen in the top trace of each of the panels in Figure 9. Specifically using power spectrum analysis (see Figure 10 for an example frequency analysis), it was possible to determine how closely participants' head motions 'matched' the stimulus frequency by computing the percentage of AP head power exerted at each target frequency. Individual and group mean values for percentage of head power exerted at each target frequency were calculated in the same way as described above for AP head ROM. An ANOVA was performed using individual mean percent AP head power for each experimental condition as cell entries. In this case, a significantly higher percentage of power (at target frequency) was found at the lowest OF (M=85.5%, SE=1.2%) compared to a lower percentage of power at the highest OF (M=62.1%, SE=3.5%), F(6, 66)=36.35, p=.000. Therefore, this main effect of OF showed a low-pass filter frequency response. No interactions or other main effects were present for AP head translation frequency.

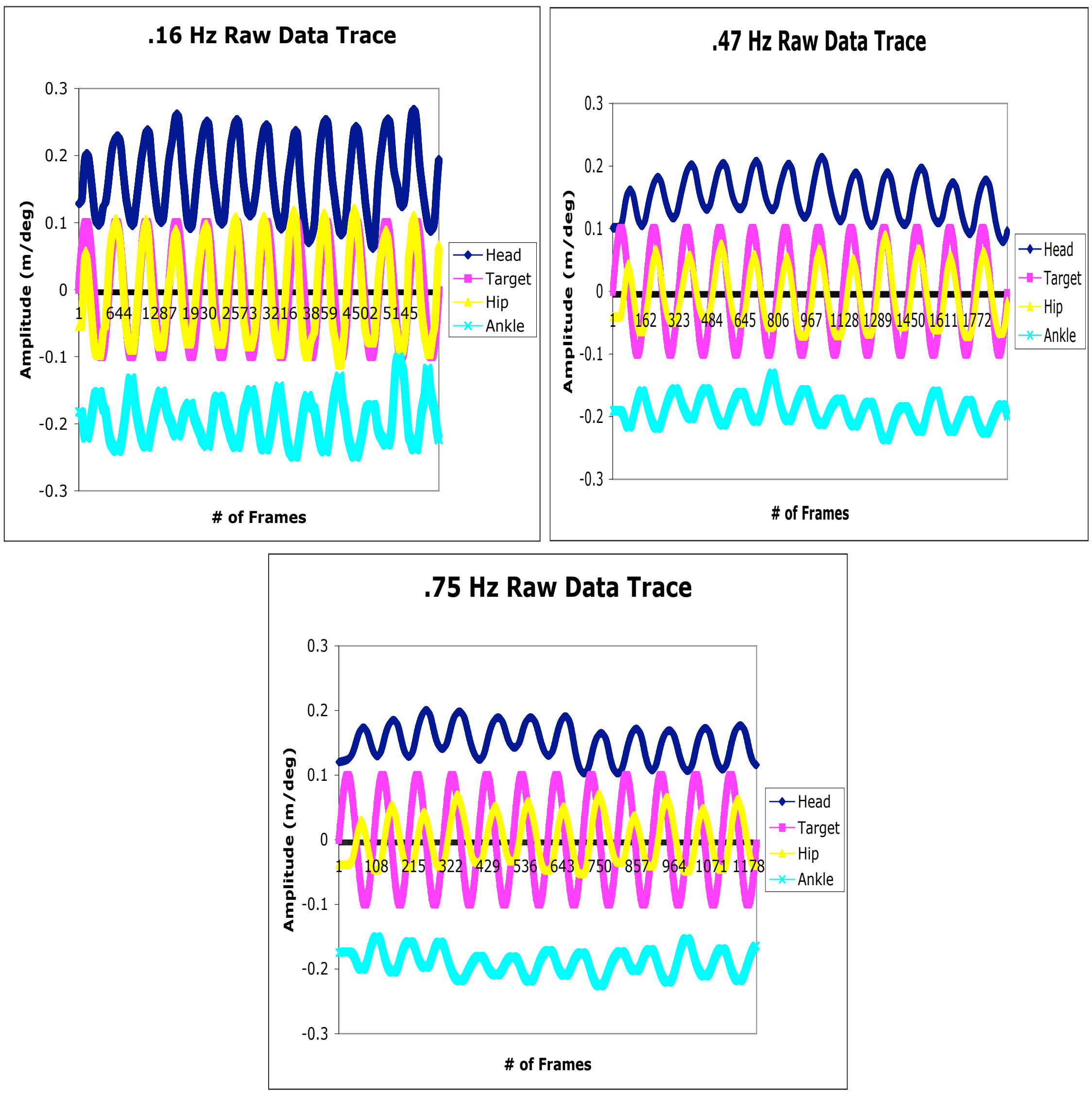


Figure (9). Raw data from one representative participant for the head, target, hip and ankle. Amplitude is expressed in meters, and degrees have been divided by 100 to fit on the graph. Data were obtained from a flat surface, and increasing FO trial.

AP head spectral analysis also demonstrated that participants accomplished the task reasonably well. As with the AP head ROM results, the worst performance occurred at the highest frequency. Both the AP head ROM data (described above) and the present frequency data confirm that standing posture behaves like a heavily damped low-pass system (cf. Kay & Warren, 2001), such that progressively higher frequency movements were reduced due to damping. The significant damping observed here is also consistent with recent data from a sinusoidally moving platform study (Buchanan & Horak, 1999). Damping is defined as resistance to motion and is a physical characteristic of all biologic structures including soft tissues such as ligament, cartilage, and bone (Panjabi & White, 2001). Viewing the postural system as a vibrational damping system can also explain why the largest amplitude of motion occurs at .16 Hz.

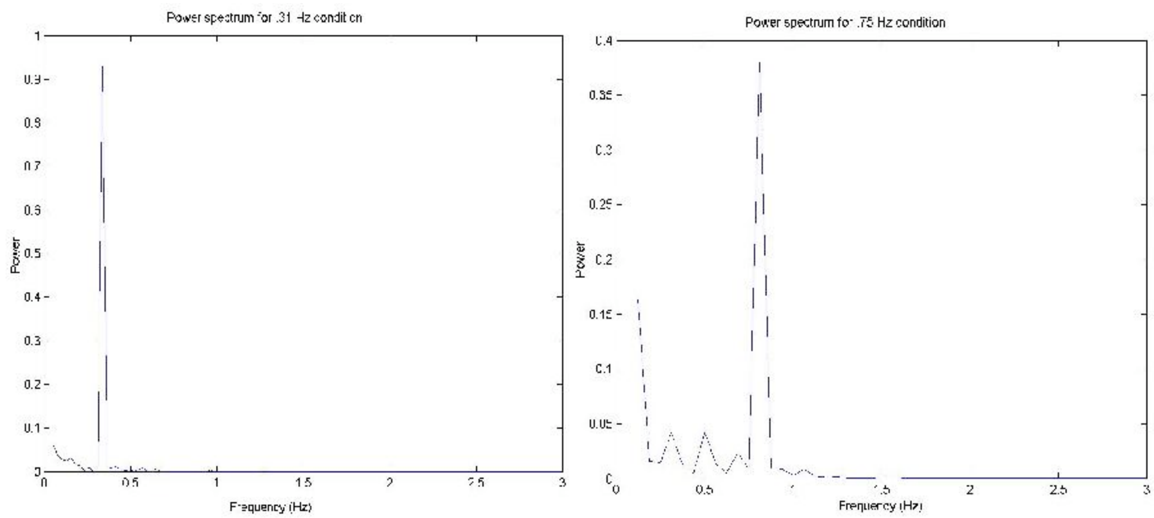


Figure (10). The frequency spectra of hip rotation (flexion/extension) from a representative participant at OF of .31 Hz (left) and .75 Hz (right).

C. AP Head Phase

In order to determine how well participants accomplished the task of oscillating "in phase" with the target, a phase analysis of AP head motion with respect to the target was performed. Figure 9 shows an example of AP head oscillation as well as target oscillation. Note that during the lower OFs, the peaks and valleys of the head and the target were synchronized while at the highest frequency, the head phase lagged the target. AP head phase was obtained from the FFT analysis from each trial and for each participant. Head phase was collapsed across frequency order. Therefore, four AP head phase angles (2 FO x 2 replications) for each individual were averaged together to form the first order phase data for each experimental condition. The first order data were then averaged across participants to obtain the second order data (group mean phase angles). Differences among the group mean phase angles for the various conditions were investigated. Examination of the distribution of the second order AP head phase data revealed it to be unimodal. Further, Rayleigh, Rao Spacing and Hodges-Ajne tests showed the data were non-uniform (e.g., not spread around 360º) (all <.01).

Figure 11 illustrates the second order means for AP head phase in relation to the target on the flat (left) and foam roller (right) surfaces respectively. The head was able to stay remarkably in-phase with the target at the lowest frequencies, and progressively phase lagged behind the target with higher frequencies of motion. Overall group mean head phase angle and mean circular standard deviation on the flat surface (230.56º ± 35.44º) lagged slightly behind the foam surface (238.21º ± 39.88º). A non-parametric, paired second order test between surface conditions confirmed that this surface effect was significant ($p<.01$).

Previous research has reported the transition for hip and ankle coordination at a value of ~.50 Hz (Bardy et al., 2002). Since a transition in coordination may be expected at this frequency, a non-parametric paired test was performed for second order analysis (given an asymmetric distribution) for each surface to test whether the .47 Hz head phase angle came from the same population as the .54 Hz phase angle. For both surfaces, AP head phase at .47 Hz (Flat, 236.72º ± 56.7º, Foam, 249.19º ± 39.46º) was found to be significantly different than that for .54 Hz (Flat, 205.93º ± 34.30º, Foam, 213.93º ± 36.86º), $p<.01$.

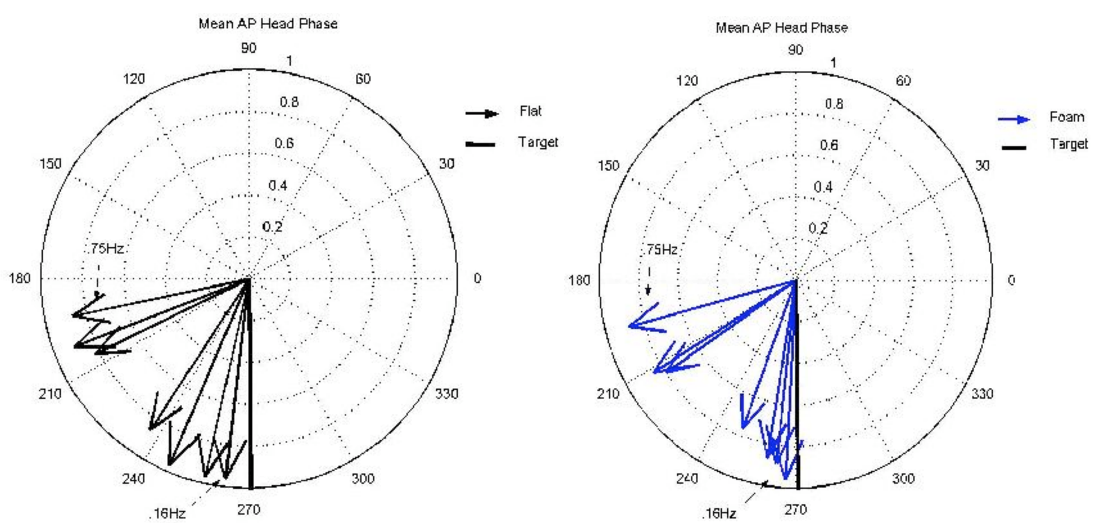


Figure (11). Mean second order AP head phase angles across surfaces at target frequencies. The flat surface is on the left, and foam roller is on the right. Mean vector length of 1 denotes no dispersion, while 0 denotes uniform dispersion across 360º. The target sine wave was arbitrarily set at 270º.

AP head phase gave further evidence that participants were able to perform the task reasonably well. Participants were slightly better at keeping phase on the foam roller as opposed to the flat surface and performed near perfect at low frequencies. Head phase lagging, lower AP power and less AP amplitude head movement as frequency increases are all consistent with the effects of musculoskeletal damping. Although the results of the AP head phase data do not show a marked transition (likely since there was no dramatic hip-ankle phase transition, see below), there was a significant difference between the .47 Hz and .54 Hz conditions on both surfaces. Since tests were not performed across all frequency pairs, it is not possible to know whether other frequency pairs were different. However, the .47-.54 Hz pair showed the largest phase difference, which corroborates the finding that ~.50 Hz is an important frequency about which transitions in postural modes may occur (cf. Bardy et al., 2002).

Overall postural motion

A. *ML head sway*

Participants were instructed to move their head in the AP direction. As such, head sway variability in the ML direction (rather than in the AP direction) was computed as a measure of stability during suprapostural performance. The standard deviation of the ML head translation positions for each trial was calculated and analyzed the same as described under peak-to-peak AP head translation. The ANOVA for ML head sway revealed significantly more mean ML head variability for increasing FO trials ($M=0.00723$, $SE=.001$) compared to decreasing FO trials ($M=0.00675$, $SE=.0001$), $F(1, 11)=13.64$, $p=.004$. No other main effects or interactions were significant. The main effect of FO means that participants were less stable in the ML direction for increasing FO trials compared to decreasing FO trials. In the absence of a main effect of frequency or other significant interaction effects, the main effect of FO is not easy to interpret.

B. *Joint angular motion*

In the first experiment, the multi-segmental mechanisms by which people maintain normal voluntary control over posture, were investigated. Here, the same multi-segmental measures were recorded while performing the suprapostural task. This method allowed for the assessment of the coordination of segments and their role in the accomplishment of the head-tracking task. To determine the contribution of each joint to the task, values for joint rotation (flexion/extension) were examined. The standard deviation of the joint rotation positions for each trial was calculated. Next, the standard deviations for the two replication trials for each individual were averaged together to form the individual mean standard deviation (IMSD) for each experimental condition. The IMSD values were averaged across participants to obtain group mean standard deviations for each joint and for each experimental condition. The group means (GMSD) for all joints averaged across FO and plotted as a function of OF can be seen in Figure 12. To be consistent with the literature, only hip and ankle ANOVA results are presented here; ANOVA summary tables for the other joints are found in Appendix 2. The analysis of variance (ANOVA) results for hip and ankle joint rotation variability are presented in Tables 10 and 11.

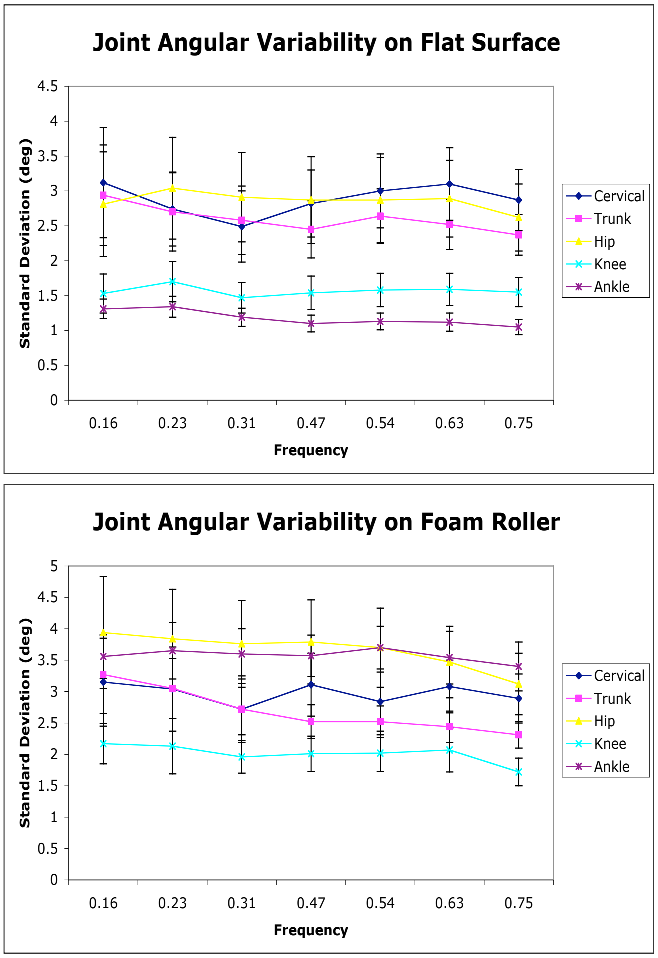


Figure (12). Mean joint angular standard deviation (GMSD) (± SE) values across frequencies. Note that ankle variability is much larger (over 3 times larger) on the foam surface compared to the flat surface.

Table 10. Hip Rotation Variability

Source	Sum of Squares	df	Mean Square	F
FO	3.34300	1	3.34300	4.997
OF	10.36300	6	1.72700	1.473
Surface	54.25500	1	54.25500	5.771
FOxOF	1.59600	6	0.26600	2.291
FOxSurface	0.08407	1	0.08407	0.833
OFxSurface	3.08500	6	0.51400	2.018
FOxOFxSurface	0.57800	6	0.09625	0.651
Subjects				
FOxS	7.35900	11	0.66900	
OFxS	77.38900	66	1.17300	
SurfacexS	103.40600	11	9.40100	
FOxOFxS	7.66400	66	0.11600	
FOxSurfacexS	1.11000	11	0.10100	
OFxSurfacexS	16.81400	66	0.25500	
FOxOFxSurfacexS	9.75500	66	0.14800	
Total		335		

Table 11. Ankle Rotation Variability

Source	Sum of Squares	df	Mean Square	F
FO	0.18700	1	0.18700	0.447
OF	2.13600	6	0.35600	0.710
Surface	482.50700	1	482.50700	60.945 *
FOxOF	1.72100	6	0.28700	1.648
FOxSurface	0.09905	1	0.09905	0.552
OFxSurface	0.82600	6	0.13800	0.502
FOxOFxSurface	1.47500	6	0.24600	1.711
Subjects				
FOxS	4.59700	11	0.41800	
OFxS	33.08000	66	0.50100	
SurfacexS	87.08800	11	7.91700	
FOxOFxS	11.48700	66	0.17400	
FOxSurfacexS	1.97400	11	0.17900	
OFxSurfacexS	18.09800	66	0.27400	
FOxOFxSurfacexS	9.48600	66	0.14400	
Total		335		

* denotes p<0.01

Multi-segmental joint flexion/extension angles provided the means to evaluate both absolute and relative joint motion in this experiment. Averaged across all conditions, absolute hip GMSD was greatest and knee GMSD was least (hip, 3.26 >

cervical spine, 2.92 > trunk, 2.64 > ankle, 2.38 > knee, 1.79). The flat curves for all joints across OF reflect the lack of any significant effect of OF (Figure 12). In the specific cases of the ankle and hip joints, the main effect of OF was not statistically significant as reflected by the same heights of the curves for angular motion across both flat and foam surfaces (Figure 12). For most joints, including the hips, the angular standard deviations on the foam surface were unchanged relative to those on the flat surface. However, the angular standard deviation for ankle rotation did change from one surface to the next. Ankle variability was smaller on the flat surface as confirmed by the statistically significant main effect of surface in the ankle ANOVA.

As might be expected with such a tracking task, hip movement in general was greater than any other joint, as the hip strategy is primary in generating sagittal body motion (Blackburn et al., 2003). Also, more joint angular variability (GMSD) was found for the ankle on the foam roller compared to the flat surface confirming results from experiment 1. It is not surprising that ankle variability changed as a function of surface, but a predicted effect of frequency for hip or ankle angular variability was not found. This is surprising because head AP ROM was most dramatically influenced by oscillation frequency. It appears that changes in head AP translation are not related to simple scaled changes in hip and ankle rotation variability. Therefore, hip and ankle rotations must be related to AP head motion in a more complex manner. To comprehend this relationship further, other more refined measures are explored in the following sections.

Spectral analysis of hip and ankle joint rotation

Performing a spectral analysis on hip and ankle joint rotation allowed for the determination of the relative amount of joint power used at each specific target frequency. This analysis allowed for a more refined investigation of the contribution of each joint to the tracking task. A representative example of hip and ankle motion for three OFs can be seen in the middle trace (overlapping the target) and bottom traces, respectively, of each of the panels in Figure 9. Figure 9 demonstrates that the hip, ankle and head all move during the head-tracking task, and that their motion is periodic. It is not surprising that the head moves periodically with the target, but clearly so do the hip and ankle. In fact, the periodicities of the hip and ankle joints look like they match the target's periodicity. It is also apparent that both the phase and amplitude of the hip and ankle traces are not always the same for different target OFs. For example, as OF increases, the amplitude (power) of ankle rotation decreases and the ankle lags behind the target (phase shift to the right in the lowest panel of Figure 9).

Figure 10 shows an example of the frequency spectra of hip rotation from a representative participant at two different OFs. From spectra like these we determine the power of each frequency component as the sum of squares of the Fourier coefficients for a given frequency. The sum power of all frequencies represents the total power of the trial. The total power also equals the variance of the angular positions for a given trial. Having power calculated, the power of each frequency component was expressed as a percentage of the overall power of the signal. Individual and group mean values for percentage of hip and ankle power exerted at each target frequency were calculated in the same way as described for AP head ROM. Hip and ankle ANOVA results for rotational power are presented in Tables 12 and 13. The group means for each joint averaged across FO and plotted as a function of OF can be seen in Figure 13. Differences among the group means for these conditions were examined.

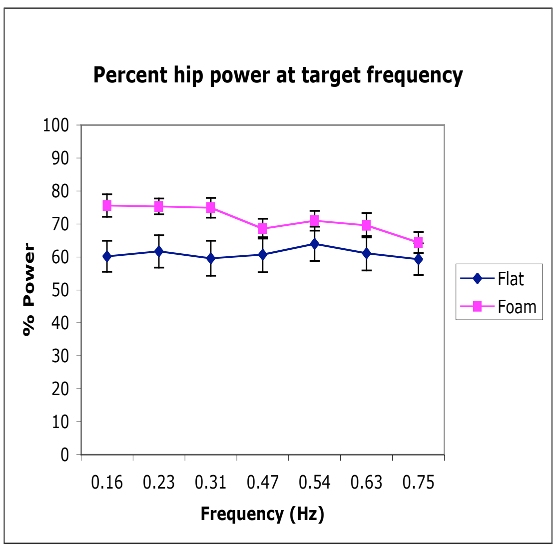
Table 12. Percent Hip Power at TF

Source	Sum of Squares	df	Mean Square	F
FO	0.01039	1	0.01039	0.434
OF	0.15800	6	0.02635	2.205
Surface	0.90300	1	0.90300	7.702
FOxOF	0.01553	6	0.00259	0.254
FOxSurface	0.00022	1	0.00022	0.014
OFxSurface	0.13100	6	0.02184	2.402
FOxOFxSurface	0.01453	6	0.00242	0.303
Subjects				
FOxS	0.26300	11	0.02391	
OFxS	0.78900	66	0.01195	
SurfacexS	1.29000	11	0.11700	
FOxOFxS	0.67300	66	0.01019	
FOxSurfacexS	0.16900	11	0.01537	
OFxSurfacexS	0.60000	66	0.00909	
FOxOFxSurfacexS	0.52800	66	0.00800	
Total		335		

Table 13. Percent Ankle Power at TF

Source	Sum of Squares	df	Mean Square	F
FO	0.00316	1	0.00316	0.124
OF	1.30200	6	0.21700	5.800 *
Surface	6.28600	1	6.28600	17.683 *
FOxOF	0.04405	6	0.00734	1.317
FOxSurface	0.01120	1	0.01120	0.626
OFxSurface	0.02853	6	0.00475	0.313
FOxOFxSurface	0.00876	6	0.00146	0.201
Subjects				
FOxS	0.28000	11	0.02546	
OFxS	2.47000	66	0.03742	
SurfacexS	3.91000	11	0.35500	
FOxOFxS	0.36800	66	0.00557	
FOxSurfacexS	0.19700	11	0.01791	
OFxSurfacexS	1.00300	66	0.01520	
FOxOFxSurfacexS	0.48000	66	0.00727	
Total		335		

* denotes p<0.01



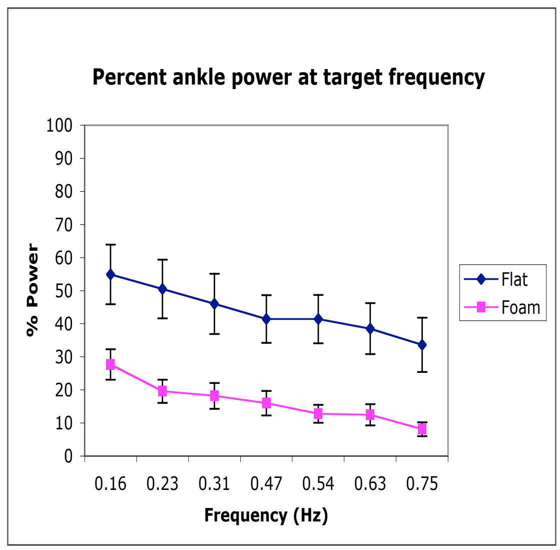


Figure (13). Mean percentage of power (± SE) of hip and ankle rotation at the 13th harmonic (target frequency) on each surface.

Spectral analysis of hip and ankle motion was able to identify the frequency components of both hip and ankle responses to body oscillation at a given frequency. The hip joint exhibited a much different frequency pattern from the ankle (see Figure 13). Relative power on the flat and foam surfaces was reversed for the hip and ankle. Tables 12 and 13 confirm this main effect of surface for the ankle although the effect of surface was not significant for the hip (p=.018). Specifically, ankle relative power was lower on the foam surface and higher on the flat surface. This result is interesting given that the ankle experiences much greater overall rotational variability (Figure 12) on the foam surface compared to the flat surface. It appears that surface affects relative power differentially from overall joint variability. This means that on the foam surface more rotational "wiggling" occurs at non-target frequencies. In other words, standing on the foam roller increases the overall rotational variability of the ankle and concurrently reduces the efficiency of the ankle to oscillate at the target frequency.

Figure 9 demonstrated that the amplitude (power) of ankle rotation dropped as oscillation frequency increased and was lowest at .75 Hz (see bottom trace). While the overall power of the trial dropped, the ankle joint also decreased target specific power output as oscillation frequency increased (represented by the negative slope of each curve in Figure 13). This main effect of OF was confirmed by the ankle ANOVA (Table 13). This low-pass filter effect of ankle rotational power as a function of frequency mimics the response of AP head ROM to OF. Based on the similarity of these two findings, it is likely that the percentage of ankle rotational power at least partially accounts for the reduction of AP head ROM with increasing OF.

Figure 13 also shows that the two power curves for the ankle joint are at all instances lower than the curves for the hip joint. This unexpected finding means the ankle joint exerted *universally* less power at the target frequency across all conditions compared to the hip joint. These results provide evidence that the hip's absolute contribution to the tracking task is greater than for the ankle. Additionally, the results suggest that the hip is used preferentially for rapid movements (in this case, high frequency movements) (cf. Horak & Nashner, 1986) since there was no statistical decrement in performance over OF. Therefore, the hip was less influenced by surface and OF constraints and more dedicated to the tracking task compared to the ankle.

To determine how power for the hip and ankle was spread over the power spectrum, the power ratio as described above (under *Spectral Analyses*) was calculated. The total power below the target frequency was divided by the total power above the target frequency. Ratios above one indicate that a greater relative power occurs for frequencies below (versus above) the target frequency. Hip power ratios ranged from a mean (mean ± *SE*) of 2.28 ± .30 at .16 Hz to 5.1 ± .82 at .75 Hz. The main effect of OF was statistically significant showing lower ratios at lower frequencies and higher ratios at progressively increasing frequencies, $F(6, 66)=9.95$, $p= .000$. A main effect of OF was also statistically significant for the ankle joint showing that ratios were lowest at low target frequencies and highest at high target frequencies, $F(6, 66)=10.52$, $p=.000$. Ratios for the ankle joint were universally higher throughout all conditions compared to the hip joint, ranging from a mean of 5.39 ± 1.48 at .16 Hz to 20.68 ± 4.47 at .75 Hz. No other main effects or interactions were significant for hip or ankle power ratios.

Recall that the analysis of the percentage of rotational power at the target frequency for the hip joint yielded no statistically significant effects. However, a main effect of OF for the hip power ratio showed that with progressively increasing OF, more relative power was spread below the target frequency compared to above the target frequency. In other words, as OF increased, there was increasingly more off-target power directed below the target frequency than above. The same was true for the ankle joint. The results suggest that there is a natural oscillatory rhythm for the ankle joint and that when the target frequency crosses above that natural rhythm there is a large increase in the power ratio. For example, the data (not shown) illustrate a dramatic rise in the ankle power ratio at .63 Hz. This observation is not consistent with the notion that maximal ankle oscillation is at .5 Hz since rotation beyond this frequency occurred (McCollum & Leen, 1989), rather it suggests the natural oscillation frequency is between .50-.63 Hz. Interestingly, a dramatic increase in the power ratio for the hip was not seen at any OF as it was for the ankle suggesting that either there may not be a natural frequency of the hip or the natural frequency was not reached.

The present results have practical implications for postural rehabilitation. If the intention is simply to train people to use an ankle strategy then more movement about that joint is desired and can be accomplished on a foam roller during upright quiet stance. However, if the ankle is to be trained during a suprapostural task, a flat surface with movements (e.g., OF) below .63 Hz will be most effective. On the other hand, a hip strategy is not well trained during quiet stance. Rather, the hip strategy is demonstrated to be effective across a wide range of OFs during large amplitude anterior-posterior movements. For both ankle and hip joints, practice across the range of effective OFs will most likely yield the best clinical results. Specific instabilities can be addressed effectively as well. For example, if the patient is unstable during slow, large amplitude AP movements, then coordination training should emphasize this activity. A reasonable progression would be to practice on a flat surface first (to engage both hip and ankle maximally) and once mastery is demonstrated, switch to a foam roller (that relies on hip more). At the same time, the training would also start at the lowest OF possible (to keep ankle engaged maximally) and then progress upwards for further challenge.

Phase relationships among the target, hip and ankle joints

This experiment was designed to examine the emergence of distinct postural strategies and the interaction between OF and support surface. The previous spectral analysis showed that the hip contributes a greater percentage of its power to the accomplishment of the head-tracking task compared to the ankle joint. The spectral analysis was informative of the relative magnitude of rotation of each segment at the target frequency. However, it was not capable of determining how well the segments were temporally matched or phase matched with respect to the target. The phase analysis presented here accomplished this goal.

A. Hip and ankle phase with respect to the target

Figure 9 illustrates representative segmental responses from raw data at three target frequencies from one participant. Notice that the head, hip and ankle maintain good sinusoidal motion over the range of frequencies. From Figure 9 we can also see that each segment is not perfectly aligned to the target, but rather are phase-shifted from the target. Therefore, while the hip and ankle exhibit a periodic motion like the target, neither joint oscillates in perfect temporal synchrony with the target. Hence, an analysis of the phase of each joint at each of the target frequencies was conducted. For consistency with the previous measures and with the existing literature, the analysis was restricted to the hip and ankle joints.

Figure 14 shows separately, the mean second order hip and ankle phase angles for each frequency and surface condition. The hip phase angles are seen in the upper two graphs, while the ankle phase angles are in the middle two graphs. All graphs on the left side of the figure represent values on the flat surface while those on the right represent the foam roller condition. Each arrow (vector) on each graph has both a magnitude and direction. A longer vector means less angular variability of the phase angle associated with that vector. The vector direction represents the actual phase angle. The phase angle of the target was arbitrarily designated as 270º. Clockwise rotations of vectors from 270º represent phase lags. Notice that the hip joint (top graphs) seemed phase-locked (as was the head) with the target frequency at frequencies below .54 Hz. This is represented as a clustering of vectors located around 270 degrees. Above this cutoff, the hip joint phase lagged, with the flat surface demonstrating greater hip angular variability. The phase lag is represented by a clockwise rotation of vectors seen clustering around 215º-220º. The vectors representing hip motion are all located in the lower semicircle. The ankle (middle graphs) vectors on the other hand are mostly located in the upper semicircle indicating that the ankle vectors are out of phase (anti-phase) with the hip vectors. Therefore, the ankle joint was approximately 180 degrees out of phase with the hip joint and target at low frequencies and phase lagged behind the hips at higher OF. This phase lag can be seen as the increased clockwise movement of the ankle vectors from 90º to 0º.

No statistical analysis was conducted on hip and ankle phase. Rather, statistical analysis was restricted to the more common measure of hip-ankle relative phase (below). However, the plots in Figure 14 clearly show the changing phase relationship of the hip joint and ankle joint with respect to the target. At low OFs the hip was phase-locked with the target while the ankle was nearly 180º out of phase with the target. At higher OF the hip begins to phase lag behind the target by as much as 70º, while the ankle phase lags behind the target by as much as 285º.

B. Hip-ankle relative phase (ϕ_{rel})

Previous experiments have used hip-ankle relative phase to measure the transition from in-phase to anti-phase coordination and vice-versa with changes in OF and support surface (Bardy et al., 1999; Bardy et al., 2002; Marin, Bardy, Baumberger et al., 1999). In order to verify the transition from in-phase to anti-phase, hip-ankle relative phase was initially examined on the flat surface. The foam roller condition was thus used to test whether the altered surface interacted with OF to produce the postural transition at a lower OF.

Participants were not given any instructions on how to accomplish the suprapostural task and yet a clear phase pattern for the hip and ankle emerged. Figure 9 illustrates that the peak of a hip oscillation lines up with the valley of an ankle oscillation at the sample OFs presented. This anti-phase relationship seemed consistent with the results of the group means as shown in the hip and ankle phase plots (Figure 14, upper 2 rows).

Hip-ankle relative phase was obtained from the FFT analysis from each trial. To determine the relative phase angle, the ankle phase was subtracted from the hip phase for each participant across each independent variable (i.e. all data points). Hip-ankle relative phase was collapsed across FO. Thus, four relative phase angles (2 FO x 2 replications) for each individual were averaged together to form the second order individual mean phase data for each experimental condition. The second order individual mean data was then averaged across participants to obtain the second order group mean phase angles. Differences among the group mean phase angles for the various conditions were investigated. Rayleigh test and Rao Spacing test showed the data were non-uniform (e.g., not spread around 360º) (both <.01).

Figure 14 (lowest row) shows the second order means for hip-ankle relative phase on the flat surface (left) and foam roller (right). Participants maintained anti-phase hip-ankle coordination at all times despite surface and frequency manipulation, confirming the results of hip and ankle phase. No evidence of a large transition in coordination from in-phase to anti-phase or vice-versa was encountered. A gradual progression from ~180º out of phase at the lowest OF to ~211º out of phase at the highest OF occurred on both surfaces. Mean relative phase and angular standard deviation on the flat surface was greater (202.56º ± 54.91º) compared to the foam roller (195.07º ± 38.39º). Figure 14 shows that the greater variability on the flat surface could be accounted for by the high angular standard deviation at low OFs and more stable relative phase at higher OFs. In all instances, hip angular motion was approximately opposite in direction of ankle angular motion. The largest single change in relative phase occurred between .31 Hz and .47 Hz. This was true for the flat surface and the foam roller. However, parametric, paired F tests on the second order data did not reveal differences between .31 Hz and .47 Hz on either surface. Further, examination of the distribution of the second order hip-ankle relative phase data revealed it to be unimodal.

One of the primary reasons for conducting this study was to determine the effect of multiple simultaneous constraints on transitions in postural coordination. However, only gradual changes in postural mode as determined by hip-ankle relative phase were found. Participants in this study adopted anti-phase relations between the hip and ankle throughout each condition (Figure 14, bottom row). No mean in-phase hip and ankle relationship was found at any time. These findings contrast to previously published research (Bardy et al., 1999; Bardy et al., 2002; Marin, Bardy, Baumberger et al., 1999; Marin, Bardy, & Bootsma, 1999) that found in-phase coordination patterns at low frequency and amplitude oscillations and anti-phase relations at the highest frequencies. The present study finds a different pattern of results. Here, an almost pure anti-phase hip-ankle relationship was found at low OFs while less anti-phase motion occurred at higher frequencies. It has been hypothesized that a configuration space for hip-ankle movement in the sagittal plane yields an attractor for erect stance that is essentially anti-phase in nature (Riccio & Stoffregen, 1988). The results of the present study provide support for this hypothesis. The tendency for anti-phase movement is also found in perturbation studies, where the trajectory of the continuum of ankle-hip responses to surface perturbation (cf. Horak & Kuo, 2000) favors anti-phase corrections.

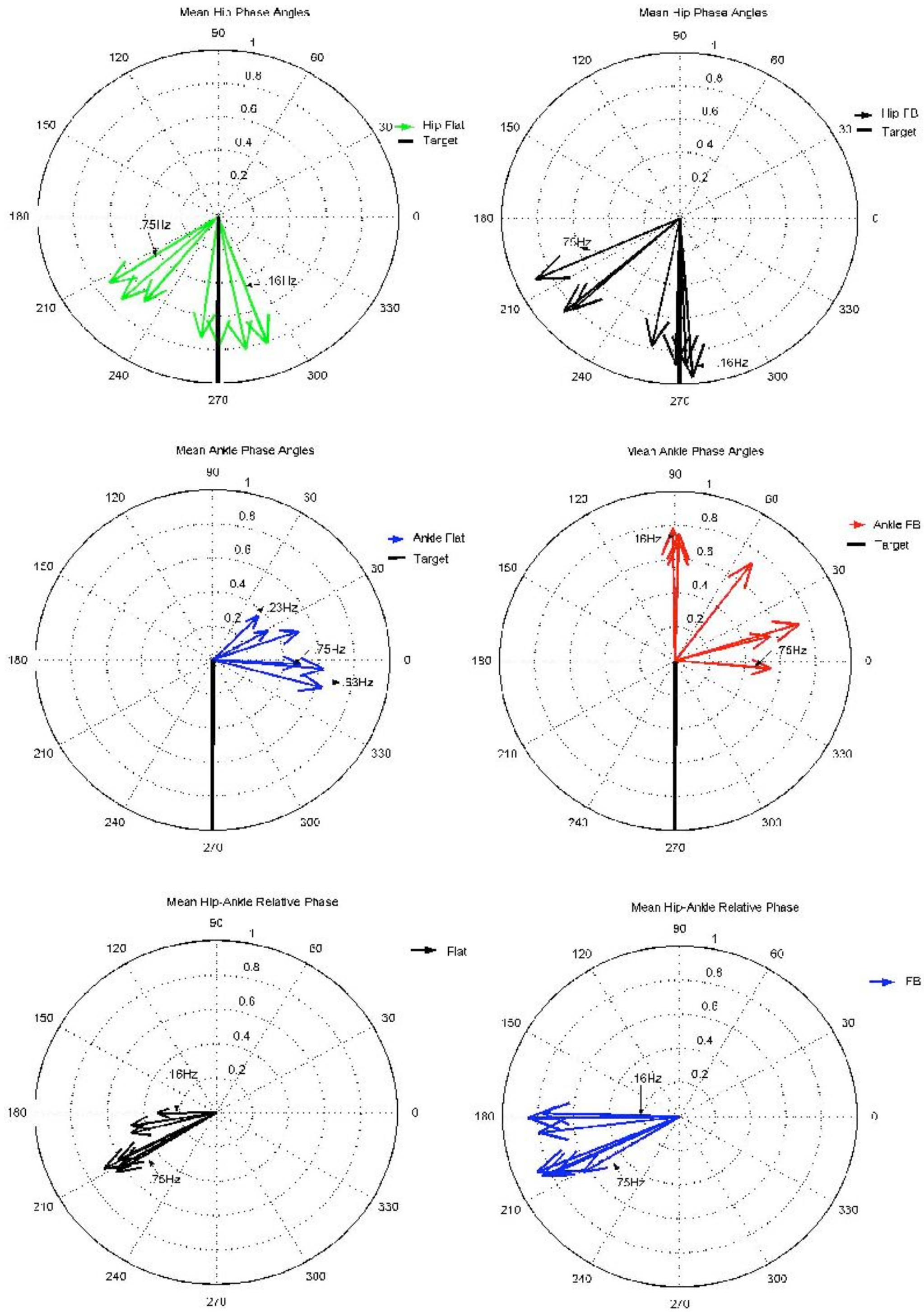


Figure (14). Mean second order hip (top) and ankle phase angles (middle). Mean hip-ankle second order relative phase angles are also shown (bottom).

However, because this study used only a single frequency (stimulus) per trial with a rest period in between, it is possible that the stimulus was too consistent, and as such, did not provoke a coordination change. Further, this study supports previous postural research that concludes that discrete kinematic strategies are likely not existent. Rather, strategies are probably best represented on a continuum (cf. Horak & Kuo, 2000).

Hip-ankle variability ratio

The hip/ankle ratios determined in the first experiment showed that the largest relative amount of hip movement compared to ankle movement occurred on the flat surface (see Figure 5). It was anticipated that these same postural coordination patterns would also hold across experiments 2 and 3. As in experiment 1, the standard deviations of hip and ankle joint rotation positions were calculated for each trial. The standard deviation of hip rotation positions was divided by the standard deviation of ankle rotation positions to form the hip-ankle variability ratio. The hip-ankle variability ratios for the two replication trials for each individual were then averaged together to form the IMVR as previously described. For each experimental condition a GMVR was computed. The GMVR for the hip and ankle averaged across FO and plotted as a function of OF can be seen in Figure 15. Only hip-ankle variability ratios are presented here; Appendix 2 provides inter-joint coordination ratios for the other joints as well as ANOVA summary tables. The ANOVA results for hip-ankle variability ratios are presented in Table 14.

Table 14. Hip/Ankle Ratio ANOVA Summary Table

Source	Sum of Squares	df	Mean Square	F
FO	0.19600	1	0.19600	0.532
OF	2.23600	6	0.37300	1.074
Surface	160.63000	1	160.63000	35.868 *
FOxOF	2.47100	6	0.41200	2.061
FOxSurface	0.28600	1	0.28600	1.082
OFxSurface	3.77300	6	0.62900	1.697
FOxOFxSurface	2.13300	6	0.35500	1.838
Subjects				
FOxS	4.05100	11	0.36800	
OFxS	22.91300	66	0.34700	
SurfacexS	49.26200	11	4.47800	
FOxOFxS	13.19100	66	0.20000	
FOxSurfacexS	2.90400	11	0.26400	
OFxSurfacexS	24.44800	66	0.37000	
FOxOFxSurfacexS	12.76500	66	0.19300	
Total		335		

* denotes, p<.01

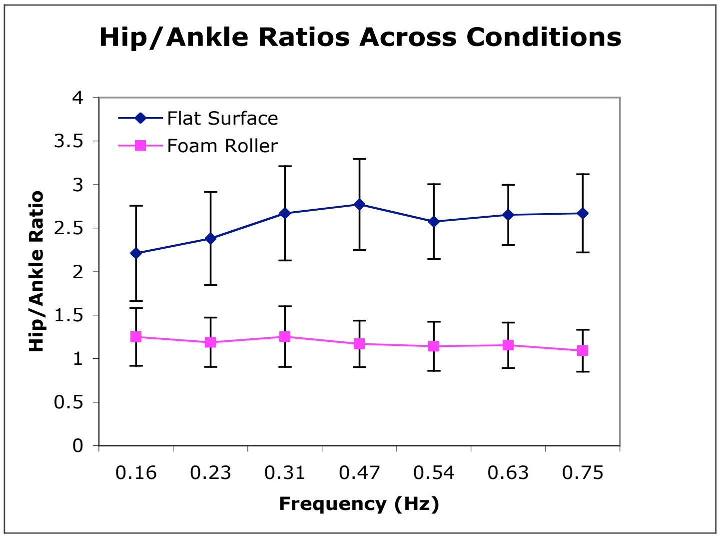


Figure (15). Mean hip/ankle ratios (± SE) collapsed across FO.

Note that hip/ankle ratios were quite stable on the foam roller versus the flat surface (Figure 15). The curve for the flat surface was higher at every instance than the curve for the foam roller indicating larger hip-ankle ratios on the flat surface (Figure 15). This main effect of surface was statistically significant as verified by the hip-ankle ratio ANOVA (Table 14). No other main effects or interactions were statistically significant. On the flat surface, participants used a range of hip/ankle ratios to accomplish the task. But on the roller, it was as if participants were unwilling to utilize any other mode of coordination other than an approximately equivalent hip and ankle strategy across all frequencies. Due to the unstable nature of the foam roller, it is possible that people tried to minimize COM excursion, which might be best accomplished by reducing the differential between ankle and hip angular movement.

Coordination of the multi-segmental regions proved to be quite interesting when compared to the AP head kinematics in this task. Hip/ankle ratios exhibited statistical significance across different surfaces (Table 14), whereas AP head ROM (Table 9) did not. This situation mimics the findings of hip and ankle joint variability discussed earlier. Together these findings confirm that changes in head AP translation are not related to simple scaled changes in hip and ankle rotation variability. Rather, hip and ankle rotations are related to AP head motion in a more complex manner. As discussed above, the more refined spectral and phase analyses at least partially account for the main effect of OF on AP head ROM.

Instructions to participants emphasized amplitude and phase matching, which they did reasonably well. Apparently, participants were able to modulate their joint coordination on different surfaces in order to direct AP head movement. This is evidenced by the main effect of oscillation frequency on head movement and the lack of a main effect of surface (Table 9). In addition to hip/ankle coordination, other segmental relationships showed clear evidence of change across both frequency and surface (see Appendix 2). Given the complexity of the postural strategies used to accomplish the task in this experiment, it seems prudent that researchers and clinicians pay attention to the entire kinematic chain during suprapostural activities.

The results of the kinematic, spectral and relative phase analyses of the hip and ankle joints have yielded valuable insight into the nature of voluntary motor strategies. As noted above the hip and ankle have approximately equal angular variability contributions to movement on the foam roller (Figure 15). However, examination of the spectral and phase hip data on foam suggests that the hip is more dedicated to the accomplishment of the tracking task than the ankle. This is reflected by a greater percentage of power exhibited by the hip at the target frequency (Figure 13) and by the in-phase relationship of the hip to the target (Figure 14).

Based on previous research (Alexandrov, Frolov, & Massion, 2001a, 2001b) and the present results, it is a reasonable assumption that the equivalent ankle movement contributed to maintenance of upright equilibrium rather than ‘driving’ the suprapostural tracking task on the foam roller. By most accounts (cf. Horak & Kuo, 2000), this relationship would constitute a hip strategy. The flat surface on the other hand yielded much higher hip/ankle ratios indicating a greater contribution of hip angular variability to the overall performance. Here again, the hip directs a greater percentage of its power to tracking the target frequency than does the ankle, although the ankle contribution is noticeably larger on the flat surface as compared to foam. The hip also displays an in-phase relationship with the target frequency on the flat surface, while the ankle is anti-phase. Although perturbation studies would predict an ankle strategy (e.g. limited hip and knee motion) on a flat surface versus a constrained surface, the current suprapostural data suggest that the accomplishment of the task required more of a hip strategy on both surfaces. The data does suggest that the ankle contributes more so to head tracking at lower frequencies of oscillation, but the hip is still dominant in terms of angular variability and contribution of power and phase to head tracking. Therefore, these results reinforce the notion that a continuum of motor strategies exist. The specific emergence of a strategy has been shown to be a function of support surface, and task. In addition, the use of more refined measures such as spectral and phase analyses allowed for a greater appreciation of the way in which segments are organized to accomplish the task.

However, the results raise the question of what should be primary in classifying a motor strategy. Does more hip angular motion during a task necessarily equate to a hip strategy, or should the contribution of joint power and/or phase analysis also determine the strategy? What about other factors not considered herein such as neurophysiology (e.g., muscle activation as with surface EMG)? Another limitation of this study was not quantifying the torque exerted about the respective joints, since torque has also been considered a method for determining motor strategies (Horak & Kuo, 2000; Kuo & Zajac, 1993). Despite these shortcomings, this study has provided information about the nature of individual and inter-joint relations in the accomplishment of an upright task. The results of this study suggest that a more pragmatic approach to classification of strategies may be appropriate. For example, although the hip was more dedicated to driving the forward and backward upper body movement, the ankle seemed to play more of an equilibrium maintenance role. To describe this scenario using a singular strategy (e.g. hip strategy) is therefore problematic as both equilibrium maintenance and tracking were the goals of the participant. Perhaps the best way to assess this scenario is to be descriptive, taking into account the dependent variables. A hypothetical example on the flat surface might be to say that participants engage an equivalent hip and ankle angular strategy with hip in phase with the target, contributing 64% of its power to the tracking task and ankle anti-phase to the target, contributing 45% to tracking. Addition of neurophysiological recordings and torque estimates could only improve on this assessment of motor strategies.

In short, this study was necessary to determine the nature of coordination dynamics at discrete frequencies in the presence of two different support surfaces. It has been shown that on a flat surface, people use a continuum of hip/ankle ratios to accomplish the head tracking task across frequency conditions. On the foam roller, people used a rather rigid (less variable) mode of coordination throughout. On both surfaces, a predominant anti-phase, hip-ankle relationship was seen. The involvement of each joint to the attainment of a given task and subcomponents (e.g. head tracking and equilibrium maintenance) of the task can be further delineated. No large transition in postural coordination was seen by any method of analysis in any condition. This may perhaps be surprising to some, given the results of several previous studies (Bardy et al., 1999; Bardy et al., 2002; Marin, Bardy, Baumberger et al., 1999; Marin, Bardy, & Bootsma, 1999). Lastly, production of movement through large amplitude suprapostural activity appears to recruit different motor strategies than a perturbation paradigm elicits.

Experiment 3 – Suprapostural Head Tracking without Rest Between Trials

Overview

Experiment 3 builds on the findings of experiment 2 such that all OFs were viewed consecutively within a block of trials without rest to examine the effect on postural coordination and to try to elicit postural transitions. There were no other changes between experiment 2 and 3. The aim of experiment 3 was to examine whether continuously oscillating and changing frequencies would exhibit a clear demarcation (transition) in strategy use. It is possible that Experiment 2 did not provide sufficient constraints to elicit postural transitions. Since hip/ankle ratios were significantly affected by surface during movement at discrete frequencies and relative phase was impacted by frequency, it was hypothesized that continuously ramping frequencies would lead to frequency modification of coordination. Furthermore, with the addition of the continuously oscillating postural motion, it was hypothesized that an interaction would occur between support surface and OF. This interaction would imply that neither variable was independent in the production of the task or postural coordination patterns necessary to accomplish the task. Rather, to accomplish the task under continuously changing constraints, coordination is hypothesized to emerge from interaction of all constraints. In addition, to coordination, the task itself (head AP movement) is hypothesized to exhibit hysteresis as would be consistent with the previous literature (cf. Bardy et al., 2002).

Participants

Twelve right-handed students (5 males, 7 females) from Miami University between the ages of 18-35 (mean ± *s*: age 21.1 ± 2.2 years, height 1.68 ± 0.13 m, mass 62 ± 15 kg) volunteered to participate in the experiment. These participants were different from those in Experiment 1 and 2. All other participant criteria from Experiment 1 applied to this experiment.

Task and Apparatus

The task and apparatus for this experiment were the same as for Experiment 2.

Design and Procedure

As in Experiment 2, participants in this experiment were instructed to actively track a continuously oscillating visual target while their segmental postural motion was assessed. Data collection and presentation of the stimulus began when the participant stated that he/she was ready. The difference in design between Experiment 2 and this experiment was that the different oscillation frequencies were viewed consecutively without rest for each of the 8 blocks of trials. This design/procedure was modified from Bardy et al. (2002). A block in this experiment consisted of either a stepwise increase in OF or a stepwise decrease in OF, such that all 7 frequencies were viewed consecutively (i.e., with no time lags between frequencies). Each oscillation frequency was considered a trial. As in Experiment 2, each trial lasted 12 oscillation cycles.

Each block was replicated to yield 56 trials (2 surfaces x 2 FO x 7 OF x 2 replications) for each participant in the experiment. The warm-up procedure for Experiment 2 was also used in this experiment. A five-minute rest break was allowed between blocks. Blocks alternated between increasing and decreasing FO. Four pseudo-random orders of blocked trials were used. Participants completed all blocks of trials on one surface before completing the blocks on the other surface. Each participant was randomly selected for each pseudo-random order of blocks. Compensatory events were recorded using the same method as in Experiment 1. The time to complete all 56 trials was approximately an hour and fifteen minutes.

Data Acquisition and Analysis

Postural motion was recorded using the same method as in Experiment 1. For comparison purposes, the dependent variables in the experiment were the same as those reported in Experiment 2. Measures of postural motion and joint coordination as well as spectral and phase analyses (including relative phase) were obtained and calculated identically to Experiment 2.

Statistical analyses were conducted using a 2x2x7 design, within subjects analysis of variance (ANOVA) with the 3 factors being support surface (foam beam, hard beam), FO (increasing, decreasing) and OF (0.16-0.75Hz). FO was included as a variable to determine if hysteresis effects were present. Alpha was equal to 0.01.

Results and Discussion

The main objective of this experiment was to test whether continuous trials of dynamic oscillation produced by the tracking task would affect the emergence of postural coordination strategies differently than with the single trial presentation from Experiment 2. Based on Bardy et al. (2002) it was predicted that OF at .5 Hz or above would elicit hip/ankle postural transitions. The results of experiment 2, however, suggest that the transition may be from anti-phase, to in-phase hip/ankle coordination with increasing OF. In addition, it was predicted that OF's ~.5 Hz or greater would interact with surface indicating a dependence on both constraints for the emergence of coordination strategies. This prediction comes from the existence of a significant OF x surface interaction for AP head ROM (Table 9), an approaching significance of OF x surface for percent hip power at TF (Table 12) and a significant difference for head-target phase between .47 Hz and .54 Hz on both surfaces. No participant had an incomplete trial; no equipment errors occurred; thus, all trials were included in the analysis.

Since participants in Experiment 2 and Experiment 3 essentially performed the same task, there were many common results between the two. However, differences did occur with the requirement to complete the 7 trials of each block in a continuous manner. These similarities and disparities are the focus of the present discussion.

Suprapostural performance

A. Peak-to-peak AP Head Translation

As in experiment 2, the aim of an individual participant was to maintain balance while tracking an oscillating (fore-aft) computer generated target with their head. They were instructed to oscillate "in phase" with the target and to "match" the amplitude produced by the target. Peak-to-peak AP head translation (ROM) served as the gauge to determine how well participants matched the amplitude component of the task. The ROM for AP head translation for each trial was calculated and formed the basic unit of postural movement analysis. The ROM values for the two replication trials for each individual were then averaged together to form the individual mean ROM (IMROM) for each experimental condition. ANOVA results for AP head ROM are presented in Table 15. The interested reader can find all of the IMROM values in Appendix 3. The IMROM values were averaged across participants to obtain group mean ROM for each experimental condition. The group means (GMROM) are given in Figures 16 and 17. Differences among the group means for the various conditions were investigated. Note that the IMROM and GMROM measures reported also have their own variability. The IMROM values constituted the cell entries for the ANOVA.

Table 15. ANOVA Table for AP Head ROM

Source	Sum of Squares	df	Mean Square	F	
FO	0.00398	1	0.00398	7.320	
OF	0.09591	6	0.01598	55.960	*
Surface	0.00175	1	0.00175	0.396	
FOxOF	0.00246	6	0.00041	1.829	
FOxSurface	0.00074	1	0.00074	1.776	
OFxSurface	0.00405	6	0.00067	3.505	*
FOxOFxSurface	0.00308	6	0.00051	3.085	*
Subjects					
FOxS	0.00597	11	0.00054		
OFxS	0.01885	66	0.00029		
SurfacexS	0.04868	11	0.00443		
FOxOFxS	0.01479	66	0.00022		
FOxSurfacexS	0.00456	11	0.00041		
OFxSurfacexS	0.01271	66	0.00019		
FOxOFxSurfacexS	0.01097	66	0.00017		
Total		335			

* denotes p<.01

Performance of the tracking task was again good (as evidenced by ROM > 14cm at low OFs) and consistent across both surfaces. A main effect of oscillation frequency showed that head translation was greatest at the 0.16 Hz OF (M=15cm, SE=1cm) and least at the 0.75 Hz OF (M=9.9cm, SE=0.8cm). Based on the results of the previous experiment it is not surprising that OF was an effective factor in determining translation distance. These results further demonstrate the low pass filter effect of oscillation frequency on head translation distance.

No main effect of surface was found. However, two interactions showed surface influenced translation distance. An OF by surface interaction (Figure 16) demonstrates that head translation was greater on the flat surface compared to the foam roller, particularly during low OF. This result was the same for Experiment 2 and indicates that participants seemed unwilling (possibly because of perceived instability) to translate their heads as far during low frequencies on a more challenging surface than the flat surface. An OF by FO significant interaction was not obtained in the experiment as it was in the previous experiment. However, a three-way interaction was significant. A frequency order by OF by surface interaction was significant. The interaction demonstrated that on the flat surface, OF and FO illustrate a clear hysteresis effect (see Figure 17). Both properties of hysteresis are exhibited in this interaction; namely history effects and different values of ROM at the same OF for the two FO. In particular, history effects were demonstrated by ROM values during increasing FOs being systematically greater than those for decreasing FOs. In addition, at each OF, ROM was different for each FO, demonstrating the second property of hysteresis.

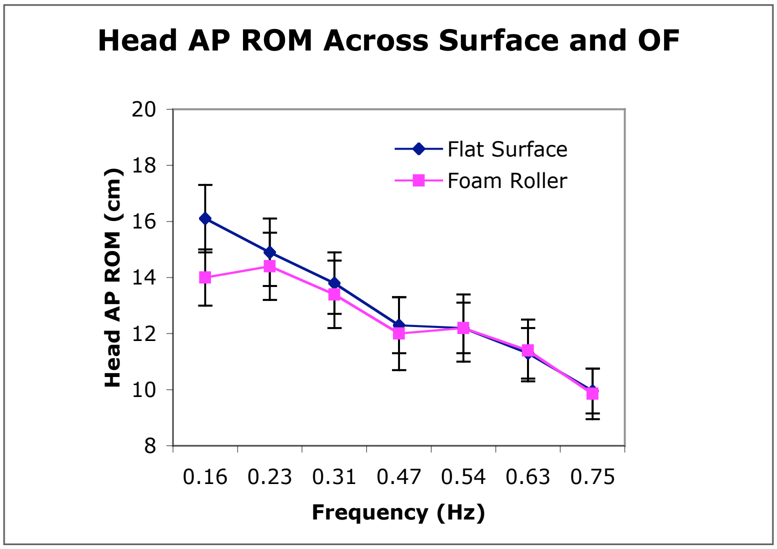


Figure (16). AP head ROM (cm) across surface and OF (± SE).

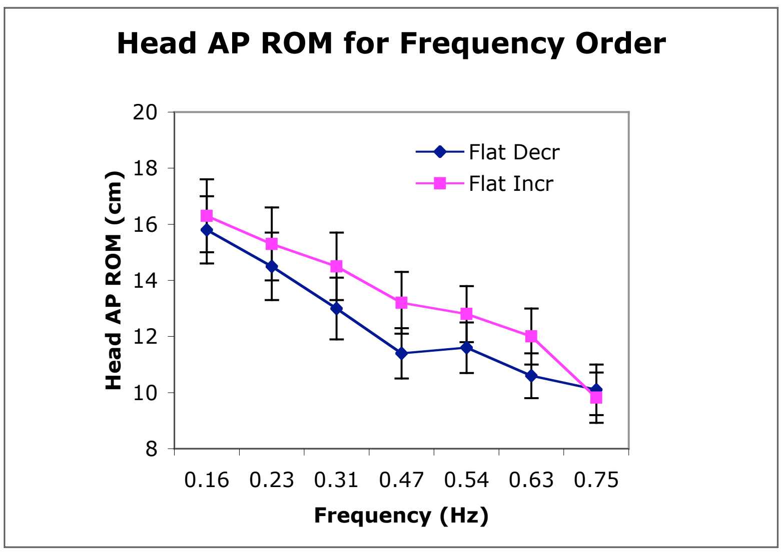


Figure (17). AP head ROM (cm) for FO (± SE). Abbreviations: Flat Decr (Flat Surface, Decreasing FO), Flat Incr (Flat Surface, Increasing FO)

B. Spectral analysis of AP Head Translation

Power spectrum analysis was attained for AP head translation to determine how well participants "matched" the target frequency by determining the percentage of AP head power at each target frequency (TF). See Figure 10 for a representative example of a power spectrum analysis. The procedures for determining the percentage of AP head power as well as the statistical analysis were identical to the previous experiment. Recall from the previous experiment that both the percentage of AP head power and AP head peak-to-peak translation data showed a low-pass filter frequency response. The ANOVA for the percentage of AP head power at the TF is shown in Table 16. Group means averaged across FO and plotted as a function of TF (OF) are shown in Figure 18.

Table 16. ANOVA Table for Percentage of AP Head Power at TF

Source	Sum of Squares	df	Mean Square	F
FO	0.00748	1	0.00748	0.673
OF	1.59700	6	0.26600	65.517 *
Surface	0.76400	1	0.76400	37.225 *
FOxOF	0.04106	6	0.00684	0.889
FOxSurface	0.00049	1	0.00049	0.091
OFxSurface	0.10000	6	0.01670	2.838
FOxOFxSurface	0.04649	6	0.00775	2.582
Subjects				
FOxS	0.12200	11	0.01112	
OFxS	0.26800	66	0.00406	
SurfacexS	0.22600	11	0.02052	
FOxOFxS	0.50800	66	0.00770	
FOxSurfacexS	0.05871	11	0.00534	
OFxSurfacexS	0.38800	66	0.00589	
FOxOFxSurfacexS	0.19800	66	0.00300	
Total		335		

* denotes p<.01

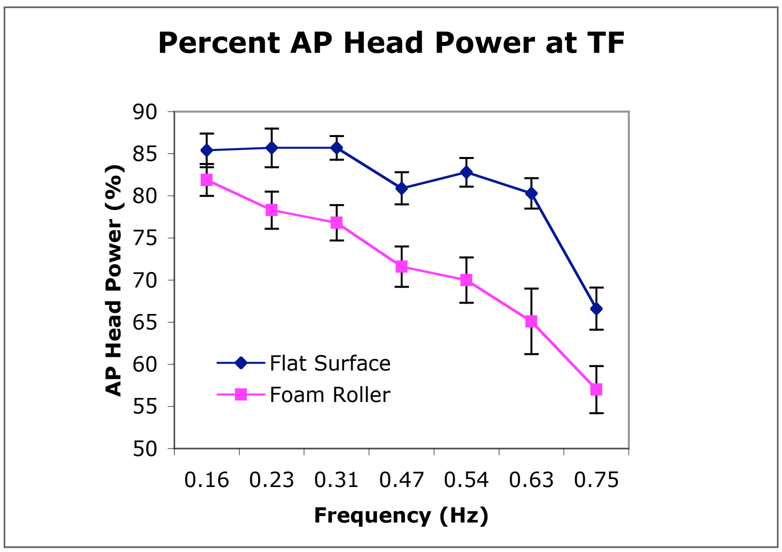


Figure (18). Percent AP head power at TF across surfaces (± SE).

Unlike the second experiment, where percent AP head power at the TF showed only an OF effect, this experiment showed main effects of both surface and OF (Figure 18). In addition, an OF x surface interaction approached significance (p=.016). Less relative power was exhibited during progressively increasing OF confirming the main effect of frequency and the low-pass filter effect. A main effect of surface showed that power was greater in every instance on the flat surface.

AP head translation results showed a pattern comparable to Experiment 2, but with a few key differences. As was expected, OF was a major determinant in the range of AP head movement. The higher the OF, the lower the magnitude of AP head movement (Figure 16), exhibiting low-pass filter characteristics similar to experiment 2. Although surface was not an independent factor in changing head range of motion, participants were able to translate further on the flat surface at lower OF. A predicted hysteresis effect (Figure 17) was significant for head movement on the flat surface. A potential explanation for this phenomenon is the energy loss exhibited by viscoelastic materials (e.g. muscles, tendons) when they are subjected to loading (e.g., increasing FO) and unloading (e.g., decreasing FO) cycles (Panjabi & White, 2001) and is often considered characteristic of a dynamic system (cf., Bardy et al., 2002). Lastly, a surface effect was observed for percent AP head power at the TF (Table 16, Figure 18). This finding contrasts to the previous experiment in which only OF impacted target specific head power. The combination of an emergent surface effect (Figure 18) and an OF x FO x surface interaction (Figure 17) provides only marginal support for the apriori hypothesis that higher OF would interact with surface.

C. AP Head Phase

AP head phase was attained to determine how well participants oscillated "in phase" with the target. Recall that the previous experiment demonstrated an overall difference between mean head phase on the flat surface compared to the foam surface such that the head lagged behind on the flat surface versus the foam. In addition, participants matched head phase best during low OF and lagged behind the target at higher OF. AP head phase was determined by the same methods and statistical analysis as described in experiment 2. The distribution of the second order AP head phase data was unimodal. Further, Rayleigh, and Rao Spacing tests showed non-uniformity (e.g., not spread around 360º) (<.01).

Figure 19 illustrates the second order means for AP head phase in relation to the target on the flat (left) and foam roller (right) surfaces respectively. The head was able to stay close to the target at the lowest OF, and progressively phase lagged behind the target at higher OF. Visual inspection of Figure 19 shows that the flat (left) and foam (right) conditions overlap almost perfectly demonstrating no effect of surface on head phase. In addition, mean head phase angle and mean circular standard deviation within the flat and foam conditions were similar (237.96º ± 25.39º flat, 237.30º ± 28.9º foam). Since the hypothesized transition for hip and ankle coordination was expected to occur at ~ 0.5 Hz, a parametric paired test (given a symmetric distribution) was performed within each surface to test whether the .47 Hz head phase angle was significantly different than the .54 Hz phase angle. For both surfaces, mean AP head phase direction at .47 Hz was found to be different than that for .54 Hz, $p<.01$.

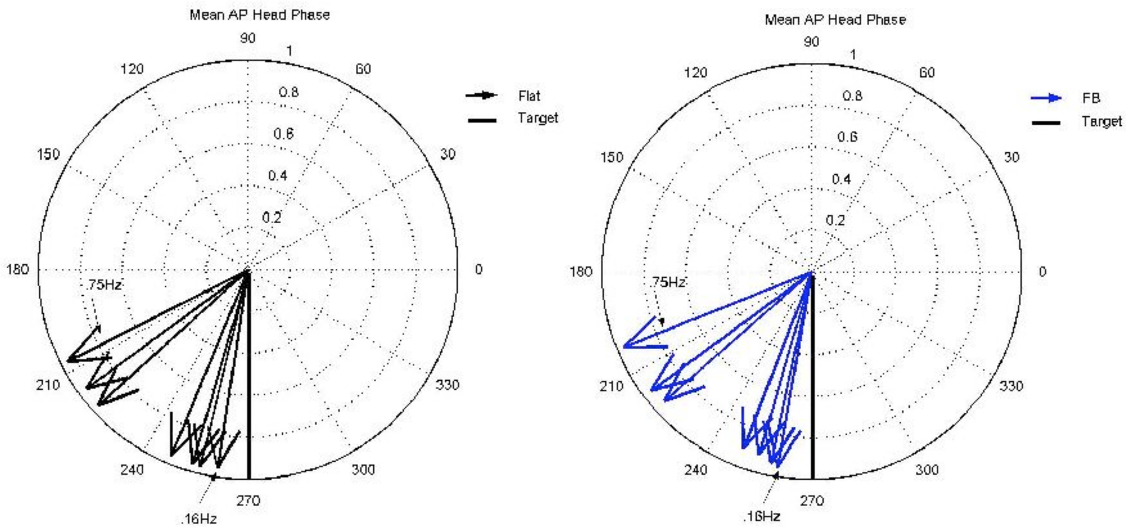


Figure (19). Mean second order AP head phase angles across foam surface (right), flat surface (left) and target frequencies. Mean vector length of 1 denotes no dispersion, while 0 denotes uniform dispersion across 360º. The target sine wave was arbitrarily set at 270 degrees.

The results of AP head phase for this experiment follow those of the previous experiment with one difference. In experiment 2, mean head phase lagged on the flat surface compared to the foam surface. In this experiment, head phase was nearly identical across surfaces (Figure 19). It is also noteworthy that the mean circular standard deviation across surfaces was much larger for experiment 2 than for this experiment. The reduced circular standard deviations in this study suggest that head phase was more stable and under more control while continuously ramping OF than compared to single trial presentations followed by a rest period.

Overall postural motion

A. ML head sway

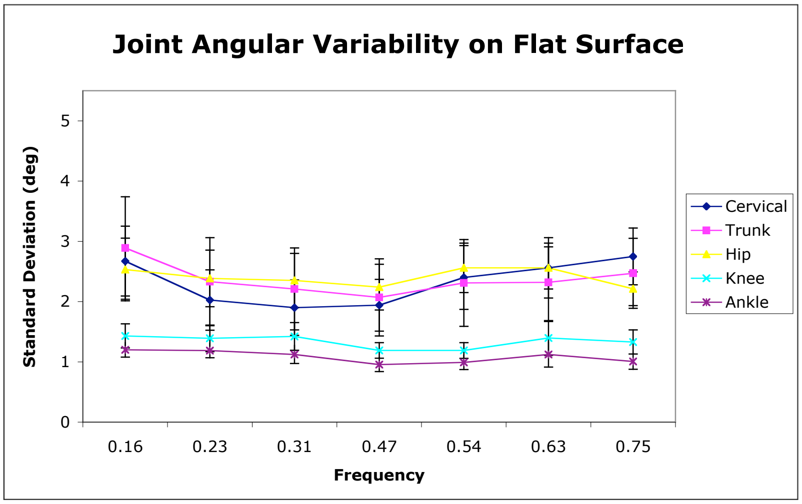
Recall that ML head sway was used in experiment 2 as an indicator of postural stability for the head-tracking task because ML head movement was not the direction of task oscillation. Head sway in the ML direction was calculated the same as in Experiment 2. ML head sway was found to be greater for the increasing FO condition compared to the decreasing FO condition in the second experiment. Although no apriori hypotheses were made for the ML direction in this study, head sway variability revealed one main effect for frequency, $F(6, 66)=4.48$, $p=.001$. Specifically, ML head sway variability was greater at low OF and lower at high OF. No other main effects or interactions existed for ML head variability.

Increased sway in the mediolateral direction has been found to be indicative for risk of falling and age-related disease (Maki, Holliday, & Topper, 1994; Mitchell, Collins, De Luca, Burrows, & Lipsitz, 1995). In the previous experiment a FO effect was significant showing people to have more ML sway during increasing frequency trials compared to decreasing frequency trials. That result was not easy to explain given the absence of any other effects. However, when participants increased the AP frequency of their bodily oscillation in this experiment, they actually produced *less* mediolateral head sway. The reduced ML head sway at higher OF is a clear indication of greater ML stability. This result contrasts with common postural rehabilitation advice to move slowly in effort to move "safely". However, the present results suggest that not taking advantage of the physical properties of the body in motion could inhibit patients from producing momentum and ease of movement resulting in reduced stability. In summary, it appears that both ML and AP head sway behave as a low pass-filters when trials are completed successively without delay. Furthermore, trials that are completed without delay yield greater ML head stability when performed at high OF.

B. *Joint angular motion*

Multi-segmental motions were demonstrated in the first experiment involving quiet posture, and during a dynamic, suprapostural task in the second experiment. This provided the justification to examine inter-segmental motion in this study. Results from experiment 2 showed that the hip moved more than any other joint during the tracking task. While the hip was not affected by any variable, ankle rotation was greater on the foam surface compared to the flat surface. This result was surprising given that AP head ROM was most dramatically influenced by OF. To determine the contribution of each joint in performing the continuous fore-aft oscillations in the study, values for joint rotation (flexion/extension) were determined. The standard deviation of the joint rotation positions were calculated the same as in Experiment 2. The group means (GMSD) for all joints averaged across FO and plotted as a function of OF are shown in Figure 20. Consistent with the literature and previous experiment, only hip and ankle ANOVA results are presented; ANOVA summary tables for the other joints are found in Appendix 3. The ANOVA results for hip and ankle joint rotation variability can be seen in Tables 17 and 18.

Multi-segmental joint flexion/extension angles allowed the comparison of absolute and relative joint motion. Averaged across all conditions, absolute hip GMSD was greatest and knee GMSD was least (hip, 2.73 > ankle, 2.59 > cervical spine, 2.35 > trunk, 2.33 > knee, 1.69). Figure 20 clearly shows that all measured joints were active during the suprapostural task. The curves for joint rotation variability generally appear higher on the foam surface than for the flat surface (Figure 20). Specifically the curves for ankle and hip were higher on the foam surface reflecting a significant main effect of surface for both joints as confirmed by the ANOVAs (Table 17-18). The finding that ankle rotation variability was larger on the foam versus the flat surface is consistent with both previous experiments. Hip joint variability was also larger on the foam surface compared to the flat surface (Table 17). This finding was seen in the first experiment during quiet stance, but not in the second experiment with rest between trials. Apparently continuous ramping of body oscillation either up or down allows the surface to impact hip rotation variability although the mechanism by which this occurs is unknown.



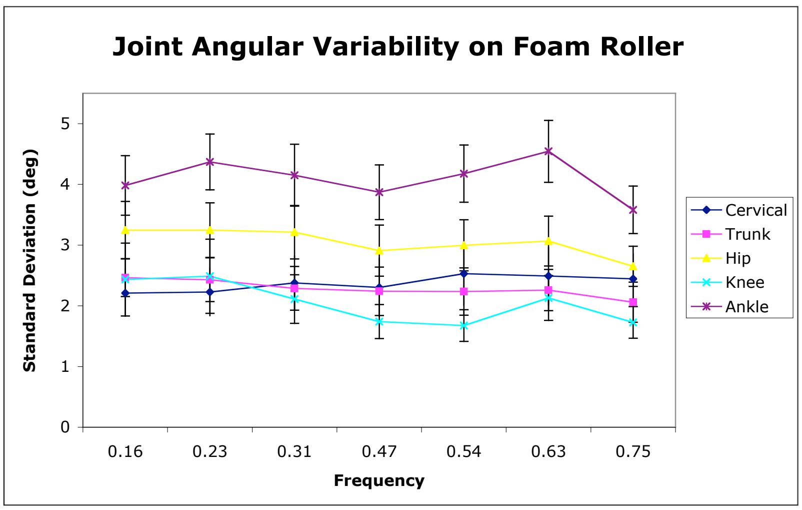


Figure (20). Mean joint angular standard deviation (GMSD) (± SE) values across OF. Note that ankle variability is much larger on the foam surface, compared to the flat surface.

Table 17. Hip Rotation Variability

Source	Sum of Squares	df	Mean Square	F
FO	4.14200	1	4.14200	6.514
OF	7.52700	6	1.25400	2.405
Surface	34.56500	1	34.56500	12.390 *
FOxOF	2.90800	6	0.48500	1.919
FOxSurface	0.01863	1	0.01863	0.131
OFxSurface	2.41100	6	0.40200	1.611
FOxOFxSurface	3.41600	6	0.56900	3.965 *
Subjects				
FOxS	6.99400	11	0.63600	
OFxS	34.42000	66	0.52200	
SurfacexS	30.68600	11	2.79000	
FOxOFxS	16.66800	66	0.25300	
FOxSurfacexS	1.56400	11	0.14200	
OFxSurfacexS	16.46300	66	0.24900	
FOxOFxSurfacexS	9.47700	66	0.14400	
Total		335		

* denotes p<.01

Table 18. Ankle Rotation Variability

Source	Sum of Squares	df	Mean Square	F
FO	0.00690	1	0.00690	0.017
OF	10.37700	6	1.73000	3.191 *
Surface	762.37400	1	762.37400	44.956 *
FOxOF	0.77300	6	0.12900	0.350
FOxSurface	0.10400	1	0.10400	0.178
OFxSurface	5.75700	6	0.96000	1.741
FOxOFxSurface	3.05300	6	0.50900	1.402
Subjects				
FOxS	4.48600	11	0.40800	
OFxS	35.77100	66	0.54200	
SurfacexS	186.54200	11	16.95800	
FOxOFxS	24.32800	66	0.36900	
FOxSurfacexS	6.45100	11	0.58600	
OFxSurfacexS	36.38600	66	0.55100	
FOxOFxSurfacexS	23.95000	66	0.36300	
Total		335		

* denotes p<.01

A hip joint three-way interaction of FO by OF by surface (Table 17) revealed a complex pattern whereby hip rotation variability: a) was greater at.16, .54 and .63 Hz (particularly during increasing OF trials) and less at the other frequencies and; b) was universally greater on the foam surface compared to the flat surface. This pattern is similar to the results found for the percentage of hip rotation power at the target frequency (below). In addition, a main effect of OF on ankle rotation variability (Table 18) revealed another complex result where large ankle rotation occurred at low OF (.16, .23, .31 Hz) and at .63 Hz with less rotation at the other frequencies.

It is noteworthy that the ankle was influenced by OF (Table 18) in this experiment compared to experiment 2, and that the hip was influenced by both surface and a three-way interaction (Table 17), when no significant effects were present in experiment 2. As with the last experiment, these effects do not map well onto any of the AP head movement results. Therefore, hip and ankle rotations must be related to AP head motion in a more complex manner. More refined measures of hip and ankle relations are presented in the following sections to address this concern. In addition, the lack of surface x OF interactions for the hip and ankle joints individually, fails to support the hypothesis regarding the interactive nature of these variables.

Spectral analysis of hip and ankle joint rotation

As was demonstrated previously, the hip, ankle and head all move with a periodicity similar to the target oscillation (see Figure 9). Additionally, the amplitudes of the hip and ankle traces did not always match the target indicating power loss for rotation under certain conditions (Figure 9). Recall from experiment 2 that the ankle was less effective at producing power at the target frequency on the foam roller compared to the flat surface, and while oscillating at progressively increasing OFs (Figure 13). The evidence showed that the hip was better able to oscillate at the TF under every experimental condition, whereas the ankle was less effective at producing rotation at the TF. Thus, the spectral analysis permitted a more refined investigation of hip and ankle motion in relation to the performance of the task. Under the present conditions of continuous bodily oscillation without rest between trials, it was expected that this more refined analysis would uncover an interaction between OF and surface as predicted at the beginning of this study.

Individual and group mean values for percentage of hip and ankle power at the target frequency were calculated the same as described in experiment 2. Hip and ankle ANOVA results for rotational power are presented in Tables 19 and 20. The group means for each joint averaged across FO and plotted as a function of OF can be seen in Figures 21 and 22. Differences among the group means for these conditions were examined.

Table 19. Percent Hip Power at TF

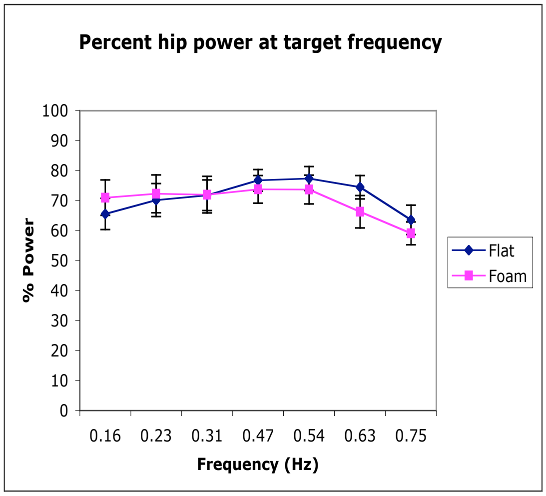
Source	Sum of Squares	df	Mean Square	F
FO	0.00394	1	0.00394	0.313
OF	0.66900	6	0.11100	7.867 *
Surface	0.02347	1	0.02347	0.227
FOxOF	0.17700	6	0.02957	3.597 *
FOxSurface	0.01548	1	0.01548	2.344
OFxSurface	0.14900	6	0.02479	1.312
FOxOFxSurface	0.03006	6	0.00501	0.559
Subjects				
FOxS	0.13900	11	0.01260	
OFxS	0.93500	66	0.01416	
SurfacexS	1.13700	11	0.10300	
FOxOFxS	0.54200	66	0.00822	
FOxSurfacexS	0.07267	11	0.00661	
OFxSurfacexS	1.24800	66	0.01890	
FOxOFxSurfacexS	0.59100	66	0.00896	
Total		335		

* denotes p<.01

Table 20. Percent Ankle Power at TF

Source	Sum of Squares	df	Mean Square	F
FO	0.00075	1	0.00075	0.027
OF	0.29200	6	0.04864	1.841
Surface	8.04800	1	8.04800	36.708 *
FOxOF	0.05008	6	0.00835	0.594
FOxSurface	0.00365	1	0.00365	0.283
OFxSurface	0.04739	6	0.00790	0.424
FOxOFxSurface	0.08462	6	0.01410	0.879
Subjects				
FOxS	0.30200	11	0.02746	
OFxS	1.74300	66	0.02641	
SurfacexS	2.41200	11	0.21900	
FOxOFxS	0.92800	66	0.01406	
FOxSurfacexS	0.14200	11	0.01289	
OFxSurfacexS	1.23000	66	0.01863	
FOxOFxSurfacexS	1.05900	66	0.01605	
Total		335		

* denotes p<.01



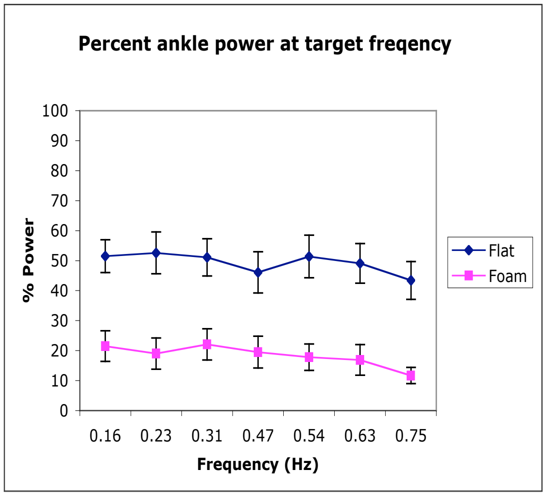


Figure (21). Mean percentage of power (± SE) for each joint at the 13th harmonic (target frequency) on both surfaces.

The examination of relative hip rotation power yielded no statistically significant effects in the previous experiment. However, this experiment yielded different results. Taking the average of the two surface curves for the hip in Figure 21 indicates that the percentage of power at the target progressively increases from .16 Hz to .54 Hz and then drops off at .63 Hz and .75 Hz. This main effect of OF was confirmed by the hip ANOVA (Table 19). The pattern of a higher percentage of hip power over the lower OFs and lower relative power at the highest OF is not indicative of any corresponding change with either hip rotation variability or AP head ROM. Figure 22 shows the percentage of hip power during increasing and decreasing FO trials as a function of frequency. The decreasing FO curve begins higher at the lowest OF and ends lower than the increasing FO curve at the highest OF. The hip ANOVA confirms that this FO by OF interaction is significant (Table 19), although no clear pattern emerges from the results (Figure 22).

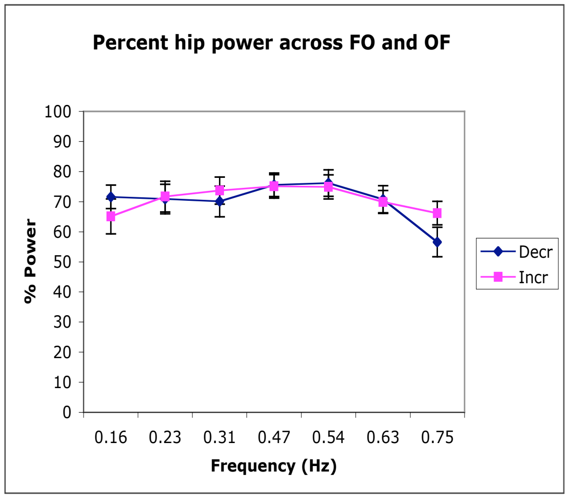


Figure (22). Mean percentage of power (± SE) for the hip joint at the 13th harmonic (target frequency) across FO and OF. Abbreviations: Decreasing FO (Decr), Increasing FO (Incr)

Figure 21 also shows that the two power curves for the ankle joint are again in both cases lower than the curves for the hip joint. These results provide confirmatory evidence that the hip's absolute contribution to the tracking task is greater than for the ankle regardless of whether a break is taken between trials or not. The results from experiments 2 and 3 are conclusive in that the hip is used preferentially for large amplitude movements irrespective of OF. Therefore, the hip was less influenced by surface and OF constraints and more dedicated to the tracking task compared to the ankle.

Figure 21 (right) shows the ankle percentage of power as a function of OF. Clearly the foam surface curve is well below that of the flat surface curve. This main effect of surface was confirmed by the ANOVA results for ankle percent power (Table 20). The main effect of surface for the ankle is not surprising given the same results in experiment 2. For a second time it appears that surface affects relative power differentially from overall joint variability for the ankle. Specifically, standing on the foam roller increases the overall rotational variability of the ankle and concurrently reduces the effectiveness of the ankle to oscillate at the target frequency. However, no main effect of OF was present for the ankle which does contrast to the previous experiment. Examination of Figure 21 and Figure 13 show that the frequency response of the ankle was dampened in experiment 2, but not presently. Since the only thing that changed between experiments was the continuous ramping of the task, it can be inferred that continuous active oscillation removed the OF dampening effect at the ankle. This effect could be due to reducing the stiffness of the ankle musculature (through continuous motion), by lowering thixotropic effects and decreasing viscosity (cf. Knutson & Owens, 2003). The decrease in viscosity would reduce damping by removing viscoelastic friction.

To understand how power for the hip and ankle was spread across the power spectrum, the power ratio was calculated as before. Hip power ratios ranged from a mean (mean ± *s*) of 3.07 ± .40 at .16 Hz to 6.16 ± .72 at .75 Hz. This main effect of OF was statistically significant showing lower ratios at lower OFs and higher ratios with progressively increasing OF, $F(6, 66)=9.67$, $p= .000$. No other main effects or interactions were significant for the hip. For the ankle, power ratios were also lowest at low OFs and highest at high OFs, $F(6, 66)=19.49$, $p=.000$. As in the previous experiment ratios for the ankle were universally higher throughout ranging from a mean of 4.18 ± .66 at .16 Hz to 14.39 ± 1.75 at .75 Hz. One ankle interaction was also statistically significant, OF x surface, $F(6, 66)=3.67=.003$, demonstrating that ratios were greater on the flat surface for the lowest four frequencies (.16 Hz- 47 Hz), but lower on the flat surface for frequencies above .5 Hz.

Hip power ratios for this experiment mimicked those from the previous experiment with lower ratios at the lowest OFs and higher ratios at the highest OFs. This was also true for the ankle joint. Unlike the previous experiment though, no dramatic rise in the ankle power ratio was observed at any frequency, indicating that continuous practice without rest may improve the capacity of the ankle to oscillate between .63 Hz and .75 Hz. Ankle power ratios also demonstrated an additional interaction, an OF by surface interaction. As predicted, this interaction showed relatively higher frequency ankle oscillation was obtained above .5 Hz on the flat surface as opposed to the foam surface. These results indicate that continuous oscillation on the flat surface seemed to provide some degree of stability to the ankle, allowing for faster frequency motion not afforded by the foam surface.

Measures of Joint Coordination

A. Hip and ankle phase with respect to the target

Recall from the previous experiment that at low OFs the hip was phase-locked with the target while the ankle was out of phase with the target. At higher OFs the hip phase lagged behind the target by as much as 70º, while the ankle phase lagged by as much as 285º. The spectral analyses (above) for the hip and ankle showed that the hip was more dedicated to the tracking task than was the ankle as evidenced by a greater relative magnitude of rotation at the target frequency. In order to determine how well the joints were temporally matched (phase matched) with respect to the target, a phase analysis was conducted.

It was previously shown (Experiment 2) that the rotations of the hip and ankle joints were not perfectly aligned to the target. The same was true for the present experiment. This yielded a phase-shift from the target that was analyzed by the phase of each joint at each of the target frequencies. Only hip and ankle joint phases were investigated.

Figure 23 shows separately, the mean second order hip and ankle phase angles for each frequency and surface condition. As with Experiment 2, the hip phase angles are

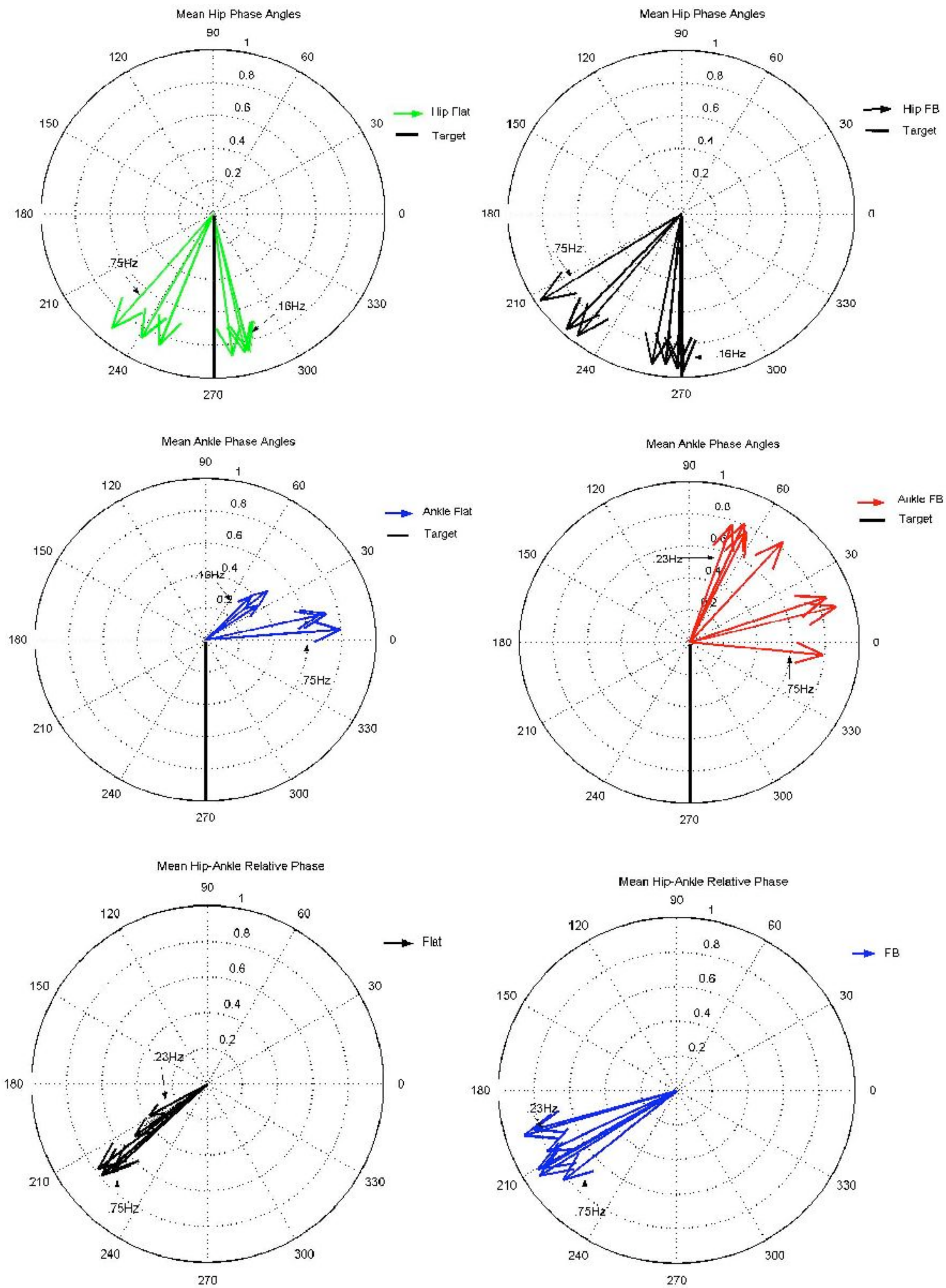


Figure (23). Mean second order hip (top) and ankle phase angles (middle). Mean hip-ankle second order relative phase angles are also shown (bottom).

seen in the upper two graphs, while the ankle phase angles are in the middle two graphs. All graphs on the left side of the figure represent values on the flat surface while those on the right represent the foam roller condition. The phase angle of the target was arbitrarily designated as 270º with clockwise rotations of vectors from the target representing phase lags. The hip joint (top graphs) was tightly coupled to the target frequency at OFs below .54 Hz, and phase lagged above this frequency. Note that the flat surface elicited greater hip phase variability compared to the foam roller. The ankle joint (middle graphs) was close to 180 degrees out of phase with the hip and target at low frequencies, but phase lagged at higher frequency oscillation. The phase lag by the ankle can be seen as the increased clockwise movement of the ankle vectors from 85º to 0º.

No statistical analysis was conducted on hip and ankle phase. However, as with the previous experiment, there was a clear changing phase relationship of the hip joint and ankle joint with respect to the target (Figure 23). At low OFs the hip was close to phase-locked with the target while the ankle was nearly anti-phase with the target. At higher OFs the hip began to phase lag behind the target by as much as 60º, while the ankle phase lagged behind the target by as much as 275º.

B. Hip-ankle relative phase (ϕ_{rel})

Hip-ankle relative phase was determined to examine the predicted emergence of distinct postural coordination strategies as a function of the interaction between support surface and OF. Recall from the previous experiment that *no* dramatic transitions occurred as described by Bardy et al. (2002). Rather, hip-ankle relative phase showed gradual changes in coordination mode, progressing from nearly a pure anti-phase relationship at the lowest OF to ~210º out of phase at the highest OF. By instructing participants to complete all OF in a block (without rest) in this experiment, it was thought that an interaction between OF and surface would elicit the predicted abrupt transitions in postural coordination.

Participants were given no instruction on how to accomplish the suprapostural task, yet a clear phase pattern for hip and ankle emerged as it did when rest was given between trials. Figure 9 illustrated an anti-phase relationship between the hip and ankle for experiment 2 such that the peak of a hip oscillation lined up with the valley of an ankle oscillation. The same relationship held here as verified by the group mean phase angles for the hip and ankle (Figure 23).

Hip-ankle relative phase was calculated in the same manner as described in experiment 2. Differences among the group mean phase angles for the various conditions were investigated. Rayleigh test and Rao Spacing test did not show uniformity (both <.01). Examination of the hip-ankle distribution revealed it to be a unimodal and mostly symmetric distribution. Figure 23 (bottom row) illustrates hip-ankle group mean relative phase angles across surfaces and frequencies. Figure 23 shows participants maintained anti-phase hip-ankle coordination throughout the experiment. Large transitions in coordination modes were absent. A gradual progression from ~200º out of phase at the lowest frequencies of oscillation to ~220º out of phase at the highest OF occurred on both surfaces. However, mean relative phase angle and circular standard deviation (mean ± *s*) on the flat surface was much more variable (217.00º ± 53.15º) compared to the foam roller (207.43º ± 30.72º). Figure 23 shows this could be accounted for by the high angular standard deviation at low OFs on the flat surface with stabilization of relative phase at higher OFs.

Despite manipulating frequency of oscillation in a continuous ramping manner, no large phase related postural transitions occurred. Again, only gradual changes in relative phase were seen. At all times, an anti-phase hip-ankle pattern was observed. One limitation of experiments 2 and 3, was the absence of target frequencies above .75 Hz, due to software limitations. It is possible that frequencies above .75 Hz would have elicited a large postural transition. However, given the already large impact of the multiple simultaneous postural constraints on the other studied variables, such as head sway, and inter-joint variability it would seem unlikely that even higher frequency oscillation would provoke such a transition. Rather, it is likely that a gradual transition as observed presently would be found. Support for a gradual transition in postural coordination modes comes from Buchanan and Horak (2001). They found that participants who were translated on a sinusoidally moving platform adopted gradual rather than abrupt changes in postural strategies.

A paper by Riccio and Stoffregen (1988) in principle seems to contradict the usefulness of in-phase motion (generally) during upright stance, since this would correspond to a situation that would put particpants near the limits (or beyond) of the reversibility region (1988, pg. 271). The existence of in-phase trunk and lower extremity segments is also counter to studies (Babinsky, 1899; Crenna, Frigo, Massion, & Pedotti, 1987; Oddsson & Thorstensson, 1986; Pedotti, Crenna, Frigo, & Massion, 1989) examining trunk bending, as cited in Massion, Alexandrov and Frolov (2004). Moving platform studies have also illustrated the tendency for responses to follow an anti-phase trajectory following perturbation (Horak & Kuo, 2000, Figure 19.1). In contrast, sinusoidally moving platform studies have found predominantly in-phase hip-ankle relations at frequencies between .50 Hz and 1.25 Hz (Buchanan & Horak, 1999) using a discrete method (as in Experiment 2) and primarily anti-phase hip-ankle relations at frequencies between .54 Hz and 1.46 Hz (Ko et al., 2003) using a ramping method (as in Experiment 3). Thus, sinusoidally moving platform studies have not reported hip-ankle relative phase for frequencies below .50 Hz, and results above .50 Hz have differed with methodological differences. In summary, the anti-phase hip and ankle movements encountered in this study (and experiment 2) are supported by the observations of several studies (Babinsky, 1899; Crenna et al., 1987; Oddsson & Thorstensson, 1986; Pedotti et al., 1989) yet conflict with the works of Bardy and colleagues.

The findings thus far seem to suggest that continuously ramping oscillation frequency (this experiment) when compared to discrete frequency oscillation (Experiment 2) provides a possible source of task related postural stability to participants. Evidence supporting improved stability in experiment 3 compared to experiment 2 includes: a) greater ML head stability with increasing OF; and b) much lower circular standard deviations about the mean phase angles for AP head phase on both surfaces

(Figure 19 vs. Figure 9). Given the available evidence, continuously ramping OF as opposed to discrete frequency oscillation can confer improvements in postural stability.

Hip-ankle variability ratio

Both experiments one and two demonstrated that hip/ankle ratios were influenced predominantly by surface. There is converging evidence for the generalization of this effect on posture, since the effect has been shown during both quiet stance (eyes open and closed) and dynamic bodily oscillation (Figures 5 and 15). Thus, it was predicted that surface would also influence the present hip/ankle variability ratios. The hip-ankle variability ratios were calculated and analyzed using the identical method described in experiment 2. The GMVR for the hip and ankle averaged across FO and plotted as a function of OF can be seen in Figure 24. Figure 25 shows hip-ankle ratios averaged across surface and plotted as a function of OF. Only hip-ankle variability ratios are presented here; Appendix 3 provides inter-joint coordination ratios for the other joints as well as ANOVA summary tables. The ANOVA results for hip-ankle variability ratios are presented in Table 21.

Table 21. Hip/Ankle Ratio ANOVA Summary Table

Source	Sum of Squares	df	Mean Square	F	
FO	0.88600	1	0.88600	3.216	
OF	4.74800	6	0.79100	1.307	
Surface	212.70100	1	212.70100	23.923	*
FOxOF	3.37500	6	0.56200	3.369	*
FOxSurface	0.01037	1	0.01037	0.017	
OFxSurface	8.74700	6	1.45800	3.176	*
FOxOFxSurface	3.35500	6	0.55900	3.204	*
Subjects					
FOxS	3.02900	11	0.27500		
OFxS	39.97300	66	0.60600		
SurfacexS	97.80100	11	8.89100		
FOxOFxS	11.01900	66	0.16700		
FOxSurfacexS	6.69600	11	0.60900		
OFxSurfacexS	30.29400	66	0.45900		
FOxOFxSurfacexS	11.51800	66	0.17500		
Total		335			

* denotes, p<.01

As was the same in experiment 2, the hip/ankle ratios were quite stable on the foam roller versus the flat surface (Figure 24). The curve for the flat surface was universally higher than the curve for the foam surface. This main effect of surface was statistically significant as shown by the hip-ankle ratio ANOVA (Table 21). Hip-ankle ratios stayed remarkably constant, near 1, throughout all frequencies on the foam roller, while ratios fluctuated on the flat surface (Figure 23). This is indicative of the emergence of flexible hip and ankle rotational movements on the flat surface. As noted previously, these findings imply that participants could flexibly modulate their inter-joint coordination in order to perform both the postural and suprapostural components of the task.

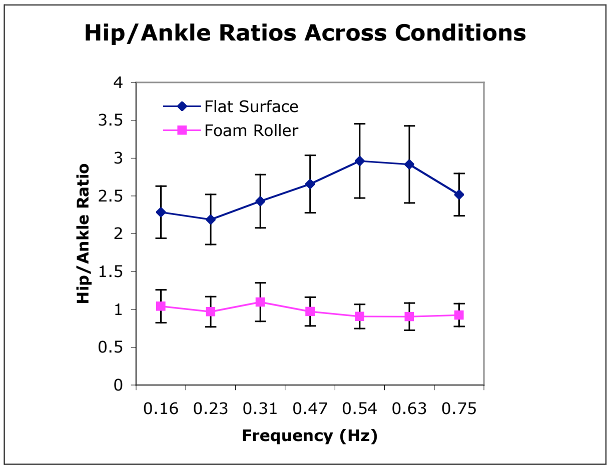


Figure (24). Mean hip/ankle ratio (± SE) values across surface and OF.

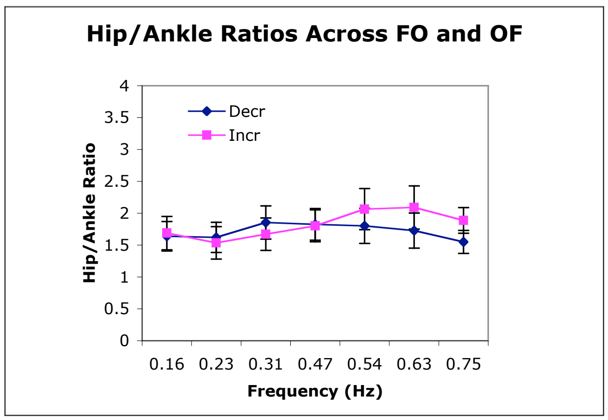


Figure (25). Mean hip/ankle ratio (± SE) values across FO and OF. Abbreviations: decreasing FO (Decr), increasing FO (Incr)

Figure 24 shows that hip motion increased relative to ankle motion within the .31-.54 Hz range on the flat surface compared to the foam roller. This OF by surface interaction was statistically significant as shown in Table 21. The result also verifies an earlier prediction that a surface by OF interaction would occur mostly in the range of ~ .50 Hz. In addition, during increasing FO trials, higher ratios existed at higher OFs (above .54 Hz) with lower ratios at lower OFs. This pattern was opposite of the decreasing FO results (Figure 25). The FO by OF interaction just described was statistically significant (Table 21). It is not clear what significance this interaction may play in the emergence of coordination modes. Although not predicted, the FO by OF interaction also seems to hinge on the differences occurring about the .50 Hz oscillation frequency as this is where the curves for the FOs cross. Additionally, a three-way interaction between FO, OF and surface was significant, but this interaction yielded no clear pattern of results (graph not shown).

Overall, the experiment demonstrated some important differences when compared to experiment 2. Additional interactions among independent variables were common and resulted from the continuous trial methodology. More importantly though, a dynamic form of stability seemed to be an inherent benefit from the continuous, yet changing bodily oscillation, particularly with higher frequency motion. The effect was evidenced by lower ML head variability during higher OFs and the reduced mean head phase circular standard deviations observed in this experiment compared to the previous experiment. Further, AP head translation showed a hysteresis effect as predicted. However, there were numerous similarities in results between Experiment 2 and 3. The most striking of these similarities was the lack of abrupt transition between postural strategies as hypothesized based on the findings from previous voluntarily produced postural coordination studies (Bardy et al., 1999; Bardy et al., 2002).

Overall Discussion

Humans require active control of posture because our morphology, mechanics, environmental constraints (e.g. gravity) and suprapostural goals demand it if we are to remain stable. The multi-segmental nature of our bodies necessitates that posture be coordinated in order to achieve optimal functioning. To date, coordination strategies have been investigated primarily with a platform perturbation model. Thus, the nature and extent of multi-segmental kinematics during suprapostural activity and non-perturbed upright posture remains to be tested and described in detail.

Postural motion was found to be multi-segmental in each experiment as verified by joint angular rotation and coordination data. The multi-segmental basis for postural motion in these experiments permitted a detailed examination of coordination. Specifically, coordination was assessed by the patterning of the body and limbs with respect to each other and to the environment.

Postural coordination changed under specific circumstances. Each experiment verified our previous finding (Smith et al., 2002) that surface of support has an independent effect on hip-ankle coordination as measured by the coordination ratio. However, the third experiment also found interactions between support surface, OF and FO, that confirmed our prediction of an interaction between support surface and OF. Apparently, eliminating a small rest break between trials was sufficient to elicit the interaction. It is suggested therefore that future suprapostural studies consider rest as a variable that can influence coordination.

Separate analyses of the components of hip-ankle coordination ratios (ankle and hip joint rotation variability) have shown these two joints to be differentially affected by both surface constraints and suprapostural task. This could account for the finding that the separate analysis of hip and ankle rotation variability does not appear to be related to changes in coordination mode. With the exception of the second experiment, the coordination ratio was influenced by a different pattern of variables than for the hip and ankle considered individually. Therefore, the emergence of coordination modes seems to be different than the sum of its parts. A related issue is that changes in AP head translation (task) were not related to simple scaled changes in hip and ankle rotation variability. Rather, hip and ankle rotations were related to AP head motion in a complex manner that were only revealed through more refined measures such as spectral and phase analysis. These measures showed the hip to play the dominant role in tracking the target by: 1) maintaining a close phase relationship with the target and; 2) contributing a greater proportion of its power at the target frequency.

Analysis of hip-ankle relative phase provided a temporal measure of coordination between these joints. Results from experiments 2 and 3 revealed that there were no large transitions between coordination strategies. Rather, an anti-phase relationship was maintained throughout all conditions. A near perfect anti-phase (~180º) relationship was seen at low OF with gradual change to less anti-phase relations (~200-210º) at higher OF. This contrasts with studies that have found in-phase relations at low frequencies followed by a dramatic transition to anti-phase hip-ankle relations occurring at ~.50 Hz (Bardy et al., 1999; Bardy et al., 2002; Marin, Bardy, Baumberger et al., 1999; Marin, Bardy, & Bootsma, 1999). One possible explanation for this difference is that the amplitude of head tracking was larger in these experiments than in the Bardy et al. studies. Thus, it is possible that the large amplitude head motion in experiments 2 and 3 prevented in-phase hip-ankle coordination. However, recent results from Oullier et al. (2004) have confirmed that only anti-phase hip-ankle relations were obtained on a narrow support surface even with a constant peak-to-peak target amplitude of only 4 centimeters. The present results also differ from the in-phase hip-ankle findings obtained by Buchanan and Horak (1999) as well as the results from Ko et al. (2003) who found a tendency from in-phase to anti-phase relations with increasing OF during sinusoidal platform perturbation.

Gradual change in postural kinematics has also been observed in a perturbation model where instead of having participants voluntarily move their bodies, a moving platform oscillates back and forth at frequencies similar to those seen in the present experiments (Buchanan & Horak, 2001). In that study (Buchanan & Horak, 2001), it was concluded that the ability to recruit and suppress DOF allows postural control to gradually change postural strategies without suffering a loss of stability. These conclusions seem also to apply particularly to Experiment 2, where people were voluntarily tracking a moving target without noticeable loss in stability or hysteresis. However, the evidence from Experiment 3 suggests that if anything, (where others have found transitions in mode with increasing frequency) people were more stable during higher frequency motion as evidenced by lower circular standard deviations of head phase, lower or comparable joint powers to produce these movements and less mediolateral head variability. It thus appears as though the continuous motion experienced in experiment 3, actually afforded some postural stability not present with the discrete frequency presentation method of experiment 2.

In summary, the three experiments reported herein have tested the effect of environmental and task constraints on the multi-segmental coordination of upright quiet standing and suprapostural performance. Several implications become apparent from these findings. The first is that models of postural control should be explicitly multi-segmental and should account for not only biomechanical factors, but task relevant factors as well. A related factor is that studies which employ a single measurement point (such as center of pressure (COP) may not allow for a complete understanding of how postural coordination influences not only stance, but the ability to successfully engage in suprapostural tasks. The second implication is that dynamic standing tasks exhibit many similarities in postural coordination and control whether performed at a singular frequency or during continuous ramping of frequencies. However, ramping oscillatory frequencies may confer stability benefits when compared to discrete frequency manipulation. Third, transitions in postural coordination strategies during upright voluntary tasks do not appear to be dramatic, nor large, but rather are gradual, implying the preservation of stability throughout a large range of frequency and surface constraints. Fourth, the results suggest that multiple measures are required to adequately describe the concept of a coordination strategy because singular measures are insufficient to capture the relationship between person and environment. Lastly, and perhaps most importantly, the data strongly argue that there is a need to examine postural control and coordination by means other than platform perturbation.

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Appendix A. Important Abbreviations and Glossary of Terms

AP – Anterior-posterior
Coordination mode – see strategy
Discrete frequency – Discrete oscillation frequencies were used in experiment two. These oscillation frequencies (trials) were separated by a rest period.
Degree of stability – Refers to how large a given deviation of posture corresponds to a given perturbation (Johansson & Magnusson, 1991). A larger degree of deviation or variability in posture implies less stability compared to a posture with a lower degree of deviation. Degree of stability is the operational definition of stability used in this experiment.
Dynamic stability – Dynamic stability implies that equilibrium tends to be restored not only under static conditions, but also during motion. It also implies a damping of velocities so that oscillations around the equilibrium are also damped. A body that oscillates about its posture equilibrium condition with ever-increasing amplitude is an example of dynamic instability (Johansson & Magnusson, 1991).
DOF – Degrees of freedom. The multitude of ways that the muscles, joints and limb segments can be combined to produce movement.
EO – Eyes open
EC – Eyes closed
FB – Foam roller
FO – Frequency order. In experiments 2 and 3, frequency order is an independent variable that describes whether target oscillation frequency is increasing or decreasing.
FR – Frequency response. This is the person's motor response to the target frequency (TF).
FS – Foam surface
GMROM – The group mean range of motion for a joint in the sagittal plane (e.g. flexion/extension). See GMSD for calculations.
GMSD – The group mean standard deviation for either translation or rotation. GMSD values were obtained from the ANOVA performed on the IMSD data. See IMSD for more details.
GMVR – The group mean variability ratio. GMVR values were obtained from the ANOVA performed on the IMVR data. See IMVR for more details.
HB – Hard beam
HS – Hard surface
Hysteresis – Hysteresis is a property of a dynamic system. A system is said to exhibit hysteresis when the behavior of the system depends not only on its current state, but also on its history. Hysteresis demonstrates two different response values for the same stimulus depending on the direction (e.g., frequency order) of the system.
IMROM – The individual mean range of motion for a joint in the sagittal plane (e.g. flexion/extension). See IMSD for calculations.
IMSD - The standard deviation of translation or rotation measures for each trial was calculated and formed the basic unit of postural movement analysis. The standard deviations of the replication trials for each individual were then averaged together to form the individual mean standard deviation (IMSD) for a condition. The IMSD values comprised the data for the ANOVA calculations. The ANOVA subsequently generated

group mean standard deviations (GMSD) for each condition and these GMSDs are reported in each experiment. Note that all mean measures of variability reported in these experiments have their own variability.

IMVR – The individual mean variability ratio. The angular standard deviation of one joint for each trial was divided by the angular standard deviation of the second joint for the same trial and this formed the basic variability ratio. The variability ratios of the replication trials for each individual were then averaged together to form the individual mean variability ratio (IMVR) for a condition. The IMVR values comprised the data for the ANOVA calculations. The ANOVA subsequently generated group mean variability ratios (GMVR) for each condition and these GMVRs are reported in each experiment.

Inter-joint coordination ratio – A composite measure of coordination between two joints. The ratio is obtained by dividing the first order standard deviation measures of one joint's sagittal motion by the first order standard deviation of another joint's sagittal motion. A unity number is obtained and represents the coordination between two joints.

ML – Medio-lateral

OF – Oscillation frequency is the frequency of oscillation of the target. A total of 7 oscillation frequencies (each with 12 cycles) were used in the experiments, ranging from 0.16 Hz to 0.75 Hz.

ROM – Range of angular motion (or linear translation distance) of the specified joint or landmark

Sagtittal – Sagittal refers to the anatomical sagittal plane. The sagittal plane herein passes through the mid-point of the respective joint.

Stability – Stability (or even the lack of it) is a property of a state of equilibrium, equilibrium being said to be stable if, when the body is slightly disturbed in any of its degrees of freedom, it ultimately returns to its initial state (Johansson & Magnusson, 1991). The operational definition of stability in this experiment is at pertains to the interpretation of *degree of stability* (above). See also *dynamic stability* and *degree of stability.*

Strategy – A sensorimotor solution to maintain control over posture: includes muscle synergies, movement patterns, joint torques and contact forces. Strategy herein is synonymous to the type of coordination mode used. The solution is described in terms of the relative amounts of rotation about two or more joints. The joint with the most relative angular motion is the prime strategy. For example if hip joint motion is greater than ankle and knee motion for a given task, the solution would be called a hip strategy.

TF – Target frequency. This is the oscillation frequency of the simulated computer target that the person tracks in experiments 2 and 3.

Appendix 1. Experiment 1 Individual Mean Data and ANOVA Tables

Head AP IMSD (cm)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.00999	0.00626	0.02420	0.02533	0.00805	0.00886	0.00474	0.00933
2	0.00831	0.00747	0.01007	0.02726	0.00781	0.01478	0.00899	0.01017
3	0.00233	0.00291	0.00863	0.06525	0.00520	0.00453	0.00660	0.01678
4	0.00494	0.00839	0.00785	0.03807	0.00761	0.04210	0.00483	0.01246
5	0.00513	0.00520	0.01447	0.01550	0.01085	0.01016	0.00598	0.00999
6	0.00782	0.00714	0.00773	0.04944	0.00601	0.01037	0.01067	0.01186
7	0.00511	0.00762	0.00426	0.04499	0.00605	0.03212	0.00722	0.00824
8	0.00550	0.00434	0.00986	0.02890	0.01522	0.04197	0.01214	0.00986

Head ML IMSD (cm)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.00449	0.00486	0.01372	0.01028	0.00613	0.00325	0.00550	0.00855
2	0.00268	0.00156	0.00438	0.01220	0.00286	0.00559	0.00868	0.01321
3	0.00147	0.00228	0.00499	0.03946	0.00259	0.00264	0.00779	0.00886
4	0.00208	0.00105	0.00735	0.01716	0.00306	0.02101	0.00502	0.00579
5	0.00112	0.00208	0.00544	0.00456	0.00258	0.00217	0.00504	0.00502
6	0.00253	0.00172	0.00677	0.02349	0.00377	0.00309	0.00477	0.00983
7	0.00197	0.00227	0.00419	0.01216	0.00344	0.00625	0.00415	0.00693
8	0.00117	0.00172	0.00644	0.01097	0.00316	0.01910	0.00555	0.00750

Ankle IMROM (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	1.7175	1.5179	31.8619	49.7764	3.9906	2.8912	2.8855	5.2467
2	1.7659	1.6348	17.3623	34.4327	3.6321	13.7353	7.0441	6.8053
3	0.8128	0.9688	14.8445	113.7066	1.5686	2.1530	4.8470	12.6457
4	1.2282	1.3772	12.9614	33.7951	3.7609	21.9591	2.9715	10.0459
5	1.0461	1.1264	13.2188	20.5275	3.0318	4.9641	2.9128	6.3899
6	1.9074	1.8463	16.2673	72.8363	2.3424	5.6694	6.3045	8.3325
7	1.6252	1.9731	12.4417	56.0610	7.2484	70.2568	4.3150	5.8263
8	0.9887	0.8918	9.2433	19.8776	8.8141	49.2735	5.5026	7.2529

Ankle IMSD (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.4310	0.4148	5.8344	10.6910	1.0321	0.7246	0.6892	1.2339
2	0.4905	0.4295	3.6625	6.3275	0.8690	1.9039	1.7146	1.5579
3	0.1821	0.2280	3.0952	23.4282	0.3591	0.4248	1.1040	2.6738
4	0.3061	0.2799	2.0937	7.7715	0.9444	3.5663	0.6009	2.1186
5	0.2693	0.2835	2.8030	4.1312	0.6765	1.0754	0.6770	1.4746
6	0.4764	0.4796	2.7874	10.0758	0.5449	1.2779	1.7755	2.1371
7	0.4024	0.5151	2.7625	11.3679	1.4786	8.4087	1.2366	1.5223
8	0.2430	0.2382	2.0505	4.7761	2.4268	5.2955	1.4335	1.6344

Knee IMROM (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	3.1965	2.2282	16.2633	12.2277	3.4902	3.3264	1.6409	3.0202
2	2.4484	2.5139	3.2542	6.3639	2.7627	5.6354	3.7946	4.3249
3	1.0693	1.2487	3.9578	26.1193	1.6807	2.0357	3.3250	6.5825
4	1.4830	2.4961	3.3090	19.4879	2.2527	15.3763	1.4285	3.7007
5	1.5078	1.7645	4.0076	4.5356	3.2444	3.4261	2.3301	3.8354
6	2.2938	1.9829	4.1150	41.0556	1.9073	4.2019	3.7808	4.2431
7	2.0361	2.8225	3.0198	18.6459	3.8737	27.1036	3.1569	3.3201
8	1.8926	1.5018	3.3690	7.9416	5.2955	27.5491	4.2949	4.5042

Knee IMSD (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.8629	0.6699	2.5694	1.9997	0.9377	0.8270	0.3895	0.6652
2	0.6430	0.6561	0.8714	1.1054	0.7215	1.0658	0.8685	0.9998
3	0.2472	0.3163	0.8789	4.1825	0.3661	0.4096	0.7455	1.6648
4	0.3778	0.5759	0.7370	3.8092	0.4592	2.7292	0.3039	0.9047
5	0.4182	0.4228	0.9421	0.9596	0.6998	0.7906	0.5566	0.8487
6	0.5679	0.4974	0.8734	7.1384	0.4315	0.9992	1.0084	1.1321
7	0.5333	0.7586	0.8156	3.2040	0.9261	3.2955	0.8788	0.8981
8	0.4859	0.3939	0.7845	1.6007	1.3762	4.0496	1.1269	1.0526

Knee ROM Table

Source	Sum of Squares	df	Mean Square	F
Eyes	449.65	1	449.65	12.296 *
Surface	780.95	3	260.32	6.309 *
EyesxSurface	378.57	3	126.19	3.57
Subjects				
EyesxS	255.98	7	36.57	
SurfacexS	866.51	21	41.26	
EyesxSurfacexS	742.33	21	35.35	
Total		63		

* denotes p<0.01

Knee Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
Eyes	10.74	1	10.74	10.913
Surface	19.92	3	6.64	6.956 *
EyesxSurface	8.91	3	2.97	3.756
Subjects				
EyesxS	6.89	7	0.98	
SurfacexS	20.05	21	0.96	
EyesxSurfacexS	16.60	21	0.79	
Total		63		

* denotes p<0.01

Hip IMROM (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	1.1237	0.9935	17.3786	15.0167	1.0170	2.3577	1.3857	1.5329
2	1.0075	1.0531	1.7303	14.0946	1.7025	6.3549	1.0944	1.1325
3	1.9641	1.4582	1.9989	32.4339	1.0242	1.3477	2.0226	1.9125
4	0.8068	1.1877	2.5644	20.4791	1.0660	18.1948	0.9354	2.4456
5	0.6288	0.7114	1.2309	2.4485	1.4984	1.1092	0.9091	0.9271
6	0.7257	0.7259	1.9629	34.0035	0.7116	0.8487	0.6304	1.0217
7	0.4181	1.1539	2.0084	13.9283	0.8460	14.3826	1.0745	1.1159
8	0.3670	0.5053	2.7069	16.0891	1.5899	21.6007	1.3431	2.1535

Hip IMSD (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.2461	0.2419	2.0065	3.0997	0.2525	0.5732	0.3256	0.3319
2	0.2258	0.2236	0.3998	3.0902	0.3869	1.3365	0.2868	0.2478
3	0.4232	0.3689	0.4667	9.1782	0.2511	0.2830	0.4229	0.4297
4	0.1723	0.2143	0.5634	4.9317	0.2961	4.5803	0.1917	0.6889
5	0.1365	0.1334	0.3042	0.4326	0.3590	0.2257	0.2025	0.1946
6	0.1776	0.1584	0.3620	7.0939	0.1863	0.1544	0.1466	0.1994
7	0.0893	0.2884	0.4770	3.0518	0.1560	2.0969	0.2633	0.2366
8	0.0928	0.1174	0.8023	2.8717	0.3967	4.0169	0.3407	0.5188

Trunk IMROM (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	1.0894	1.5812	23.2902	14.4344	1.5519	1.3245	1.0853	1.7448
2	1.2253	1.6898	1.8857	9.5251	1.8994	4.0889	0.7818	1.6422
3	2.0650	1.0870	1.1358	16.4826	1.5016	1.3120	2.0096	1.6323
4	1.0381	1.9083	3.8390	11.5273	1.2187	10.6830	1.1565	1.9006
5	0.8946	1.0622	1.5314	1.4617	2.1028	1.6757	0.7246	0.8485
6	0.7772	1.1314	3.4344	19.8792	0.8496	0.9036	1.0118	0.9450
7	0.6764	1.1459	1.2683	16.2162	1.5260	14.4184	1.3531	1.1870
8	0.7565	1.3847	3.1839	6.9021	1.3014	12.4228	0.6840	1.2719

Trunk IMSD (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.2730	0.4171	3.0187	3.1548	0.3858	0.2310	0.2430	0.3535
2	0.2403	0.4043	0.4281	1.5305	0.4402	0.7814	0.1550	0.4308
3	0.4177	0.2651	0.3028	3.7896	0.3557	0.2632	0.4764	0.3436
4	0.2467	0.3781	0.8060	3.4636	0.2267	2.5588	0.2567	0.4236
5	0.2229	0.2621	0.3574	0.3163	0.4191	0.2818	0.1811	0.1999
6	0.2163	0.2867	0.7994	3.2279	0.2364	0.1728	0.2009	0.2026
7	0.1809	0.2757	0.3348	3.5140	0.3449	3.4841	0.2958	0.2603
8	0.2140	0.4184	0.9876	1.0686	0.3190	2.6314	0.1624	0.3208

Trunk ROM Table

Source	Sum of Squares	df	Mean Square	F
Eyes	145.72	1	145.72	9.108
Surface	563.11	3	187.70	10.111 *
EyesxSurface	133.11	3	44.37	3.405
Subjects				
EyesxS	111.99	7	16.00	
SurfacexS	389.85	21	18.56	
EyesxSurfacexS	273.62	21	13.03	
Total		63		

* denotes p<0.01

Trunk Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
Eyes	7.54	1	7.54	12.016 *
Surface	21.12	3	7.04	11.816 *
EyesxSurface	6.81	3	2.27	4.738
Subjects				
EyesxS	4.39	7	0.63	
SurfacexS	12.51	21	0.60	
EyesxSurfacexS	10.06	21	0.48	
Total		63		

* denotes p<0.01

Cervical IMROM (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	3.9470	2.2017	20.2344	15.5343	1.0450	2.5675	2.1415	3.6816
2	1.8907	0.9052	1.5437	5.6477	1.2441	2.3913	0.7029	1.2068
3	3.8527	2.7209	3.0681	40.5976	1.5390	1.2457	2.7389	1.5899
4	3.1924	2.8870	4.5966	14.9456	3.4129	17.6775	4.8761	5.2969
5	1.8478	1.6265	1.8547	2.6860	1.6568	2.1266	3.0128	1.8892
6	0.6591	1.6786	3.1024	28.2365	1.4275	2.2899	1.2493	2.6687
7	0.6813	0.6759	4.9135	17.4357	1.4844	12.5298	0.8376	1.3824
8	0.6563	0.8410	2.1119	12.3674	2.6428	25.9574	0.6832	1.4297

Cervical IMSD (Flexion-Extension) (degrees)

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.7883	0.5840	3.9137	3.1378	0.2457	0.5160	0.5331	0.7773
2	0.5247	0.2060	0.4131	1.1121	0.3155	0.4738	0.1542	0.2454
3	0.8966	0.6892	0.9786	11.1733	0.4604	0.3118	0.6015	0.3782
4	1.0241	0.8297	1.0185	4.2878	0.8251	3.4447	1.4224	1.3385
5	0.5806	0.4571	0.4235	0.5303	0.3146	0.4835	0.7201	0.5229
6	0.1782	0.4838	0.6811	5.0975	0.3625	0.6071	0.2963	0.6055
7	0.1469	0.1664	1.0895	5.0107	0.3555	2.8469	0.2152	0.3869
8	0.1725	0.2507	0.5253	2.7590	0.7306	5.7098	0.1898	0.4003

Cervical ROM Table

Source	Sum of Squares	df	Mean Square	F
Eyes	342.58	1	342.58	11.238
Surface	889.60	3	296.54	7.601 *
EyesxSurface	406.06	3	135.35	4.022
Subjects				
EyesxS	213.38	7	30.48	
SurfacexS	819.29	21	39.01	
EyesxSurfacexS	706.68	21	33.65	
Total		63		

* denotes p<0.01

Cervical Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
Eyes	18.84	1	18.84	10.392
Surface	47.66	3	15.89	7.039 *
EyesxSurface	24.66	3	8.22	4.214
Subjects				
EyesxS	12.69	7	1.81	
SurfacexS	47.40	21	2.26	
EyesxSurfacexS	40.97	21	1.95	
Total		63		

* denotes p<0.01

Hip/Ankle IMVRs

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.6461	1.1479	0.2937	0.2998	0.3124	0.7911	0.4726	0.3217
2	0.4923	0.5205	0.1092	0.4846	0.4455	0.7344	0.1597	0.1622
3	2.3846	1.7511	0.1498	0.3922	0.9012	0.6537	0.3919	0.1567
4	0.7610	0.7698	0.3214	0.5164	0.3584	1.1847	0.3273	0.3286
5	0.5071	0.4935	0.1102	0.1033	0.6017	0.2096	0.2997	0.1693
6	0.3460	0.3390	0.1251	0.7078	0.3357	0.1501	0.0843	0.1043
7	0.3084	0.5286	0.1676	0.2081	0.1077	0.2517	0.2222	0.1554
8	0.3756	0.5673	0.4276	0.6171	0.2121	0.7592	0.2370	0.3172

Cervical/Trunk IMVRs

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	3.0040	1.6077	1.8426	1.0602	0.8991	2.2336	2.1968	2.3929
2	2.2061	0.5095	0.9650	0.7258	0.7220	0.6078	0.9925	0.6187
3	2.1454	2.6186	3.1854	2.9513	1.3454	1.1721	1.4236	1.0966
4	4.4808	2.1687	1.1829	2.8221	3.6400	2.0176	5.5797	3.3115
5	3.0354	1.7951	1.2574	1.9154	0.8622	1.8771	5.3775	2.6583
6	0.8401	1.9536	1.0560	1.5732	1.5002	3.6134	1.4435	2.9144
7	0.8150	0.7142	4.1422	1.4266	1.0866	0.7615	0.7431	1.6405
8	0.8060	0.6133	0.5516	2.8320	2.4935	2.0158	1.1559	1.2232

Cervical/Trunk Variability Ratio Table

Source	Sum of Squares	df	Mean Square	F
Eyes	0.48	1	0.48	0.421
Surface	2.09	3	0.70	0.496
EyesxSurface	2.17	3	0.72	0.871
Subjects				
EyesxS	7.95	7	1.14	
SurfacexS	29.44	21	1.40	
EyesxSurfacexS	17.40	21	0.83	
Total		63		

Trunk/Hip IMVRs

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	1.0631	1.6193	1.2324	1.0186	1.5192	0.4030	0.8193	1.1309
2	1.0761	1.8088	1.0707	0.5109	1.1370	0.8328	0.6449	1.8770
3	0.9965	0.7554	0.6737	0.4184	1.4487	0.9426	1.1108	0.8990
4	1.3469	1.7648	1.6615	0.5171	0.8408	0.4499	1.3818	0.6141
5	1.6276	2.1852	1.3036	0.7479	1.2741	1.3101	0.8876	1.0189
6	1.3165	1.7012	1.9340	0.4546	1.3536	1.1294	1.3690	1.0511
7	2.1663	0.8900	0.7489	1.0818	2.3049	1.7391	1.2328	1.1603
8	2.9238	3.5234	1.3175	0.3552	0.7929	0.8023	0.5132	0.6190

Trunk/Hip Variability Ratio Table

Source	Sum of Squares	df	Mean Square	F
Eyes	0.52	1	0.52	3.826
Surface	5.22	3	1.74	4.17
EyesxSurface	1.73	3	0.58	3.503
Subjects				
EyesxS	0.95	7	0.14	
SurfacexS	8.76	21	0.42	
EyesxSurfacexS	3.46	21	0.17	
Total		63		

Hip/Knee IMVRs

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	0.3470	0.7971	0.8729	1.6052	0.3226	0.6931	0.8208	0.5289
2	0.3637	0.3407	0.4588	2.7887	0.5362	1.2659	0.3368	0.2484
3	1.7555	1.1775	0.5382	2.1934	0.8375	0.6869	0.5670	0.2589
4	0.4542	0.4222	0.7840	1.4518	0.6318	1.7891	0.6383	0.7640
5	0.3271	0.3257	0.3201	0.4491	0.5037	0.2885	0.3725	0.2545
6	0.3078	0.4086	0.3978	1.0732	0.4251	0.1735	0.1465	0.1744
7	0.2656	0.3597	0.5750	0.6915	0.1708	0.6803	0.3121	0.2627
8	0.1986	0.3546	1.0516	1.9656	0.3517	0.9301	0.3019	0.4929

Hip/Knee Variability Ratio Table

Source	Sum of Squares	df	Mean Square	F
Eyes	1.44	1	1.44	11.529
Surface	4.16	3	1.39	8.394 *
EyesxSurface	2.30	3	0.77	6.689 *
Subjects				
EyesxS	0.88	7	0.13	
SurfacexS	3.47	21	0.17	
EyesxSurfacexS	2.41	21	0.12	
Total		63		

* denotes p<0.01

Knee/Ankle IMVRs

Participant	HSEO	HSEC	FBEO	FBEC	HBEO	HBEC	FSEO	FSEC
1	1.9241	1.5245	0.3606	0.1869	0.9407	1.1413	0.6089	0.5911
2	1.4455	1.5276	0.2379	0.1749	0.8305	0.5623	0.5153	0.6453
3	1.3579	1.4262	0.2792	0.1806	1.0471	0.9766	0.6861	0.6301
4	1.4725	2.1233	0.3825	0.3875	0.6077	0.6786	0.5082	0.4291
5	1.5533	1.5109	0.3379	0.2329	1.0916	0.7357	0.8169	0.6304
6	1.3094	1.0075	0.3124	0.7256	0.7929	0.8236	0.5727	0.6060
7	1.2605	1.4683	0.2908	0.2548	0.6299	0.3734	0.7115	0.5899
8	1.9074	1.6262	0.3903	0.3493	0.5856	0.8233	0.7852	0.6441

Knee/Ankle Variability Ratio Table

Source	Sum of Squares	df	Mean Square	F
Eyes	0.01	1	0.01	0.745
Surface	12.68	3	4.23	78.096 *
EyesxSurface	0.01	3	0.00	0.102
Subjects				
EyesxS	0.14	7	0.02	
SurfacexS	1.14	21	0.05	
EyesxSurfacexS	0.59	21	0.03	
Total		63		

* denotes p<0.01

Inter-segmental joint coordination GMVRs (flexion/extension) Summary Table

	Cervical/Trunk	Trunk/Hip	Hip/Knee	Knee/Ankle
HSEO	2.17 (.47)	1.57 (.24)	.50 (.18)	1.53 (.09)
HSEC	1.50 (.28)	1.78 (.30)	.52 (.11)	1.53 (.11)
FSEO	2.36 (.70)	1.00 (.12)	.44 (.08)	.65 (.04)
FSEC	1.98 (.34)	1.05 (.14)	.37 (.07)	.60 (.03)
HBEO	1.57 (.36)	1.33 (.17)	.47 (.07)	.82 (.07)
HBEC	1.79 (.34)	.95 (.16)	.81 (.18)	.76 (.08)
FBEO	1.77 (.44)	1.24 (.15)	.63 (.09)	.32 (.02)
FBEC	1.91 (.31)	.64 (.10)	1.53 (.28)	.31 (.07)

Appendix 2. Experiment 2 Individual Mean Data and ANOVA Tables

AP head peak-to-peak translation (IMROM) (cm)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.15236	0.14011	0.11924	0.08105	0.07763	0.05697	0.06425	0.17304	0.20016	0.16776	0.17526	0.16005	0.12256	0.09353
2	0.11272	0.09626	0.09326	0.08610	0.08897	0.07088	0.07215	0.11373	0.11790	0.09445	0.09342	0.09228	0.07887	0.07578
3	0.17160	0.20016	0.15276	0.12440	0.13001	0.11193	0.10059	0.20933	0.18671	0.19670	0.11765	0.14369	0.15580	0.13210
4	0.10495	0.09180	0.08648	0.06240	0.06682	0.04972	0.05329	0.09746	0.07973	0.07338	0.07294	0.06692	0.05904	0.05976
5	0.29574	0.27242	0.24553	0.23365	0.22533	0.20593	0.18071	0.24673	0.21851	0.20285	0.16578	0.13841	0.14080	0.12421
6	0.14798	0.15732	0.16309	0.12945	0.12924	0.14565	0.13134	0.12466	0.11599	0.14433	0.10757	0.11631	0.13337	0.11568
7	0.14311	0.12536	0.12188	0.09530	0.09139	0.08978	0.08268	0.11752	0.10786	0.09856	0.10440	0.08867	0.07181	0.07661
8	0.22750	0.22351	0.20684	0.16945	0.15966	0.15520	0.14794	0.15812	0.13856	0.13176	0.11618	0.11660	0.11511	0.09968
9	0.18971	0.17867	0.14768	0.14910	0.14756	0.13085	0.14053	0.14714	0.12221	0.14158	0.16451	0.14033	0.10909	0.12026
10	0.21779	0.20911	0.15973	0.13005	0.15063	0.12768	0.12311	0.18407	0.15081	0.13658	0.09746	0.10744	0.11301	0.07928
11	0.23450	0.19108	0.21643	0.14390	0.13632	0.13503	0.11009	0.22802	0.21896	0.15874	0.14252	0.14288	0.14074	0.11485
12	0.16787	0.16091	0.12359	0.13340	0.12957	0.12220	0.12298	0.20814	0.15790	0.14590	0.14224	0.14196	0.14841	0.17206

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.11492	0.11148	0.11417	0.09346	0.09532	0.08834	0.07234	0.14270	0.15509	0.14977	0.14342	0.16713	0.13442	0.13386
2	0.10655	0.11599	0.10197	0.09054	0.09155	0.09166	0.06757	0.10916	0.09594	0.08618	0.09161	0.09622	0.10514	0.08440
3	0.21160	0.16273	0.15367	0.12196	0.12459	0.11952	0.09577	0.19028	0.19211	0.14529	0.14304	0.13091	0.12254	0.11664
4	0.09940	0.08217	0.07988	0.07261	0.07282	0.06509	0.06367	0.09640	0.07750	0.07421	0.08185	0.08614	0.06971	0.05868
5	0.29692	0.24131	0.19891	0.19390	0.18650	0.18983	0.16920	0.24225	0.22315	0.18630	0.19736	0.15920	0.14486	0.13558
6	0.14653	0.15503	0.13600	0.13487	0.14122	0.17124	0.14223	0.11188	0.11942	0.13352	0.13917	0.13122	0.15544	0.10544
7	0.13788	0.12676	0.12264	0.10053	0.12006	0.08297	0.08587	0.11008	0.10895	0.10669	0.08407	0.08121	0.07826	0.08853
8	0.24839	0.25755	0.22739	0.19101	0.20360	0.19484	0.17327	0.16048	0.13939	0.15985	0.13546	0.15195	0.12031	0.12295
9	0.19038	0.19268	0.17397	0.16094	0.15623	0.15952	0.13899	0.16041	0.15216	0.14389	0.13894	0.15152	0.13803	0.13148
10	0.15562	0.14257	0.13246	0.13883	0.14168	0.14614	0.12726	0.16420	0.13524	0.12351	0.11306	0.13069	0.11056	0.09458
11	0.26184	0.20046	0.18690	0.15195	0.15341	0.13677	0.10254	0.17705	0.18016	0.18433	0.23255	0.18018	0.12412	0.11734
12	0.15898	0.13975	0.12951	0.12571	0.12135	0.12467	0.10204	0.19359	0.18263	0.16256	0.23743	0.11751	0.12458	0.13051

Note: up = increasing FO, do = decreasing FO, flat = flat surface, fb = foam roller, .16-.75 = OFs

Percentage of power for AP head translation (Individual Means) (%)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.91760	0.85994	0.86567	0.72190	0.74692	0.66315	0.40534	0.83168	0.81762	0.83596	0.56939	0.70973	0.71247	0.72658
2	0.80622	0.82458	0.85126	0.81190	0.68873	0.71119	0.56909	0.85370	0.80888	0.76163	0.71650	0.75724	0.59889	0.58702
3	0.85879	0.87190	0.85619	0.76555	0.71406	0.70353	0.56340	0.86778	0.79182	0.87888	0.79199	0.75555	0.77829	0.59954
4	0.81840	0.83409	0.74278	0.84420	0.80183	0.74118	0.62039	0.76977	0.71954	0.65655	0.72523	0.64962	0.53300	0.55062
5	0.86170	0.77976	0.73922	0.66040	0.63537	0.63148	0.51113	0.87431	0.77735	0.72152	0.60509	0.67896	0.54040	0.46847
6	0.73290	0.64529	0.64915	0.66615	0.46689	0.59320	0.26134	0.86312	0.84918	0.77381	0.73639	0.67118	0.75231	0.49348
7	0.89095	0.77717	0.72610	0.72040	0.77993	0.74756	0.64374	0.84996	0.88533	0.77869	0.59396	0.74672	0.70740	0.46025
8	0.83585	0.87888	0.85962	0.79385	0.84867	0.85120	0.79981	0.69404	0.80681	0.69810	0.63445	0.58576	0.72991	0.71272
9	0.94611	0.88931	0.91714	0.91855	0.46773	0.88416	0.80140	0.86848	0.88505	0.87978	0.86576	0.80999	0.82851	0.67810
10	0.95067	0.94190	0.93199	0.86740	0.84124	0.84498	0.81591	0.93391	0.92088	0.89564	0.87119	0.85782	0.83557	0.80878
11	0.87793	0.83034	0.87114	0.79210	0.75680	0.76265	0.75457	0.87559	0.72305	0.82109	0.72760	0.33082	0.83538	0.63484
12	0.80244	0.77340	0.85864	0.85815	0.84432	0.75925	0.61581	0.82429	0.83426	0.78674	0.78797	0.70687	0.72918	0.58648

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.86981	0.87230	0.88283	0.78804	0.69080	0.51120	0.61103	0.85297	0.83075	0.85473	0.76818	0.62257	0.72148	0.79148
2	0.87467	0.87264	0.80707	0.72834	0.72719	0.66413	0.64717	0.84072	0.76679	0.84417	0.72732	0.77208	0.59892	0.64934
3	0.92844	0.81874	0.80552	0.41181	0.40989	0.64752	0.56503	0.87503	0.87270	0.83886	0.75191	0.64413	0.65952	0.43295
4	0.83114	0.84283	0.84794	0.76977	0.73708	0.71657	0.66527	0.79328	0.75476	0.73957	0.65658	0.64429	0.52523	0.57710
5	0.88099	0.81442	0.78873	0.65799	0.64848	0.49378	0.40065	0.85539	0.37472	0.39710	0.39245	0.41014	0.64527	0.41736
6	0.78100	0.72561	0.71935	0.75499	0.68641	0.52639	0.52569	0.83611	0.82666	0.78790	0.69164	0.65610	0.60426	0.49268
7	0.91863	0.87923	0.83218	0.75017	0.72688	0.76869	0.59787	0.88069	0.83861	0.82420	0.73584	0.66618	0.55634	0.43066
8	0.89813	0.88698	0.90393	0.87622	0.87764	0.82367	0.82493	0.78601	0.79508	0.81434	0.77764	0.78364	0.73221	0.76513
9	0.95900	0.95466	0.94388	0.88544	0.90938	0.85271	0.85856	0.92658	0.88302	0.85532	0.87964	0.79038	0.85934	0.73760
10	0.82516	0.90639	0.92986	0.85208	0.88505	0.82304	0.78370	0.90728	0.90685	0.86826	0.85705	0.81189	0.82619	0.83401
11	0.88246	0.90461	0.84310	0.85948	0.81778	0.80495	0.64640	0.72237	0.72872	0.72464	0.51486	0.72270	0.76971	0.50598
12	0.88895	0.90207	0.87833	0.82992	0.84855	0.78836	0.78415	0.83822	0.88037	0.88006	0.52440	0.74954	0.66461	0.60152

Percentage of power for AP head translation Table

Source	Sum of Squares	df	Mean Square	F
FO	0.00000	1	0.00000	0.000
OF	1.93500	6	0.32300	36.352 *
Surface	0.13600	1	0.13600	4.084
FOxOF	0.03487	6	0.00581	1.095
FOxSurface	0.01793	1	0.01793	2.240
OFxSurface	0.01834	6	0.00306	0.534
FOxOFxSurface	0.01151	6	0.00192	0.413
Subjects				
FOxS	0.16500	11	0.01504	
OFxS	0.58600	66	0.00887	
SurfacexS	0.36700	11	0.03335	
FOxOFxS	0.35000	66	0.00531	
FOxSurfacexS	0.08807	11	0.00801	
OFxSurfacexS	0.37800	66	0.00573	
FOxOFxSurfacexS	0.30600	66	0.00464	
Total		335		

* denotes p<.01

Head ML IMSD (cm)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.00473	0.00276	0.00469	0.00520	0.00380	0.00384	0.00333	0.00703	0.00728	0.00571	0.00656	0.00535	0.00524	0.00440
2	0.00676	0.00606	0.00753	0.00735	0.00720	0.00810	0.00811	0.00638	0.00673	0.00560	0.00613	0.00661	0.00612	0.00615
3	0.00934	0.00777	0.00876	0.00805	0.00792	0.00687	0.00684	0.00944	0.00819	0.00658	0.00756	0.01139	0.00700	0.00759
4	0.00634	0.00585	0.00617	0.00410	0.00421	0.00581	0.00720	0.00915	0.00926	0.00651	0.01257	0.00771	0.00755	0.01011
5	0.00483	0.00398	0.00354	0.00390	0.00343	0.00462	0.00413	0.00574	0.00580	0.00403	0.00521	0.00490	0.00352	0.00477
6	0.00636	0.00665	0.00779	0.00800	0.00749	0.00698	0.00635	0.00455	0.00516	0.00646	0.00495	0.00619	0.00542	0.00454
7	0.00280	0.00279	0.00332	0.00360	0.00364	0.00236	0.00287	0.00453	0.00458	0.00359	0.00608	0.00596	0.00494	0.00390
8	0.00681	0.00897	0.00784	0.00835	0.00726	0.00708	0.00684	0.00768	0.00895	0.00636	0.00668	0.00588	0.00713	0.00511
9	0.00893	0.00834	0.00822	0.00990	0.00887	0.00815	0.00799	0.00760	0.00884	0.00659	0.00845	0.00770	0.00808	0.00675
10	0.00587	0.00879	0.00703	0.00915	0.01029	0.01072	0.01299	0.00791	0.00743	0.00823	0.00757	0.00868	0.00968	0.01146
11	0.00556	0.00786	0.00793	0.00635	0.00512	0.00595	0.00652	0.00917	0.00959	0.00699	0.00753	0.00860	0.00842	0.00624
12	0.00635	0.00817	0.00596	0.00810	0.00770	0.00770	0.00719	0.00761	0.00652	0.00754	0.00699	0.00820	0.00847	0.00888

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.00433	0.00377	0.00318	0.00397	0.00527	0.00584	0.00679	0.00560	0.00526	0.01035	0.00542	0.00520	0.00709	0.00502
2	0.00623	0.00570	0.00720	0.00604	0.00823	0.00726	0.00665	0.00876	0.00677	0.00618	0.00576	0.00593	0.00833	0.00886
3	0.00872	0.00872	0.00842	0.00853	0.00909	0.00811	0.00678	0.00988	0.01060	0.00682	0.00889	0.00983	0.00823	0.00905
4	0.00726	0.00657	0.00407	0.00801	0.00531	0.01034	0.00733	0.01316	0.00742	0.01022	0.00821	0.00853	0.01398	0.00621
5	0.00531	0.00488	0.00432	0.00354	0.00404	0.00330	0.00230	0.00639	0.00599	0.00430	0.00417	0.00406	0.00489	0.00471
6	0.00612	0.00708	0.00541	0.00644	0.00608	0.00702	0.00713	0.00457	0.00445	0.00540	0.00560	0.00555	0.00653	0.00407
7	0.00403	0.00315	0.00289	0.00403	0.00382	0.00495	0.00372	0.00437	0.00391	0.00552	0.00502	0.00494	0.00394	0.00614
8	0.00784	0.00767	0.00833	0.00877	0.00931	0.00977	0.00847	0.00892	0.00692	0.00549	0.00731	0.00617	0.00616	0.00568
9	0.00862	0.00866	0.01044	0.00985	0.00895	0.01039	0.00934	0.00711	0.00839	0.00982	0.01056	0.00922	0.00971	0.01105
10	0.00574	0.00540	0.00564	0.01113	0.00915	0.01746	0.01605	0.00918	0.00901	0.00836	0.00701	0.01097	0.01002	0.01287
11	0.00828	0.00682	0.00735	0.00589	0.00620	0.00852	0.00634	0.01031	0.00833	0.00768	0.01602	0.00756	0.00694	0.00679
12	0.00775	0.00752	0.00741	0.00799	0.00814	0.00855	0.00598	0.00756	0.00784	0.00678	0.00845	0.00686	0.00760	0.00971

Head ML Translation Variability Table

Source	Sum of Squares	df	Mean Square	F
FO	0.00002	1	0.00002	13.643 *
OF	0.00002	6	0.00000	0.979
Surface	0.00002	1	0.00002	1.341
FOxOF	0.00002	6	0.00000	2.454
FOxSurface	0.00000	1	0.00000	0.117
OFxSurface	0.00001	6	0.00000	1.326
FOxOFxSurface	0.00001	6	0.00000	1.037
Subjects				
FOxS	0.00002	11	0.00000	
OFxS	0.00023	66	0.00000	
SurfacexS	0.00014	11	0.00001	
FOxOFxS	0.00009	66	0.00000	
FOxSurfacexS	0.00001	11	0.00000	
OFxSurfacexS	0.00012	66	0.00000	
FOxOFxSurfacexS	0.00012	66	0.00000	
Total		335		

* denotes p<.01

Ankle IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	2.01365	1.51731	1.46287	1.03759	0.76591	0.60869	0.62018	6.15455	5.09925	5.06065	4.26839	4.46533	4.28907	2.98934
2	0.81025	0.76616	0.81096	1.00524	0.82819	1.09636	1.03089	2.37553	2.25480	2.56049	2.15786	3.43758	1.94122	2.05879
3	3.44145	3.57183	2.88056	2.70079	2.35995	2.18943	1.85996	5.97419	8.09638	6.52247	4.27319	5.05899	6.70236	6.56396
4	0.80382	0.69261	0.86115	0.61334	0.40224	0.37947	0.71293	1.65338	1.77036	1.56937	2.19866	1.51244	0.97331	1.88602
5	1.45249	1.38357	1.34073	1.41872	1.46979	1.65297	1.50829	2.75216	2.91446	2.57138	2.91993	1.78597	2.33468	2.19669
6	1.11881	1.55600	1.80570	1.64337	1.79863	1.84341	1.83241	1.78006	2.24700	2.56459	1.78320	2.28443	2.99431	2.30374
7	0.67079	0.38635	0.34472	0.33124	0.39275	0.34883	0.45485	3.10985	3.11205	2.93714	3.41824	2.72996	1.84389	2.29683
8	1.54210	1.10952	1.20736	1.14058	1.27013	1.69667	1.38000	4.85646	4.12229	4.13414	3.73328	4.51943	4.04109	4.04200
9	1.06680	1.41744	1.02944	1.31611	1.51558	1.36073	1.22025	3.94742	2.28519	4.02072	5.00901	4.46991	3.77640	4.21488
10	1.46735	1.25159	0.92538	0.66959	0.72030	0.50789	0.52725	3.10678	3.65136	3.72313	2.76406	2.94378	1.69045	3.13482
11	0.74848	1.72367	0.75250	0.78816	1.01487	0.73182	0.68944	4.02294	4.79865	5.21560	3.57877	4.60859	5.21922	5.12741
12	0.59270	0.75758	0.69316	0.59048	0.59186	0.72286	1.00631	2.96794	4.08893	3.87200	3.64131	4.90379	4.56435	5.23714

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.61758	1.58533	1.59233	1.03694	0.97991	0.69730	0.73926	5.54142	5.61199	5.88684	4.13488	5.24898	4.98085	3.49657
2	0.81891	1.09827	0.99201	1.15090	1.10353	1.14368	1.00468	2.84152	2.81755	2.64970	2.40933	3.16091	2.77264	2.28355
3	3.13371	2.95425	2.71884	2.11544	2.48187	2.16485	1.83368	4.84555	6.48397	4.95636	5.58583	4.95198	6.34889	5.43251
4	0.69283	0.94225	0.44495	0.54623	0.59211	0.68482	0.34712	2.58427	1.50368	1.30962	2.04272	2.10442	1.99043	1.36865
5	1.73275	1.57412	1.09499	1.09210	1.52783	1.12636	0.77020	2.92601	3.14115	1.73385	2.89135	2.46686	2.43506	2.69697
6	1.29148	1.72344	1.44127	1.79481	1.85355	2.52340	2.26975	1.90603	1.77104	2.33605	2.87114	3.97410	3.34165	1.87606
7	0.77220	0.50645	0.47416	0.28968	0.45718	0.37738	0.47418	3.46995	3.02154	3.05352	2.62921	2.56462	2.86550	3.38736
8	1.29167	1.53798	1.19983	1.94172	1.46575	1.65340	1.94787	3.88255	3.96560	3.92157	4.59557	5.74591	4.66417	4.68417
9	1.43437	1.41773	1.58932	1.29577	1.47302	1.32609	1.18722	3.57119	3.32344	4.02646	5.38788	4.90058	4.83593	3.05845
10	0.99703	1.04160	0.97310	0.74719	0.49902	0.70845	0.50252	3.46473	3.49749	3.22740	2.43108	2.95122	2.51135	2.21492
11	1.10823	0.93883	1.39308	0.66350	0.74610	0.79856	0.68044	4.34190	4.74862	5.64129	5.94804	4.57975	4.82729	5.77929
12	0.93888	0.64829	0.55428	0.44621	0.68620	0.50189	0.70597	3.35240	3.17211	3.11750	5.03120	3.21921	2.98817	3.31553

Knee IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.06595	1.18088	1.05693	0.82371	0.83527	0.96846	1.02197	2.79921	2.63281	2.56398	2.22887	2.50904	1.94121	1.48387
2	2.24355	2.12225	2.01524	2.67465	2.31041	2.69415	2.29892	2.46690	2.03868	1.63170	1.94760	2.26165	1.92570	2.34007
3	3.30237	3.51398	2.82813	2.80131	2.11924	2.02830	1.78621	4.85988	6.71747	3.74272	2.02125	2.27417	4.44239	2.28499
4	0.88642	0.61278	0.88680	0.99024	0.62761	0.53964	0.88946	0.61867	0.84895	0.89349	0.67072	0.53310	0.50670	0.75730
5	1.59804	1.57311	1.29842	1.69581	2.09386	1.83319	2.61485	1.44445	2.04706	1.63267	2.35552	2.72252	2.21013	2.09213
6	1.37280	2.07392	2.14254	2.07013	2.31135	2.38719	2.34762	1.57570	1.73295	1.91688	1.85252	1.70529	2.12228	1.65916
7	0.50483	0.55380	0.48332	0.48016	0.74028	0.62059	0.57976	0.93290	0.98416	0.76462	0.84424	0.68596	0.49429	0.47854
8	3.28786	2.37774	2.42224	2.09298	2.19987	2.63760	1.86752	3.71820	3.21920	4.01715	4.36793	3.85958	3.10022	1.88665
9	1.26463	1.30429	1.08534	1.04643	1.14848	1.19559	1.03547	1.35594	0.79609	1.15065	1.11348	1.08641	0.88683	1.00198
10	0.32847	0.35078	0.38831	0.48366	0.53916	0.65638	0.53673	1.48633	1.43632	1.18992	1.01721	0.98134	0.94903	0.97246
11	1.15978	2.83767	0.99743	1.48542	1.77072	1.55750	1.38900	3.02351	1.53779	1.35504	1.73246	1.43252	2.08298	1.71704
12	0.71514	0.81657	1.02824	1.08692	0.77233	1.42620	1.83640	2.83240	3.43793	1.94070	1.84462	3.79979	3.91238	3.70996

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.95990	0.81834	1.03662	1.25780	1.00382	0.87862	1.27015	1.55908	2.14692	2.75653	2.00330	2.10841	2.03206	1.88227
2	2.25462	3.25129	2.71515	2.85217	2.69879	2.34684	2.49855	2.58909	2.51074	2.44442	2.62390	2.43145	2.53987	2.15646
3	3.39246	2.97431	2.58223	1.94401	2.34872	2.04781	1.67905	4.20721	5.72703	2.80308	3.80247	2.25992	4.16065	2.73863
4	0.94064	0.99464	0.82099	0.66083	0.93956	1.17526	0.83486	2.79415	0.83751	0.69825	0.49233	0.72037	0.76155	0.48253
5	2.03007	2.94574	1.96453	2.68781	3.63597	2.91681	2.41839	1.64329	1.48011	1.88406	2.05477	1.75151	1.79903	2.91769
6	1.61836	1.88232	1.61606	2.12642	2.21911	3.11828	2.72575	1.35355	1.38477	1.74387	2.31485	2.78646	2.78392	1.60310
7	0.57951	0.65036	0.69940	0.39961	0.82899	0.55372	0.64071	0.86335	0.68324	1.10523	0.59216	0.53112	0.60596	0.70877
8	3.33661	4.02887	2.57478	3.20483	2.42400	2.38476	2.65110	4.20387	3.66161	3.39528	3.87394	4.39078	3.77630	2.69002
9	1.49684	1.54602	1.58454	1.23998	1.12383	1.06489	0.90445	1.23891	1.30602	1.35343	1.30170	1.30980	1.28752	1.08370
10	0.39922	0.40939	0.33663	0.47553	0.57450	0.68342	0.60423	1.12870	1.08817	0.95823	1.10185	1.33525	0.95030	0.94232
11	1.45699	1.34089	2.01806	1.64865	1.94932	1.55054	1.44723	1.46678	0.85331	3.66416	3.10539	2.49717	1.05242	1.90572
12	0.57907	0.63223	0.69045	0.64176	0.79470	0.79581	1.25116	1.90290	2.08170	1.48777	3.07612	2.41017	3.33823	1.67248

Knee Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
FO	0.52300	1	0.52300	1.049
OF	2.49900	6	0.41600	0.770
Surface	16.73700	1	16.73700	5.298
FOxOF	0.85100	6	0.14200	0.760
FOxSurface	0.30000	1	0.30000	1.490
OFxSurface	1.42300	6	0.23700	0.948
FOxOFxSurface	0.96900	6	0.16200	0.922
Subjects				
FOxS	5.48200	11	0.49800	
OFxS	35.69300	66	0.54100	
SurfacexS	34.75000	11	3.15900	
FOxOFxS	12.31000	66	0.18700	
FOxSurfacexS	2.21800	11	0.20200	
OFxSurfacexS	16.51700	66	0.25000	
FOxOFxSurfacexS	11.56600	66	0.17500	
Total		335		

Hip IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.06595	1.18088	1.05693	0.82371	0.83527	0.96846	1.02197	2.79921	2.63281	2.56398	2.22887	2.50904	1.94121	1.48387
2	2.24355	2.12225	2.01524	2.67465	2.31041	2.69415	2.29892	2.46690	2.03868	1.63170	1.94760	2.26165	1.92570	2.34007
3	3.30237	3.51398	2.82813	2.80131	2.11924	2.02830	1.78621	4.85988	6.71747	3.74272	2.02125	2.27417	4.44239	2.28499
4	0.88642	0.61278	0.88680	0.99024	0.62761	0.53964	0.88946	0.61867	0.84895	0.89349	0.67072	0.53310	0.50670	0.75730
5	1.59804	1.57311	1.29842	1.69581	2.09386	1.83319	2.61485	1.44445	2.04706	1.63267	2.35552	2.72252	2.21013	2.09213
6	1.37280	2.07392	2.14254	2.07013	2.31135	2.38719	2.34762	1.57570	1.73295	1.91688	1.85252	1.70529	2.12228	1.65916
7	0.50483	0.55380	0.48332	0.48016	0.74028	0.62059	0.57976	0.93290	0.98416	0.76462	0.84424	0.68596	0.49429	0.47854
8	3.28786	2.37774	2.42224	2.09298	2.19987	2.63760	1.86752	3.71820	3.21920	4.01715	4.36793	3.85958	3.10022	1.88665
9	1.26463	1.30429	1.08534	1.04643	1.14848	1.19559	1.03547	1.35594	0.79609	1.15065	1.11348	1.08641	0.88683	1.00198
10	0.32847	0.35078	0.38831	0.48366	0.53916	0.65638	0.53673	1.48633	1.43632	1.18992	1.01721	0.98134	0.94903	0.97246
11	1.15978	2.83767	0.99743	1.48542	1.77072	1.55750	1.38900	3.02351	1.53779	1.35504	1.73246	1.43252	2.08298	1.71704
12	0.71514	0.81657	1.02824	1.08692	0.77233	1.42620	1.83640	2.83240	3.43793	1.94070	1.84462	3.79979	3.91238	3.70996

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.95990	0.81834	1.03662	1.25780	1.00382	0.87862	1.27015	1.55908	2.14692	2.75653	2.00330	2.10841	2.03206	1.88227
2	2.25462	3.25129	2.71515	2.85217	2.69879	2.34684	2.49855	2.58909	2.51074	2.44442	2.62390	2.43145	2.53987	2.15646
3	3.39246	2.97431	2.58223	1.94401	2.34872	2.04781	1.67905	4.20721	5.72703	2.80308	3.80247	2.25992	4.16065	2.73863
4	0.94064	0.99464	0.82099	0.66083	0.93956	1.17526	0.83486	2.79415	0.83751	0.69825	0.49233	0.72037	0.76155	0.48253
5	2.03007	2.94574	1.96453	2.68781	3.63597	2.91681	2.41839	1.64329	1.48011	1.88406	2.05477	1.75151	1.79903	2.91769
6	1.61836	1.88232	1.61606	2.12642	2.21911	3.11828	2.72575	1.35355	1.38477	1.74387	2.31485	2.78646	2.78392	1.60310
7	0.57951	0.65036	0.69940	0.39961	0.82899	0.55372	0.64071	0.86335	0.68324	1.10523	0.59216	0.53112	0.60596	0.70877
8	3.33661	4.02887	2.57478	3.20483	2.42400	2.38476	2.65110	4.20387	3.66161	3.39528	3.87394	4.39078	3.77630	2.69002
9	1.49684	1.54602	1.58454	1.23998	1.12383	1.06489	0.90445	1.23891	1.30602	1.35343	1.30170	1.30980	1.28752	1.08370
10	0.39922	0.40939	0.33663	0.47553	0.57450	0.68342	0.60423	1.12870	1.08817	0.95823	1.10185	1.33525	0.95030	0.94232
11	1.45699	1.34089	2.01806	1.64865	1.94932	1.55054	1.44723	1.46678	0.85331	3.66416	3.10539	2.49717	1.05242	1.90572
12	0.57907	0.63223	0.69045	0.64176	0.79470	0.79581	1.25116	1.90290	2.08170	1.48777	3.07612	2.41017	3.33823	1.67248

Trunk IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.91153	0.78645	0.85329	0.70408	0.81946	1.01964	0.94154	1.45695	2.11108	1.65333	2.56209	2.16535	1.94048	1.60146
2	2.12143	2.50562	2.36717	2.27554	1.66879	2.19288	2.09898	1.76067	2.00866	2.10610	2.26177	1.94911	1.92135	2.23897
3	2.12631	1.91790	1.41577	1.74616	1.57566	1.54535	1.39251	2.78501	2.13720	1.92022	1.56936	2.00622	2.18552	2.22806
4	1.82207	2.61408	2.38198	2.66986	3.02509	2.68790	2.53213	3.08503	3.06862	3.05703	3.09712	2.65478	3.08285	2.23767
5	4.49985	3.36754	3.33321	3.27163	3.34038	3.29928	3.24050	1.68642	1.60383	1.38506	1.39905	1.47159	1.03771	1.04437
6	2.39831	2.43794	2.69764	1.85836	1.93437	2.20648	1.82794	1.74010	1.65537	2.22130	1.76112	2.05296	1.93021	1.84973
7	1.17925	1.50295	1.46957	1.44937	1.68358	1.60386	1.52201	2.42811	2.47258	2.39598	2.40868	2.42204	2.11570	1.92922
8	1.92889	2.09885	2.44053	2.25546	2.11071	2.07506	2.13366	3.10605	2.80045	2.39985	1.91236	1.81485	2.09573	1.62508
9	2.41419	2.27885	2.27520	2.06367	3.32774	3.29630	3.45828	2.09641	2.05368	1.90045	1.95198	2.25179	1.91945	2.04340
10	0.71735	0.77778	0.85656	0.90704	1.14278	1.21135	2.29935	5.09690	4.12187	3.21021	2.89640	3.25400	2.03254	2.74663
11	8.04564	6.51852	7.11084	5.96972	5.71633	5.23672	5.01343	8.29671	6.74678	4.96103	3.64499	3.37787	4.32973	3.53095
12	8.21161	5.63993	4.73985	3.77664	3.56527	3.26793	2.72082	7.50101	6.55646	5.82635	3.74371	3.77137	4.30866	3.24852

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.72482	0.62738	0.67120	0.89287	0.97531	1.07578	1.27800	1.55921	1.37373	1.23377	1.40379	1.36052	1.67079	1.96312
2	1.92366	1.79415	2.08733	1.49270	2.66616	2.13141	1.63131	2.34903	2.31095	2.06378	2.16241	2.41364	2.21757	1.88309
3	2.25237	1.59195	1.83425	1.60796	1.94588	1.53668	1.41944	1.78086	1.70983	1.49588	2.11770	2.06363	2.23639	1.80606
4	1.83151	2.31412	2.01717	2.67207	3.11126	2.71129	2.75191	2.85403	3.19733	2.92631	2.72880	3.02578	2.83611	2.49389
5	3.17684	2.77618	2.40771	1.69402	2.48750	1.88410	1.55346	1.99161	2.08613	1.49645	1.51516	1.37723	1.62888	1.52584
6	2.24959	2.15724	1.91825	2.05609	2.22414	2.11250	2.03571	1.65973	1.87775	2.03897	1.89202	1.94147	1.83761	1.72298
7	1.26528	1.51383	1.76238	1.97886	1.89224	1.73113	1.50419	2.40718	2.29723	2.61051	2.13893	2.28614	1.87741	1.82768
8	2.43599	2.53261	2.36387	2.16497	2.72125	2.44706	2.34069	2.29373	3.25243	2.04096	1.69398	2.10135	2.23142	2.29759
9	1.91727	2.29219	2.22498	3.60828	3.15182	3.20613	3.01653	1.98229	1.90971	1.73439	2.60210	2.32302	2.60065	3.05373
10	0.62460	0.62866	0.80810	0.98661	1.41167	1.66605	1.94955	4.60831	3.77073	3.47670	3.24759	3.74127	2.97546	2.96572
11	7.84400	7.90328	6.27796	6.20133	5.79344	5.73521	4.51149	7.41066	5.66465	5.89306	4.75559	5.35348	4.45362	4.56990
12	7.81324	6.25059	5.51589	4.47890	5.05192	4.61661	3.75461	6.54605	6.39867	5.30613	4.97764	3.16930	3.15487	2.88267

Trunk Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
FO	0.00608	1	0.00608	0.022
OF	19.85200	6	3.30900	2.541
Surface	0.67900	1	0.67900	0.107
FOxOF	1.85500	6	0.30900	3.156 *
FOxSurface	0.01102	1	0.01102	0.016
OFxSurface	2.75500	6	0.45900	1.944
FOxOFxSurface	0.53400	6	0.08895	0.677
Subjects				
FOxS	3.11100	11	0.28300	
OFxS	85.95500	66	1.30200	
SurfacexS	70.03300	11	6.36700	
FOxOFxS	6.46500	66	0.09796	
FOxSurfacexS	7.56900	11	0.68800	
OFxSurfacexS	15.58800	66	0.23600	
FOxOFxSurfacexS	8.66600	66	0.13100	
Total		335		

* denotes p<.01

Cervical IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.38880	0.65744	0.69672	0.66168	0.99961	0.76851	0.78025	1.75709	1.66252	1.57642	3.03778	1.31093	1.72001	1.61127
2	2.03073	2.76731	2.42284	2.53698	3.61018	2.75180	2.76515	4.19550	5.26029	4.62921	4.57815	4.80490	4.73791	3.93262
3	3.33175	3.22544	2.72201	3.34171	2.67526	2.96455	2.55816	3.71581	4.26736	2.89122	2.19547	1.94234	3.13926	3.29896
4	1.98257	2.42268	2.40514	2.66386	2.66392	2.36134	3.74179	2.68272	2.68129	2.88148	2.83153	2.97375	3.86636	2.61471
5	10.97062	7.67172	7.58021	7.58898	7.16390	7.27299	6.99627	10.09429	8.70495	7.00621	5.93010	5.85559	5.70830	5.32104
6	1.50626	1.97065	2.15371	2.32612	3.71358	3.94507	4.20002	1.36673	1.34781	1.53068	2.24021	2.70753	3.14282	3.27292
7	2.47758	1.86305	1.32025	1.39367	1.77756	1.39113	1.32497	1.84240	2.00648	1.27333	1.42421	1.59524	1.15826	1.16833
8	1.26105	1.32084	1.34480	1.58832	1.99715	2.13898	2.15193	1.47204	1.22621	1.00289	0.85270	1.14994	1.18880	1.56422
9	3.72498	3.33630	2.88695	3.34984	5.38884	3.96170	4.52421	3.89273	3.26765	2.35035	2.75653	3.32669	3.36336	3.61619
10	0.69581	1.08046	0.60643	0.56389	0.62386	0.89083	1.32539	1.37400	1.20518	0.99677	1.46964	0.95837	1.29716	1.49747
11	7.54114	3.05737	2.60924	2.31138	2.33003	5.33368	2.23775	2.65645	2.59023	2.47041	2.02862	2.46308	2.65097	3.03924
12	2.14133	2.46864	2.30181	2.19267	1.36642	2.27782	2.16832	3.31273	1.96310	2.83927	2.00140	2.08063	2.90380	1.66543

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.74771	0.54766	0.86896	1.60172	1.30599	0.89388	1.43579	1.52171	1.53990	1.21241	1.10450	1.28002	3.84941	3.35172
2	1.89906	2.90722	2.66704	3.78843	2.89035	3.58142	2.88631	4.01319	4.07101	4.79955	4.97403	5.08376	4.70332	3.86406
3	2.97930	2.84790	2.76025	2.37418	3.15345	3.53329	3.02138	3.30849	4.22548	2.87826	2.96782	3.08755	2.26529	3.10399
4	2.24951	2.64720	2.40200	3.57406	3.90213	3.58326	3.39539	2.73523	3.02491	2.58422	2.62989	2.93994	3.21004	2.68198
5	10.53384	8.04425	7.16255	6.18436	6.63647	6.92107	5.43879	10.31676	10.05024	7.90896	7.95851	6.65004	6.63504	6.17042
6	1.45128	3.62780	1.30587	2.92183	3.82695	6.09595	5.03196	1.24193	1.35596	1.89851	2.73465	3.97588	3.57461	2.93434
7	2.08023	1.75622	1.73034	1.65882	1.71551	1.41727	1.43186	1.47094	1.45039	1.41181	1.42116	1.32068	1.26188	1.52596
8	1.88571	1.53031	1.35313	2.38629	1.74866	2.48421	2.20221	1.21790	1.64934	1.31324	1.15271	1.39436	1.80707	1.73707
9	3.42901	4.02790	4.53189	5.57879	5.96292	4.44425	3.61497	3.27551	4.15190	4.10620	5.52901	5.07329	5.36172	5.42444
10	1.07390	0.79634	0.88528	0.83698	0.70006	0.86317	1.08677	1.66294	1.47908	0.93483	1.29636	1.28579	1.55165	1.51978
11	3.88465	2.62618	3.06839	4.74763	2.83502	2.45829	2.48306	4.22216	2.17738	3.10422	6.99224	3.22587	2.64714	2.66135
12	3.54369	2.56708	1.90246	1.61440	2.15300	2.21576	2.11702	2.12496	1.69963	1.76010	4.56075	1.61201	2.06316	1.64687

Cervical Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
FO	4.56500	1	4.56500	7.549
OF	8.53700	6	1.42300	0.802
Surface	0.86300	1	0.86300	0.270
FOxOF	6.21600	6	1.03600	2.542
FOxSurface	0.78700	1	0.78700	0.840
OFxSurface	2.11700	6	0.35300	0.898
FOxOFxSurface	0.64900	6	0.10800	0.303
Subjects				
FOxS	6.65200	11	0.60500	
OFxS	117.05000	66	1.77300	
SurfacexS	35.13600	11	3.19400	
FOxOFxS	26.89800	66	0.40800	
FOxSurfacexS	10.31000	11	0.93700	
OFxSurfacexS	25.92000	66	0.39300	
FOxOFxSurfacexS	23.52600	66	0.35600	
Total		335		

Percentage of power for hip rotation at TF (Individual Means) (%)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.53829	0.28134	0.55943	0.45075	0.55047	0.46836	0.49958	0.82044	0.81258	0.77692	0.67385	0.80092	0.79382	0.78385
2	0.89026	0.86114	0.85712	0.80745	0.85972	0.83685	0.76680	0.87164	0.66329	0.83395	0.72656	0.71882	0.71763	0.52592
3	0.73063	0.71808	0.73140	0.65600	0.83981	0.74435	0.76445	0.86347	0.86988	0.91294	0.88546	0.79243	0.85616	0.78157
4	0.75536	0.85189	0.66909	0.73410	0.82294	0.79729	0.77952	0.68733	0.70433	0.66665	0.73747	0.73601	0.58748	0.68226
5	0.74415	0.78050	0.75227	0.73260	0.63239	0.68573	0.65370	0.86272	0.82698	0.80321	0.72893	0.69078	0.70889	0.65011
6	0.45501	0.24602	0.07683	0.16755	0.28694	0.24632	0.30962	0.75037	0.62811	0.42544	0.49810	0.60356	0.43617	0.37777
7	0.47705	0.63730	0.66885	0.74895	0.67447	0.63842	0.47200	0.65083	0.79847	0.84634	0.50127	0.74655	0.64171	0.56385
8	0.70858	0.60582	0.61093	0.63780	0.69679	0.72805	0.67465	0.70698	0.75697	0.68711	0.67101	0.59672	0.76483	0.74932
9	0.56606	0.48918	0.40428	0.59700	0.38397	0.63082	0.64638	0.70074	0.82969	0.78869	0.74285	0.77939	0.76293	0.69329
10	0.26091	0.61422	0.56265	0.63030	0.76176	0.76183	0.73736	0.93464	0.94129	0.84698	0.82589	0.87294	0.79144	0.67311
11	0.54023	0.66694	0.71471	0.69400	0.53420	0.52932	0.43519	0.74276	0.82178	0.80091	0.68694	0.34778	0.80669	0.60448
12	0.31403	0.61874	0.63164	0.34065	0.52024	0.26991	0.23173	0.50251	0.44981	0.50212	0.66903	0.58616	0.41259	0.43016

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.27615	0.46033	0.56173	0.50501	0.56562	0.52854	0.39266	0.77838	0.64970	0.85966	0.85743	0.81646	0.81691	0.80454
2	0.88684	0.89848	0.89916	0.83893	0.82753	0.76417	0.74819	0.82860	0.78954	0.86336	0.75972	0.79903	0.71247	0.63230
3	0.73562	0.52741	0.60114	0.86088	0.84925	0.69258	0.60376	0.90143	0.88802	0.83940	0.85030	0.83821	0.78300	0.70537
4	0.71794	0.84351	0.78986	0.77261	0.78078	0.82080	0.76774	0.75154	0.83135	0.63031	0.61369	0.71686	0.61470	0.62227
5	0.74567	0.71682	0.76498	0.64164	0.59907	0.59562	0.58058	0.88309	0.41329	0.41385	0.44136	0.44263	0.79789	0.62843
6	0.41377	0.34018	0.29313	0.38129	0.17400	0.39318	0.48255	0.37903	0.69299	0.74964	0.58921	0.54811	0.47647	0.53148
7	0.50563	0.66009	0.66272	0.73555	0.65731	0.56357	0.61395	0.78114	0.74816	0.79639	0.77435	0.78774	0.62518	0.60543
8	0.74585	0.75515	0.71193	0.66372	0.75368	0.70874	0.71674	0.76083	0.80178	0.78396	0.73177	0.85015	0.80617	0.80213
9	0.69085	0.68677	0.50375	0.80564	0.75276	0.71446	0.78421	0.88217	0.78818	0.79689	0.80274	0.69973	0.80855	0.75592
10	0.54980	0.65022	0.46133	0.53260	0.79282	0.66460	0.75580	0.90416	0.80979	0.90971	0.75578	0.83986	0.75195	0.75947
11	0.53695	0.47022	0.62853	0.41290	0.67310	0.68973	0.51029	0.55010	0.71669	0.64044	0.44416	0.77079	0.71053	0.50245
12	0.65584	0.42775	0.18929	0.21904	0.37219	0.19861	0.30439	0.65252	0.82881	0.78981	0.49085	0.64996	0.50925	0.58521

Percentage of power for ankle rotation at TF (Individual Means) (%)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.82045	0.66491	0.79503	0.44405	0.41122	0.14136	0.01005	0.44687	0.30278	0.35336	0.07830	0.12330	0.08479	0.08289
2	0.84692	0.74490	0.78138	0.70665	0.75202	0.76547	0.68994	0.09222	0.15581	0.16039	0.09880	0.02954	0.03405	0.03319
3	0.01500	0.01039	0.09856	0.01640	0.01419	0.01922	0.00670	0.12880	0.08759	0.10981	0.04555	0.03299	0.07669	0.01185
4	0.71827	0.82581	0.71811	0.74715	0.82383	0.72934	0.71898	0.33556	0.20819	0.09051	0.42779	0.16905	0.16736	0.06278
5	0.69004	0.48722	0.43503	0.56160	0.52741	0.61016	0.40462	0.57987	0.12823	0.13214	0.06593	0.12887	0.06875	0.06400
6	0.17109	0.02608	0.07243	0.01495	0.02333	0.03810	0.00358	0.31490	0.18395	0.01587	0.10882	0.15610	0.09239	0.02934
7	0.60537	0.16870	0.04980	0.06145	0.17619	0.17320	0.12463	0.47670	0.32669	0.11955	0.06225	0.07190	0.04355	0.02968
8	0.56468	0.48785	0.55163	0.52395	0.66699	0.68398	0.60327	0.07088	0.08656	0.11183	0.15566	0.04335	0.17754	0.14122
9	0.62441	0.48370	0.41896	0.51320	0.42561	0.70102	0.66314	0.49545	0.43188	0.44281	0.46732	0.39168	0.35332	0.18798
10	0.91122	0.89772	0.79486	0.48460	0.31657	0.32719	0.36368	0.53646	0.37857	0.53523	0.12906	0.17639	0.22708	0.10753
11	0.02286	0.27768	0.18581	0.23080	0.08955	0.17946	0.21273	0.03116	0.02896	0.04978	0.05066	0.03496	0.09512	0.02568
12	0.72585	0.70460	0.54138	0.36795	0.61970	0.17327	0.21503	0.22340	0.07749	0.07632	0.12219	0.11166	0.06200	0.14051

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.77855	0.78373	0.78906	0.40935	0.44738	0.25180	0.08155	0.30164	0.46801	0.50281	0.09517	0.03017	0.11503	0.17684
2	0.80976	0.80346	0.77538	0.76696	0.72787	0.67175	0.67158	0.33451	0.16112	0.16359	0.09636	0.10039	0.04205	0.01866
3	0.00291	0.01698	0.03021	0.38220	0.35184	0.03642	0.01428	0.01405	0.13157	0.07057	0.04063	0.04816	0.01430	0.00990
4	0.64111	0.79282	0.82353	0.78955	0.81478	0.88201	0.77202	0.25913	0.24400	0.10934	0.21927	0.11252	0.15979	0.06504
5	0.54739	0.38053	0.41315	0.25378	0.12190	0.11853	0.06851	0.38291	0.07896	0.09259	0.16064	0.09681	0.10131	0.03002
6	0.11033	0.02627	0.05348	0.04182	0.02689	0.02087	0.08157	0.12776	0.07904	0.02018	0.18980	0.17030	0.07525	0.02141
7	0.73750	0.24822	0.03084	0.07569	0.07494	0.11484	0.08279	0.50397	0.34947	0.21938	0.15690	0.08040	0.03674	0.01141
8	0.53008	0.67250	0.71312	0.66714	0.55356	0.61169	0.69565	0.25430	0.15480	0.22096	0.24521	0.24670	0.11964	0.10256
9	0.58030	0.79879	0.55602	0.79345	0.70543	0.63423	0.73824	0.45336	0.29924	0.33876	0.51504	0.39320	0.53305	0.32095
10	0.87730	0.85259	0.86998	0.37288	0.33780	0.34467	0.34096	0.15375	0.21265	0.17053	0.22295	0.14085	0.16828	0.20442
11	0.06090	0.24093	0.04132	0.14265	0.36329	0.45777	0.19318	0.02710	0.01360	0.11097	0.01771	0.11368	0.03026	0.04245
12	0.78284	0.73215	0.50719	0.56488	0.55648	0.54885	0.31363	0.09401	0.11739	0.14138	0.07593	0.06387	0.11588	0.02732

Hip/ankle IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.37407	0.34838	0.53485	0.63255	0.95042	1.22804	1.20106	0.47920	0.84460	0.74759	0.76800	0.81975	0.66599	0.82629
2	7.09715	6.46326	6.65730	4.92435	6.68367	4.64603	3.89693	2.74893	3.01613	2.59516	3.49815	2.32067	3.45984	2.93041
3	1.93190	1.69178	1.80881	1.60915	1.89275	1.98946	1.95670	1.05027	0.70779	0.66576	0.81129	0.70473	0.55744	0.51402
4	0.61884	1.09884	0.73317	0.90310	1.10930	1.65501	0.93041	0.70097	0.67842	0.89288	0.47090	0.81689	1.02595	0.66458
5	5.32044	6.07921	5.40681	6.98695	5.51724	3.43505	4.00374	4.28213	3.64955	3.54622	2.73548	4.38995	3.23193	3.01012
6	2.02504	2.10191	2.22513	2.13610	2.11047	2.05510	1.99568	0.88230	0.67724	0.92103	1.25858	0.92937	0.77683	0.94741
7	0.93475	1.92793	2.93801	3.33210	2.80234	3.34811	2.30359	0.37252	0.36564	0.45664	0.43452	0.45620	0.61269	0.41750
8	1.23386	1.65885	1.65311	1.87930	1.95509	1.45629	1.66536	0.51933	0.56551	0.60677	0.58617	0.52037	0.56873	0.49711
9	3.95565	3.72229	4.05340	3.48665	2.76142	2.56925	2.56286	1.35713	2.01468	1.21768	1.00909	0.97942	1.11002	1.03995
10	0.35220	0.47767	0.69069	1.06385	1.36199	1.98913	2.17555	0.87456	0.70884	0.54607	0.70398	0.68780	1.05288	0.57998
11	2.22304	1.99214	2.86118	2.64425	1.96888	2.96288	3.37834	0.97817	0.89533	0.86494	1.28393	0.95638	0.82161	0.56145
12	1.91887	2.08040	2.15952	2.60030	2.59420	2.21966	1.83394	0.79531	0.42133	0.71873	0.76836	0.76351	0.84572	0.69785

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.27270	0.37710	0.51660	0.97593	1.03005	1.39648	1.26899	0.40389	0.56711	0.47059	0.93402	0.91298	0.85016	1.16345
2	5.68010	6.01794	5.76838	4.74693	5.13075	4.57643	4.81837	3.03159	2.36254	2.66138	3.00768	2.40118	2.58118	2.46289
3	2.08383	1.95396	2.05412	2.08537	1.83771	1.87904	1.89702	0.95359	0.77359	0.90960	0.69320	0.75548	0.50948	0.58228
4	1.03167	0.92905	1.83941	1.31651	0.98967	1.23413	1.97834	0.58253	0.75628	0.76496	0.40482	0.40014	0.51060	0.54564
5	4.90892	5.00397	7.05959	7.23521	4.60462	6.59684	9.57787	4.13225	3.40438	5.70025	3.07907	3.27824	2.94382	2.70097
6	1.94462	2.26504	2.32940	2.23181	2.26722	2.16362	1.94866	0.72971	1.21677	1.08526	1.05998	0.79902	1.08810	1.42074
7	0.78185	1.69194	2.01357	3.19569	2.61942	3.17576	2.25954	0.34098	0.46495	0.43300	0.46473	0.50748	0.37938	0.35577
8	1.38096	1.40062	2.21441	1.37938	1.81371	1.75251	1.58318	0.82710	0.72000	0.78390	0.53562	0.48371	0.54720	0.60482
9	3.21671	3.55832	3.50117	3.81725	3.03607	3.14614	3.21186	1.78947	1.64489	1.34318	1.20290	1.19833	0.95167	1.44102
10	0.48439	0.53141	0.65130	1.11735	1.87912	1.70918	2.62052	0.63232	0.57300	0.63747	0.80256	0.74444	0.81675	0.87744
11	1.79061	2.23197	2.48142	3.28694	3.07045	3.20050	2.98962	0.68171	0.72344	0.75778	0.86712	0.74882	0.72033	0.48759
12	1.54582	1.56481	1.93963	2.94736	1.75707	3.25671	2.04195	0.83659	0.78680	0.75632	0.72196	0.86574	1.08764	0.87649

Cervical/trunk IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.64285	0.83597	0.81545	0.94560	1.26506	0.77996	0.84327	1.16689	0.78954	0.98591	1.18459	0.66114	0.92879	0.96417
2	0.93886	1.13127	1.06830	1.18165	2.15188	1.32654	1.32044	2.35814	2.68308	2.25221	2.02415	2.56828	2.47836	1.75410
3	1.57087	1.67986	1.91004	1.83940	1.69710	1.91203	1.83979	1.37996	2.00819	1.50567	1.43967	0.96816	1.42422	1.49080
4	1.08808	0.92562	1.04654	1.00910	0.88497	0.87676	1.41806	0.87169	0.89169	0.94175	0.91160	1.12070	1.25011	1.17147
5	2.78769	2.61332	2.77113	3.20460	2.22491	2.27229	2.66285	5.98563	5.44230	5.09453	4.25474	3.97561	5.73418	5.15652
6	0.67630	0.79592	0.76017	1.22970	1.94193	1.73956	2.30948	0.77092	0.81418	0.68858	1.31283	1.30598	1.60165	1.80142
7	2.25626	1.24296	0.89696	1.01325	1.06472	0.86733	0.87051	0.76310	0.81161	0.53073	0.59108	0.65092	0.56044	0.62855
8	0.65752	0.62585	0.54766	0.70820	0.91658	1.05859	1.01498	0.47523	0.43606	0.41376	0.44782	0.63100	0.58760	0.98016
9	1.55909	1.69322	1.29683	1.65960	1.62026	1.19312	1.32559	1.85686	1.53379	1.21063	1.39891	1.43377	1.71888	1.73939
10	0.96997	1.42065	0.71804	0.63445	0.55329	0.74497	0.57494	0.26996	0.29255	0.31292	0.51559	0.29545	0.73587	0.54888
11	0.93897	0.47022	0.36722	0.38640	0.39576	0.98002	0.44784	0.32213	0.38387	0.49656	0.56188	0.73242	0.63922	0.91441
12	0.26077	0.48838	0.48349	0.61850	0.40192	0.79990	0.89355	0.44164	0.29941	0.48913	0.53133	0.55978	0.70175	0.53117

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.05800	0.91775	1.29514	1.82640	1.41568	0.83732	1.25604	1.00996	1.11337	0.98269	0.78674	0.93768	2.28249	1.83911
2	0.98721	1.61361	1.33267	2.53797	1.08409	1.74518	1.78641	1.79412	1.77146	2.40979	2.38085	2.11467	2.15620	2.05525
3	1.32239	1.75058	1.50717	1.43368	1.59853	2.34161	2.07651	1.86703	2.41639	1.92505	1.37966	1.50073	1.01292	1.72131
4	1.29898	1.17115	1.25680	1.33524	1.24985	1.33082	1.19995	0.95423	0.94405	0.88680	0.96620	0.96818	1.13894	1.07526
5	3.96698	2.91343	2.96967	3.77379	2.92273	4.03433	4.02614	5.20702	4.80255	5.28841	5.24770	4.91844	4.09612	4.03743
6	0.64090	1.68169	0.68294	1.41979	1.74364	2.89366	2.47375	0.74578	0.71572	0.95618	1.47025	2.06634	1.99105	1.76520
7	1.65295	1.17418	0.96850	0.83803	0.90749	0.83582	0.94758	0.61776	0.63169	0.53934	0.66476	0.58122	0.67180	0.83754
8	0.77474	0.60424	0.57304	1.10486	0.64191	1.01886	0.96977	0.53069	0.52736	0.64344	0.68267	0.67931	0.81011	0.75604
9	1.81542	1.90438	2.13041	1.60013	1.92464	1.41252	1.27113	1.57074	2.15667	2.33609	2.12482	2.18465	2.09025	1.89128
10	1.72087	1.30266	1.09871	0.85826	0.49384	0.53919	0.55108	0.40572	0.44069	0.27188	0.40017	0.35084	0.52386	0.51695
11	0.54475	0.33207	0.50425	0.78168	0.49148	0.43509	0.55238	0.58220	0.38969	0.53495	1.44324	0.60931	0.59085	0.58148
12	0.45404	0.42711	0.35673	0.36825	0.43294	0.49019	0.55892	0.32543	0.26359	0.33023	0.81833	0.49781	0.67136	0.57169

Cervical/trunk variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	1.16200	1	1.16200	8.228
OF	1.52500	6	0.25400	1.202
Surface	0.94200	1	0.94200	0.328
FOxOF	0.57300	6	0.09544	1.238
FOxSurface	0.15600	1	0.15600	0.544
OFxSurface	0.24900	6	0.04142	0.354
FOxOFxSurface	0.55100	6	0.09187	0.929
Subjects				
FOxS	1.55300	11	0.14100	
OFxS	13.95100	66	0.21100	
SurfacexS	31.55000	11	2.86800	
FOxOFxS	5.08900	66	0.07711	
FOxSurfacexS	3.15600	11	0.28700	
OFxSurfacexS	7.73100	66	0.11700	
FOxOFxSurfacexS	6.53000	66	0.09893	
Total		335		

Trunk/hip IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.29716	1.48781	1.19627	1.10625	1.19071	1.43423	1.45797	0.53438	0.49190	0.45727	0.83163	0.68139	0.67787	0.68209
2	0.37389	0.51097	0.44883	0.46000	0.32385	0.47518	0.53657	0.26909	0.30273	0.31659	0.31716	0.26492	0.28939	0.38927
3	0.32041	0.31938	0.27166	0.40115	0.35365	0.35755	0.38659	0.46148	0.38363	0.44220	0.45860	0.56272	0.63231	0.67253
4	3.66288	3.48255	3.87527	4.85570	7.00803	4.50515	4.29935	2.74205	3.04894	2.44340	3.46702	2.79574	3.12513	2.36335
5	0.70265	0.47498	0.55113	0.49105	0.50564	0.59526	0.69310	0.14310	0.15091	0.15299	0.17682	0.18751	0.14165	0.16041
6	1.09351	0.75590	0.67077	0.53205	0.51065	0.60763	0.51556	1.22228	1.19058	0.98858	0.87391	0.97935	0.84149	0.86429
7	1.85468	2.02329	1.48835	1.33985	1.55009	1.40254	1.51295	2.13187	2.19076	1.81811	1.71591	2.01623	1.88128	2.08246
8	1.05454	1.21441	1.23076	1.16980	0.94543	0.97791	0.91134	1.29575	1.30928	0.97437	0.88390	0.76978	0.98590	0.80247
9	0.58576	0.44267	0.56827	0.46170	0.79446	0.95643	1.13787	0.39133	0.45422	0.37863	0.40045	0.53501	0.53390	0.51334
10	1.38807	1.32848	1.36226	1.26790	1.32783	1.33850	2.00975	1.87554	1.64401	1.60147	1.58400	1.61891	1.34370	1.60313
11	5.56436	2.41602	3.30483	2.99295	2.88622	2.56529	2.33975	2.11652	1.65121	1.15345	0.86173	0.78042	1.13217	1.24042
12	7.22023	3.56977	3.23806	2.44770	2.53789	1.99491	1.54328	3.17780	3.80575	2.20938	1.37311	1.03299	1.12265	0.96355

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.62644	1.04454	0.81082	0.92241	0.96567	1.11837	1.32984	0.75955	0.45788	0.44536	0.36858	0.28587	0.40207	0.54859
2	0.41356	0.27800	0.37010	0.27323	0.47089	0.41265	0.34978	0.29469	0.35315	0.29246	0.29850	0.33642	0.30957	0.33486
3	0.34627	0.27826	0.33187	0.39381	0.45353	0.39532	0.40703	0.38765	0.35081	0.35754	0.56857	0.56946	0.69139	0.57340
4	2.73629	3.06917	3.37608	3.73908	5.40820	4.84036	4.02406	1.92385	2.82700	2.92554	3.57145	3.60910	2.81931	3.51400
5	0.41857	0.35621	0.32572	0.22107	0.35543	0.25227	0.23859	0.16735	0.19507	0.15426	0.17134	0.17331	0.22743	0.21670
6	0.90974	0.55262	0.59030	0.51588	0.53307	0.39330	0.46247	1.27484	1.03912	0.91959	0.67563	0.68570	0.60700	0.66897
7	2.11050	1.85354	1.89597	2.21014	1.72596	1.53392	1.41689	2.03900	1.68217	1.99946	1.75176	1.91341	1.73107	1.53173
8	1.50620	1.17570	1.04997	0.81380	1.03543	0.85594	0.77881	0.72023	1.14813	0.66392	0.71751	0.77061	0.87744	0.81175
9	0.42572	0.45885	0.40523	0.76333	0.70627	0.79044	0.78981	0.37629	0.35447	0.33678	0.40149	0.41239	0.57713	0.76245
10	1.51554	1.22492	1.31685	1.23268	1.51855	1.41067	1.50353	2.17683	1.92606	1.69286	1.66995	1.79132	1.46028	1.65165
11	4.51152	4.00574	3.20127	2.86219	2.55991	2.25458	2.44554	2.94227	1.72426	1.41124	1.02858	1.64455	1.31425	1.66083
12	5.40860	6.32348	5.12338	3.41016	4.42120	2.81995	2.83870	2.41254	2.58544	2.33890	1.42092	1.14202	1.02047	1.10136

Trunk/hip variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	0.01109	1	0.01109	0.048
OF	6.33000	6	1.05500	1.373
Surface	16.60900	1	16.60900	3.973
FOxOF	0.42900	6	0.07147	0.762
FOxSurface	0.00018	1	0.00018	0.000
OFxSurface	1.15700	6	0.19300	1.275
FOxOFxSurface	0.63700	6	0.10600	1.064
Subjects				
FOxS	2.52200	11	0.22900	
OFxS	50.69700	66	0.76800	
SurfacexS	45.98900	11	4.18100	
FOxOFxS	6.19400	66	0.09385	
FOxSurfacexS	5.24700	11	0.47700	
OFxSurfacexS	9.98600	66	0.15100	
FOxOFxSurfacexS	6.57900	66	0.09968	
Total		335		

Hip/knee IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.78258	0.44763	0.73708	0.78835	0.87499	0.75438	0.65727	1.01578	1.64887	1.43560	1.43475	1.47512	1.46697	1.71687
2	2.52632	2.32680	2.64785	1.86665	2.27185	1.85692	1.79846	2.71188	3.28425	4.27436	3.75424	3.26859	3.51412	2.74970
3	2.01133	1.71835	1.84719	1.56095	2.10012	2.17346	2.03386	1.31320	0.88540	1.16023	1.71652	1.56770	1.32479	1.59273
4	0.56118	1.23909	0.69409	0.55600	0.68634	1.22643	0.88006	1.86866	1.18612	1.76333	1.49500	1.83045	1.94937	1.64677
5	4.72706	4.89923	5.08000	4.11180	3.37147	3.01124	2.34884	8.15891	5.20993	5.58430	3.44938	3.04623	3.39575	3.16147
6	1.65262	1.59123	1.87707	1.68750	1.64154	1.57979	1.56962	0.95100	0.88340	1.19971	1.24448	1.37786	1.20813	1.39035
7	1.25244	1.35358	2.09346	2.33795	1.52362	1.86522	1.76476	1.26484	1.14850	2.25561	2.10082	2.53718	2.28721	2.01181
8	0.63898	0.77706	0.88707	0.99170	1.08159	0.92074	1.23081	0.69705	0.71145	0.63262	0.51634	0.61114	0.73206	1.11664
9	3.35561	3.98675	3.83762	4.41050	3.69223	3.02857	3.01640	3.95088	5.61562	4.31357	4.41074	4.01828	4.01522	3.93515
10	1.57336	1.72548	1.64277	1.51715	1.60119	1.37874	2.17463	1.83843	1.76034	1.71944	1.87443	2.08890	1.52850	1.76347
11	1.34557	1.26417	2.20468	1.37225	1.13982	1.74889	1.64408	1.52046	2.86839	4.38541	2.45362	3.51885	2.59098	1.88719
12	1.59034	1.88877	1.62866	1.51365	1.89137	1.15197	0.99453	0.83337	0.50111	1.63371	1.47727	1.37339	0.98043	1.00394

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.45905	0.73176	0.79591	0.84770	1.03363	1.09530	0.74518	1.34248	1.50410	1.00499	1.90997	2.25731	2.08425	1.96630
2	2.06310	2.07878	2.11284	1.91548	2.09795	2.20572	1.90876	3.52719	2.67104	2.87395	2.84733	3.15048	2.82078	2.61285
3	1.92799	1.93271	2.15247	2.32434	1.93209	1.98643	2.08243	1.09133	1.08115	1.60442	0.99974	1.65452	0.77744	1.17854
4	0.87907	1.66754	1.32264	1.10661	0.62989	0.55251	1.13439	0.56581	1.37487	1.50122	1.69234	1.18841	1.38319	1.49600
5	4.19180	2.67680	3.81893	3.08489	1.93107	2.54692	2.72269	7.27913	7.24162	5.23212	4.36474	4.64627	4.02549	2.70119
6	1.55221	2.07386	2.06324	1.88365	1.89235	1.75060	1.62020	1.06771	1.53339	1.42799	1.28697	1.23183	1.24824	1.67097
7	1.02784	1.31625	1.40122	2.32618	1.64205	2.24823	1.72169	1.39961	2.01480	1.19183	2.07062	2.25983	1.84859	1.97108
8	0.53239	0.53467	1.03917	0.83504	1.09904	1.20747	1.15658	0.76883	0.81256	0.90541	0.65713	0.63271	0.69756	1.10692
9	3.07727	3.24970	3.48365	3.94664	4.11067	3.86219	4.23859	4.77630	4.59529	4.67619	4.97896	4.48772	3.75712	4.01983
10	1.05573	1.25431	1.93847	1.72159	1.62237	1.74608	2.21197	1.93395	1.83499	2.21884	1.81071	1.56375	2.18893	1.92185
11	1.40711	1.71404	1.22185	1.36473	1.25934	1.83521	1.28772	1.92473	4.33374	1.19865	1.65604	1.39455	3.95761	2.89174
12	2.85882	1.63062	2.15069	2.12985	1.65060	2.08548	1.16270	1.47371	1.25629	1.59535	1.19927	1.18836	1.11105	1.66127

Hip/knee variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	0.00037	1	0.00037	0.002
OF	2.23200	6	0.37200	0.519
Surface	10.06400	1	10.06400	2.970
FOxOF	1.52800	6	0.25500	1.326
FOxSurface	0.01419	1	0.01419	0.033
OFxSurface	0.67100	6	0.11200	0.525
FOxOFxSurface	1.37300	6	0.22900	1.205
Subjects				
FOxS	2.59900	11	0.23600	
OFxS	47.34600	66	0.71700	
SurfacexS	37.27900	11	3.38900	
FOxOFxS	12.68300	66	0.19200	
FOxSurfacexS	4.71500	11	0.42900	
OFxSurfacexS	14.07100	66	0.21300	
FOxOFxSurfacexS	12.53300	66	0.19000	
Total		335		

Knee/ankle IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.52803	0.77827	0.75168	0.82260	1.16930	1.60226	1.72512	0.45810	0.51754	0.56772	0.52795	0.55850	0.45445	0.48512
2	2.79333	2.77467	2.50330	2.65940	2.87271	2.47443	2.19777	1.03256	0.91325	0.64253	0.92210	0.74690	1.00893	1.10551
3	0.96030	0.98481	0.98003	1.03455	0.90062	0.92653	0.96158	0.80793	0.81714	0.57382	0.47282	0.44953	0.59864	0.33963
4	1.10275	0.88599	1.06732	1.64445	1.60160	1.48264	1.17641	0.40155	0.56415	0.54536	0.30867	0.47224	0.52627	0.40052
5	1.13545	1.20278	1.02431	1.69740	1.81657	1.16120	1.93195	0.52484	0.70195	0.63498	0.79951	1.52313	0.97168	0.98325
6	1.22470	1.33124	1.18595	1.26885	1.28542	1.30509	1.27528	0.90427	0.75941	0.75950	1.02286	0.72045	0.68550	0.69628
7	0.75462	1.43154	1.40221	1.44245	1.87846	1.79230	1.29259	0.30161	0.31863	0.24796	0.24857	0.23341	0.26802	0.21263
8	2.00642	2.13356	1.95322	1.87185	1.78708	1.60056	1.35409	0.77240	0.77917	1.01067	1.17841	0.86087	0.76861	0.45420
9	1.18170	0.94911	1.05414	0.79165	0.75523	0.86380	0.84836	0.34350	0.36424	0.28504	0.22624	0.24325	0.25836	0.25723
10	0.22385	0.27998	0.41983	0.71755	0.82838	1.44944	1.01845	0.47755	0.39925	0.31888	0.37373	0.33136	0.70990	0.32844
11	1.62073	1.61078	1.32638	1.96115	1.73791	1.94555	2.30582	0.74895	0.31668	0.28725	0.52010	0.30704	0.49530	0.33027
12	1.20658	1.13770	1.42315	1.80575	1.35508	1.94605	1.83596	0.95433	0.84079	0.47577	0.51940	0.72426	0.86167	0.70085

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.59228	0.51546	0.64971	1.20329	1.02961	1.25033	1.71784	0.29568	0.38744	0.46825	0.48770	0.40446	0.40791	0.57222
2	2.75320	2.91474	2.73409	2.47820	2.44561	2.06846	2.50354	0.89199	0.88820	0.92393	1.10233	0.76552	0.92013	0.94347
3	1.09554	1.00969	0.95269	0.89719	0.95115	0.94594	0.91610	0.87549	0.83042	0.56622	0.68756	0.47794	0.65533	0.50210
4	1.33944	0.89021	1.67640	1.21408	1.58480	2.40481	2.24600	1.06468	0.55634	0.54309	0.24037	0.34098	0.39509	0.37182
5	1.16756	1.87000	1.82837	2.41921	2.38233	2.58993	3.42211	0.56712	0.47041	1.11541	0.70843	0.70852	0.73905	1.15932
6	1.25351	1.09219	1.13349	1.18581	1.19781	1.23589	1.20428	0.70040	0.78471	0.74545	0.80931	0.66948	0.86226	0.86038
7	0.76103	1.28414	1.47039	1.43474	1.75542	1.44369	1.38922	0.24643	0.22869	0.36249	0.22553	0.22060	0.21216	0.21817
8	2.59176	2.61959	2.13613	1.65593	1.65218	1.45346	1.37162	1.07771	0.92124	0.86580	0.84848	0.77842	0.81243	0.57713
9	1.04719	1.09560	1.00915	0.96179	0.75712	0.81334	0.76538	0.36412	0.38789	0.31793	0.24160	0.26719	0.27121	0.35529
10	0.49529	0.41561	0.37251	0.67053	1.15685	0.97389	1.19571	0.32851	0.31345	0.29380	0.45681	0.47496	0.37664	0.44834
11	1.27948	1.37085	1.89563	2.51947	2.70341	1.98467	2.34001	0.33937	0.17724	0.64448	0.52037	0.58012	0.21412	0.30775
12	0.59550	0.96809	1.19476	1.41387	1.27812	1.56682	1.75418	0.56765	0.64321	0.47577	0.59941	0.74942	1.07518	0.51828

Knee/ankle variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	0.10300	1	0.10300	0.788
OF	1.22500	6	0.20400	1.484
Surface	61.84500	1	61.84500	46.567 *
FOxOF	0.33100	6	0.05511	1.259
FOxSurface	0.20300	1	0.20300	1.340
OFxSurface	1.80300	6	0.30100	3.585 *
FOxOFxSurface	0.05155	6	0.00859	0.310
Subjects				
FOxS	1.43500	11	0.13000	
OFxS	9.08300	66	0.13800	
SurfacexS	14.60900	11	1.32800	
FOxOFxS	2.89000	66	0.04379	
FOxSurfacexS	1.66600	11	0.15100	
OFxSurfacexS	5.53200	66	0.08382	
FOxOFxSurfacexS	1.82900	66	0.02771	
Total		335		

* denotes $p<.01$

Appendix 3. Experiment 3 Individual Mean Data and ANOVA Tables

AP head peak-to-peak translation (IMROM) (cm)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.19507	0.17238	0.15290	0.14425	0.12366	0.11477	0.13754	0.12918	0.11859	0.10854	0.08831	0.09661	0.07451	0.07964
2	0.13351	0.11317	0.11726	0.11540	0.09860	0.12230	0.11585	0.18202	0.21158	0.17924	0.15725	0.18068	0.14747	0.12772
3	0.14166	0.12355	0.11083	0.09850	0.10725	0.09231	0.08805	0.12575	0.14129	0.14011	0.12847	0.10999	0.11577	0.08592
4	0.15128	0.14077	0.11775	0.09810	0.09315	0.08360	0.08374	0.12380	0.13344	0.11300	0.08376	0.07436	0.07011	0.06233
5	0.24722	0.22232	0.18822	0.15555	0.14753	0.15818	0.13972	0.22867	0.17998	0.17590	0.17738	0.15929	0.12911	0.10875
6	0.20320	0.18920	0.16885	0.16185	0.19477	0.15383	0.15536	0.19641	0.18407	0.19185	0.20166	0.19406	0.17136	0.14059
7	0.10619	0.10035	0.07038	0.07160	0.08317	0.08257	0.07575	0.11663	0.11520	0.09343	0.06962	0.07998	0.07488	0.05157
8	0.12230	0.10882	0.10287	0.08390	0.08695	0.07305	0.07267	0.10313	0.11492	0.09889	0.07980	0.08316	0.08066	0.07795
9	0.13706	0.10392	0.08537	0.08160	0.10259	0.07444	0.06268	0.11513	0.11164	0.09082	0.09079	0.07965	0.06421	0.07249
10	0.11733	0.12143	0.12113	0.08845	0.09802	0.08391	0.08442	0.12411	0.11237	0.10795	0.08954	0.08232	0.16390	0.08690
11	0.16692	0.15662	0.16038	0.13820	0.11886	0.11411	0.10742	0.18193	0.15640	0.14608	0.13601	0.14826	0.10815	0.09238
12	0.17232	0.18842	0.16973	0.12635	0.13561	0.12058	0.08700	0.12722	0.16347	0.15576	0.11930	0.12217	0.09614	0.08963

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.19584	0.18697	0.18947	0.15049	0.13318	0.13019	0.10651	0.13273	0.12004	0.12245	0.09218	0.12469	0.09046	0.07948
2	0.14113	0.14511	0.13032	0.13687	0.13523	0.15648	0.09352	0.16023	0.21213	0.20113	0.23463	0.21264	0.19264	0.13897
3	0.15349	0.13853	0.13166	0.12422	0.12395	0.10228	0.07860	0.13031	0.12943	0.10599	0.09960	0.10386	0.12696	0.09381
4	0.17112	0.16164	0.16289	0.12990	0.13308	0.12197	0.10582	0.10085	0.09290	0.08472	0.07976	0.07716	0.07854	0.08507
5	0.20131	0.22128	0.19176	0.20487	0.16474	0.15979	0.15068	0.17542	0.23080	0.19213	0.15986	0.16616	0.15067	0.18547
6	0.23213	0.22643	0.21542	0.17332	0.20139	0.19564	0.15878	0.19128	0.19952	0.23152	0.19465	0.17964	0.17938	0.16350
7	0.11039	0.10702	0.10813	0.08387	0.08367	0.08108	0.06999	0.10513	0.09000	0.09102	0.09415	0.07706	0.07888	0.05818
8	0.11564	0.11717	0.10378	0.09709	0.09776	0.08320	0.06636	0.11702	0.12366	0.10292	0.09299	0.11480	0.07762	0.07906
9	0.12052	0.11526	0.10174	0.09619	0.09782	0.08993	0.08109	0.08854	0.09290	0.09583	0.07448	0.09678	0.07292	0.06920
10	0.11123	0.08502	0.08876	0.09007	0.09157	0.08880	0.06766	0.10092	0.10858	0.10619	0.10255	0.10555	0.10775	0.08695
11	0.21173	0.17880	0.17414	0.15513	0.15116	0.12588	0.11497	0.16126	0.15110	0.14663	0.12644	0.13998	0.17405	0.13428
12	0.19421	0.14683	0.14072	0.13822	0.12366	0.10605	0.08446	0.13352	0.16255	0.12464	0.11827	0.10958	0.11991	0.11514

Note: up = increasing FO, do = decreasing FO, flat = flat surface, fb = foam roller, .16-.75 = OFs

Percentage of power for AP head translation (Individual Means) (%)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.89275	0.89035	0.87600	0.80690	0.85800	0.82475	0.62190	0.84735	0.80715	0.83335	0.67325	0.71650	0.80610	0.59040
2	0.78520	0.76850	0.75760	0.82845	0.86650	0.77245	0.56435	0.77805	0.73270	0.76155	0.76070	0.72625	0.71940	0.53240
3	0.89005	0.83710	0.79215	0.80885	0.82625	0.84320	0.63735	0.75230	0.76530	0.64820	0.69580	0.73530	0.63700	0.34090
4	0.91355	0.92440	0.85820	0.88495	0.83065	0.83570	0.80060	0.83715	0.76905	0.83250	0.68705	0.79805	0.76215	0.68270
5	0.92620	0.91870	0.90155	0.82355	0.83785	0.77925	0.70365	0.74250	0.57620	0.74345	0.57870	0.72965	0.73190	0.74970
6	0.95485	0.91065	0.89835	0.93310	0.89885	0.93995	0.83695	0.87340	0.87750	0.68955	0.78675	0.84355	0.79875	0.64720
7	0.68110	0.64145	0.76710	0.71385	0.56820	0.51365	0.44040	0.82730	0.76650	0.60245	0.62100	0.61855	0.48825	0.50645
8	0.91145	0.91870	0.84750	0.89475	0.85125	0.78855	0.63320	0.88745	0.82865	0.79245	0.81995	0.76225	0.64615	0.64230
9	0.89860	0.92070	0.88460	0.86110	0.80640	0.84280	0.56120	0.83745	0.86405	0.75565	0.64720	0.64790	0.59690	0.29965
10	0.81290	0.68370	0.84255	0.85870	0.76365	0.83505	0.64035	0.84875	0.86435	0.79655	0.79620	0.77555	0.30205	0.54240
11	0.90280	0.89585	0.84960	0.87235	0.87155	0.86910	0.63575	0.89875	0.83660	0.86555	0.79625	0.84225	0.88525	0.69620
12	0.80035	0.81385	0.82600	0.76470	0.74020	0.80570	0.69910	0.69995	0.54345	0.50120	0.56135	0.46310	0.50225	0.50500

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.89055	0.87255	0.89745	0.83575	0.85790	0.79680	0.75015	0.82475	0.73735	0.77205	0.80720	0.64245	0.73535	0.69915
2	0.80980	0.80770	0.90580	0.80315	0.87015	0.77935	0.78995	0.68370	0.78405	0.74570	0.53390	0.51085	0.67315	0.70845
3	0.90135	0.93530	0.92975	0.77705	0.83235	0.82765	0.76185	0.80995	0.88075	0.84650	0.76670	0.69425	0.53610	0.58280
4	0.89155	0.93655	0.85400	0.87045	0.83955	0.77445	0.74270	0.83025	0.78160	0.83770	0.64145	0.69110	0.67460	0.45275
5	0.81545	0.90660	0.89680	0.79390	0.86785	0.82385	0.46025	0.73770	0.79885	0.79990	0.74365	0.72740	0.65300	0.47720
6	0.91180	0.94950	0.92935	0.88925	0.94015	0.92690	0.85260	0.88145	0.89190	0.87725	0.86620	0.90255	0.81415	0.68425
7	0.80490	0.76535	0.68650	0.66590	0.81085	0.80525	0.59965	0.77605	0.75725	0.75365	0.57845	0.68935	0.72605	0.67965
8	0.92635	0.92215	0.91745	0.81025	0.81140	0.81270	0.80085	0.86845	0.87005	0.87310	0.86075	0.61675	0.82260	0.65645
9	0.81760	0.88685	0.87015	0.78655	0.84055	0.77070	0.73650	0.90300	0.78195	0.64490	0.75015	0.57795	0.72970	0.51355
10	0.65075	0.76350	0.88080	0.64965	0.85255	0.77685	0.63580	0.87545	0.67405	0.77615	0.70710	0.68595	0.51270	0.48805
11	0.89945	0.88355	0.84510	0.81935	0.87440	0.82855	0.56975	0.90355	0.90720	0.91550	0.84470	0.81085	0.61675	0.66955
12	0.81380	0.80250	0.84455	0.65300	0.76165	0.70855	0.51290	0.72060	0.68485	0.76115	0.65615	0.59845	0.26000	0.33505

Head ML IMSD (cm)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.00864	0.00738	0.00784	0.00710	0.00662	0.00770	0.00793	0.00629	0.00523	0.00600	0.00514	0.00571	0.00475	0.00369
2	0.00314	0.00507	0.00265	0.00755	0.00608	0.00623	0.00877	0.01479	0.01182	0.01694	0.00747	0.00648	0.00767	0.00737
3	0.00517	0.00427	0.00404	0.00340	0.00367	0.00469	0.00517	0.00554	0.00458	0.00471	0.00487	0.00415	0.00439	0.00455
4	0.00713	0.00716	0.00559	0.00515	0.00544	0.00467	0.00771	0.00742	0.01062	0.00527	0.00580	0.00552	0.00520	0.00461
5	0.01382	0.01385	0.01242	0.00860	0.00914	0.00932	0.00832	0.01964	0.01455	0.01579	0.01777	0.01272	0.01118	0.01132
6	0.01008	0.01052	0.00806	0.00895	0.00844	0.00798	0.00784	0.00926	0.01028	0.00859	0.00743	0.00707	0.00886	0.00611
7	0.00407	0.00561	0.00386	0.00320	0.00435	0.00276	0.00333	0.00669	0.00639	0.00744	0.00381	0.00396	0.00785	0.01273
8	0.00673	0.00469	0.00354	0.00515	0.00575	0.00393	0.00353	0.00484	0.00512	0.00391	0.00397	0.00330	0.00394	0.00461
9	0.00479	0.00448	0.00378	0.00565	0.00531	0.00505	0.00438	0.00683	0.00660	0.00755	0.00582	0.00523	0.00505	0.00544
10	0.00483	0.00409	0.00421	0.00400	0.00391	0.00344	0.00452	0.00573	0.00422	0.00475	0.00422	0.00457	0.01013	0.00442
11	0.00601	0.00516	0.00600	0.00635	0.00684	0.00483	0.00389	0.00546	0.00585	0.00456	0.00426	0.00672	0.00512	0.00600
12	0.00661	0.00735	0.00857	0.00545	0.00665	0.00581	0.00899	0.01340	0.01054	0.01587	0.00667	0.00720	0.00620	0.00980

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.00806	0.00741	0.00829	0.00714	0.00706	0.00713	0.00613	0.00595	0.00672	0.00703	0.00596	0.00648	0.00599	0.00483
2	0.00665	0.00568	0.00496	0.00508	0.00427	0.00527	0.00504	0.01314	0.01184	0.00740	0.01564	0.02218	0.00543	0.00531
3	0.00646	0.00558	0.00470	0.00442	0.00351	0.00369	0.00306	0.00794	0.00575	0.00484	0.00446	0.00549	0.00514	0.00398
4	0.00734	0.00679	0.01373	0.00627	0.00521	0.00490	0.00511	0.00619	0.00557	0.00750	0.00450	0.00555	0.00616	0.00483
5	0.01051	0.01228	0.01181	0.01078	0.00987	0.01319	0.00894	0.01376	0.01170	0.01338	0.01010	0.01021	0.01260	0.00978
6	0.00930	0.01282	0.01053	0.01013	0.01153	0.01226	0.00960	0.00909	0.01039	0.01135	0.01264	0.01032	0.00899	0.00785
7	0.00459	0.00425	0.00848	0.00471	0.00428	0.00355	0.00320	0.00518	0.00460	0.00888	0.00469	0.00393	0.00717	0.00456
8	0.00372	0.00476	0.00449	0.00477	0.00629	0.00501	0.00408	0.00552	0.00839	0.00522	0.00457	0.00480	0.00443	0.00527
9	0.00437	0.00512	0.00403	0.00556	0.00440	0.00513	0.00472	0.00697	0.00694	0.00799	0.00492	0.00723	0.00520	0.00767
10	0.00904	0.00383	0.00491	0.00406	0.00370	0.00396	0.00279	0.00670	0.00477	0.00493	0.00331	0.00494	0.00444	0.00521
11	0.00824	0.00622	0.00487	0.00458	0.00657	0.00350	0.00643	0.00582	0.00497	0.00471	0.00499	0.00564	0.00742	0.00521
12	0.00681	0.00499	0.00537	0.00481	0.00413	0.00455	0.00405	0.00968	0.01146	0.00811	0.00834	0.00768	0.02612	0.01439

Head ML Translation Variability Table

Source	Sum of Squares	df	Mean Square	F	
FO	0.00000	1	0.00000	1.075	
OF	0.00009	6	0.00002	4.475	*
Surface	0.00013	1	0.00013	3.659	
FOxOF	0.00002	6	0.00000	0.817	
FOxSurface	0.00000	1	0.00000	0.029	
OFxSurface	0.00001	6	0.00000	0.387	
FOxOFxSurface	0.00003	6	0.00001	1.254	
Subjects					
FOxS	0.00004	11	0.00000		
OFxS	0.00023	66	0.00000		
SurfacexS	0.00038	11	0.00003		
FOxOFxS	0.00032	66	0.00000		
FOxSurfacexS	0.00008	11	0.00001		
OFxSurfacexS	0.00025	66	0.00000		
FOxOFxSurfacexS	0.00031	66	0.00000		
Total		335			

* denotes $p<.01$

Ankle IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.81986	0.72342	0.57831	0.34251	0.34107	0.46770	1.31358	2.03072	1.96507	1.84252	2.09441	2.36044	1.60298	1.78285
2	1.00361	0.93996	0.62634	0.55520	0.57777	1.06689	1.51982	5.08367	4.98463	5.37477	5.79430	6.33224	6.58465	4.22046
3	1.03698	1.13172	0.80159	0.75284	1.10566	1.22700	1.24051	4.62239	5.85836	4.87798	4.99606	3.77558	5.97736	3.63036
4	1.42607	1.09477	0.80478	0.68717	0.64454	0.87836	1.08947	1.81095	4.44192	1.58274	1.68881	1.66663	1.76845	1.22986
5	1.77306	1.86526	3.37503	2.16249	1.38838	2.33031	2.41530	6.71289	5.50152	5.02301	5.18386	5.14524	5.68534	3.26974
6	0.76882	0.85208	0.76316	0.72318	0.85278	0.76773	0.90864	4.96137	4.43051	5.16996	4.16351	5.80935	6.02792	5.22742
7	0.76065	0.66142	0.65759	0.40407	0.37017	0.33397	0.35241	3.47405	3.73997	3.57125	3.75725	3.66635	4.31907	3.14530
8	0.76190	1.12708	1.88890	1.54726	1.76551	1.52260	1.54923	3.60172	4.13057	3.58274	3.06982	3.34172	3.91426	3.82403
9	1.44462	1.20564	0.96855	0.84769	0.82989	0.58994	0.46693	7.71676	7.42512	6.77983	7.27445	6.87999	6.28348	5.81283
10	0.68503	0.55636	0.92766	0.95521	1.07727	1.15671	1.09580	2.62892	2.40423	2.53732	2.71934	2.38623	5.73545	2.94366
11	1.92571	1.71510	1.70559	1.49734	1.61125	1.30936	1.04499	2.79763	2.30025	2.64108	2.54093	2.96433	2.10302	2.07716
12	0.60923	0.69244	0.85090	0.83607	1.07457	1.12662	0.94572	4.24864	5.11054	5.40381	5.20165	5.02398	5.70491	4.14110

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.75717	0.72034	0.63276	0.47095	0.29111	0.28322	1.03264	2.45533	3.17041	3.55654	2.02021	2.91244	2.93602	2.16691
2	0.88896	1.35618	0.97543	0.79339	1.02521	1.23286	1.00267	5.36321	6.31151	6.88785	6.14541	7.31454	5.99095	5.25802
3	1.58684	1.18602	1.06970	1.15962	0.85479	0.74624	0.68997	3.80373	4.10155	4.11643	3.86510	4.60179	5.73442	3.84650
4	1.64409	1.62546	1.31185	1.18801	1.12297	1.24422	0.75280	1.65803	1.45165	1.12517	1.67997	1.50598	1.28545	1.21243
5	2.27802	2.47231	1.51107	1.39509	1.71694	4.06462	1.96551	7.99639	8.24826	4.33708	2.15657	3.18754	2.87394	2.78772
6	1.38437	1.24407	0.92022	0.73146	0.75376	0.97627	0.89911	3.87839	4.57408	6.02895	4.92737	4.78726	5.21409	5.30606
7	0.69695	0.74827	0.70765	0.56257	0.60108	0.45035	0.35530	3.78152	3.26494	3.54878	3.52957	3.01138	3.15204	2.38484
8	1.69975	1.65189	1.27782	0.90191	0.92155	0.96644	0.65630	3.40069	5.21553	4.54407	3.67077	4.60269	3.00546	3.88302
9	1.22896	1.22993	1.15022	0.88362	0.84236	0.59157	0.45285	5.03106	6.03034	8.44523	6.58224	7.23538	6.73394	5.82137
10	0.84765	0.69471	0.62884	0.80296	1.07128	1.02748	0.73413	2.17898	2.81175	2.93654	3.05866	3.80006	4.05104	3.46375
11	1.61834	1.65511	1.68493	1.66705	1.92312	1.55963	1.13908	2.07501	1.90662	1.92496	2.11083	2.70299	3.93700	3.47675
12	1.18227	1.36861	1.11821	1.04676	1.03418	1.03844	0.54046	4.28019	5.47717	3.78249	4.67456	5.23633	8.44142	5.03705

Knee IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.67526	0.62455	0.70993	0.79249	0.72934	0.63438	0.74759	0.62228	1.20147	0.47974	0.39091	0.54574	0.61091	0.46035
2	0.74882	0.62778	0.75210	0.79366	1.01798	1.55488	1.95645	2.47587	2.62137	3.18671	2.57932	2.60255	3.14716	3.17641
3	2.03474	2.16986	1.43368	1.21308	1.48289	1.61000	1.84524	2.92177	2.86802	2.19928	1.33122	0.94913	1.02246	1.36600
4	0.97429	0.74854	0.71641	0.58650	0.62599	0.97029	1.41391	0.86333	1.43753	0.62281	0.51573	0.56777	0.61256	1.19872
5	1.54740	1.77190	5.06307	2.60258	1.28035	3.71750	4.09487	9.01874	9.40187	5.48085	5.00270	3.77414	3.93499	2.97735
6	1.33775	1.76169	1.41374	1.10280	1.61050	1.42738	1.71925	3.08554	3.12613	3.30039	2.25698	1.45962	1.23590	1.28713
7	0.98803	0.87302	1.03881	0.47389	0.50525	0.61483	1.01771	1.73005	1.38814	0.96722	0.73451	0.74123	0.68261	1.30328
8	1.96605	2.44477	3.15765	2.56774	2.68986	2.31272	2.42387	3.79237	4.25985	3.75660	2.26426	2.63706	2.29250	2.08057
9	0.53776	0.47134	0.43391	0.45673	0.48724	0.44529	0.75387	1.46008	1.47233	1.23365	1.25468	1.15185	1.15222	2.68614
10	1.10025	0.96124	1.35336	1.04439	1.28495	1.19026	1.16503	1.56330	1.38456	1.17116	1.14328	1.04176	4.67704	1.14160
11	1.31525	1.08359	1.11021	0.98810	1.17622	1.05115	0.87481	1.65134	0.98669	2.25902	1.99726	2.72020	2.09813	1.65202
12	1.00355	1.29708	1.47036	1.30807	1.24410	1.16969	0.85673	1.82018	2.43115	2.09396	1.74443	2.01234	1.78103	1.64445

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.77718	0.85910	0.85634	0.88604	0.82407	0.78110	2.15112	0.66136	1.04139	0.54998	0.40700	0.66967	2.53454	0.38097
2	1.06533	1.15367	1.06320	1.22417	1.48850	1.45017	1.10492	2.54567	2.90943	2.87847	3.43809	3.98840	5.90239	4.42788
3	2.43117	2.08152	2.15599	2.20329	1.33012	0.81749	0.72144	2.50085	2.44801	1.93593	1.99993	1.57110	1.37064	0.91324
4	2.26998	1.71219	1.46285	1.28056	1.09782	1.19751	0.97373	0.72728	0.51495	0.57441	0.70376	0.52183	0.46260	0.74543
5	3.76864	3.76966	1.35890	1.15848	1.26482	5.14861	2.37476	7.84872	7.31830	4.83661	1.93643	1.50611	2.07021	1.56711
6	1.56415	1.61223	1.73288	1.52205	1.55180	1.22238	1.17346	2.61536	2.31635	3.24187	2.36136	2.01314	1.94936	1.35919
7	0.96547	0.64715	0.74043	0.90399	0.72880	0.78380	0.50449	0.99553	0.83903	1.56044	0.79662	0.76426	0.86706	0.70371
8	3.20764	3.20625	2.49676	1.54774	1.88571	1.66653	1.20908	3.52039	4.80178	3.84408	3.18937	3.20227	2.62530	2.24358
9	0.69925	0.61940	0.55756	0.72907	0.57982	0.62130	0.72906	1.54470	0.93363	1.14133	0.89106	1.17325	1.08562	1.35433
10	0.63262	0.66127	0.80548	0.90088	1.20845	1.12922	0.78719	1.05811	1.14978	1.19262	1.22104	1.57322	1.28670	1.23644
11	1.35816	1.16269	1.19350	1.07598	1.16664	0.96479	0.74598	1.69333	1.07622	1.14388	1.12537	1.35097	1.16894	1.90918
12	1.35586	1.13390	1.08306	1.23177	1.27014	1.01310	0.56970	1.66825	1.76005	1.02982	2.46477	1.66780	6.53136	3.62196

Knee Angular Variability Table

Source	Sum of Squares	df	Mean Square	F
FO	0.14300	1	0.14300	0.133
OF	13.22100	6	2.20300	2.015
Surface	41.98600	1	41.98600	10.193 *
FOxOF	2.06100	6	0.34300	1.059
FOxSurface	0.32700	1	0.32700	0.385
OFxSurface	4.89000	6	0.81500	0.882
FOxOFxSurface	4.39400	6	0.73200	1.988
Subjects				
FOxS	11.78500	11	1.07100	
OFxS	72.18400	66	1.09400	
SurfacexS	45.31200	11	4.11900	
FOxOFxS	21.40200	66	0.32400	
FOxSurfacexS	9.33600	11	0.84900	
OFxSurfacexS	60.96500	66	0.92400	
FOxOFxSurfacexS	24.31500	66	0.36800	
Total		335		

* denotes p<.01

Hip IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.71903	1.52815	1.59247	1.62931	1.95327	2.71326	3.89109	3.51220	3.51470	3.66592	3.07501	3.00371	3.23426	3.35006
2	1.54352	1.43693	1.74206	1.97050	2.01033	2.58836	2.70208	2.96901	3.08332	3.16369	2.67633	2.46170	2.30561	2.38243
3	3.83281	3.49975	3.37469	3.42129	4.19149	3.98046	3.36361	3.11942	3.45734	3.74613	4.67874	4.10448	3.71181	3.46099
4	0.43334	0.66249	1.00802	1.02426	1.03055	1.34885	1.62466	2.91950	3.08469	2.94953	2.14715	2.03855	2.04376	1.83416
5	2.56889	2.85315	3.01773	2.31275	2.85565	3.09843	2.95526	4.84903	4.88060	4.50813	3.43921	3.83937	3.33951	3.74070
6	2.98171	3.03979	3.26010	3.03092	3.13543	3.21735	2.01143	4.90047	5.28838	4.32150	4.68840	4.66609	4.75260	3.78383
7	1.66343	1.72168	1.34291	1.30726	1.15778	1.03399	0.85705	2.29562	2.16710	1.34743	1.16941	1.11447	1.33840	0.86771
8	0.91554	1.07945	1.30176	1.24812	1.34226	1.15121	1.20172	1.10578	1.08933	1.00233	0.88915	0.92798	0.81941	0.89083
9	0.57529	0.47511	0.51331	0.48339	0.62945	0.61663	0.70243	0.89497	0.70370	0.93152	0.86595	1.07480	0.82616	1.99255
10	1.96039	1.80961	2.71788	2.49896	2.54585	2.78190	2.50729	3.35907	3.47109	3.29749	3.10910	2.98028	3.73942	2.48371
11	7.07704	6.18718	5.90372	4.65638	4.94713	4.18402	3.39013	7.59589	6.38787	5.59181	4.65118	4.72537	4.29153	3.82384
12	1.84719	2.01709	2.54886	1.99626	2.16470	2.39429	2.50097	2.06597	2.94460	3.39969	2.24046	2.09944	1.83885	2.14279

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	2.48330	1.60057	1.37624	1.96864	2.36461	2.32473	2.37260	3.89309	3.42545	3.76743	3.37539	3.40748	2.97233	2.48722
2	1.64620	2.32052	1.63270	2.23930	3.26006	3.26503	2.51306	2.96037	3.51504	3.40513	3.19971	3.55056	2.93792	2.33239
3	4.98579	4.21835	4.17495	3.97052	4.57894	4.46663	3.61413	4.42737	4.00303	3.74420	4.07561	4.57915	4.54605	3.73869
4	1.42496	1.15620	0.69346	0.82074	1.10300	1.26004	1.38327	2.39091	2.41403	2.38685	2.09223	2.15611	2.16445	1.78524
5	2.46307	2.76154	2.80415	2.89075	3.98552	3.90678	3.25168	3.78835	4.37802	4.41305	3.63896	4.73854	4.21436	4.64556
6	4.85534	4.62417	3.66397	2.69624	2.80810	3.13037	2.23712	5.57807	5.63677	6.28671	5.94584	5.75604	5.22309	4.14097
7	1.43395	1.29011	1.37607	1.39584	2.12470	1.96567	1.45405	1.80791	1.67791	2.19758	1.59048	1.69410	2.13432	1.58309
8	1.39915	1.36477	1.12164	0.87898	0.93010	0.97967	0.83178	1.46874	1.52401	1.15650	1.11481	1.17699	1.03441	0.89630
9	0.64372	0.54494	0.51559	0.60313	0.59439	0.82173	0.87072	1.16222	0.76555	0.80941	0.79132	1.37643	1.19513	1.28554
10	2.24669	1.93360	1.88080	2.08503	2.69255	2.50914	1.80796	2.29004	2.22901	2.76570	2.94608	3.28635	2.78424	2.46481
11	6.91155	6.63204	6.52825	6.07070	6.28007	5.12887	3.75079	5.87816	5.54768	5.95304	5.36375	5.30346	6.05006	4.54000
12	3.16856	2.48324	2.39137	2.61954	2.68158	2.44839	1.32665	2.72328	2.72907	2.27432	2.04466	1.84550	6.08848	2.97975

Trunk IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.62003	0.64920	0.53950	0.39593	0.46975	0.68138	2.12009	2.16041	1.64861	1.04491	0.95160	1.08963	1.03446	0.78521
2	1.63412	0.99091	1.09499	1.34531	1.31189	1.83039	4.04831	2.29827	2.58902	3.54031	2.96129	3.47296	3.00531	2.60604
3	1.43898	1.26839	1.28143	1.44332	1.64761	1.79180	2.70835	1.41783	1.47170	1.40634	1.35397	1.38306	1.50971	1.51903
4	0.52988	0.58810	1.15114	1.02746	1.07061	0.96887	1.16062	1.88568	1.87921	1.93023	1.63250	1.36441	1.30473	1.22696
5	6.43789	5.39330	5.79229	4.68707	3.99360	4.78416	5.00856	4.22175	5.22418	4.82897	3.94376	3.60847	3.82770	3.33581
6	11.34875	8.97050	6.79038	7.52166	8.27883	7.69537	8.53484	3.62010	3.42373	3.41587	4.77038	5.39027	5.02163	4.50147
7	3.55137	2.83978	2.51529	2.19233	2.09517	2.05624	2.25438	2.71027	2.12527	2.23266	1.63124	1.89078	2.66556	2.21929
8	0.52527	0.57682	0.79561	0.68090	1.25372	1.06604	1.38339	0.91430	1.14126	1.14055	1.15782	1.12593	1.01475	1.39037
9	0.52527	0.57682	0.79561	0.68090	1.25372	1.06604	1.38339	0.91430	1.14126	1.14055	1.15782	1.12593	1.01475	1.39037
10	1.40402	1.13744	1.01625	1.01742	1.25957	1.32046	2.01834	1.82152	1.33329	1.20491	1.58404	1.07723	2.31516	1.87819
11	2.12476	2.28229	2.23125	2.03187	1.87743	2.05629	2.09080	2.34984	1.90957	2.08348	1.76922	1.50341	1.64251	2.05550
12	1.57965	1.11721	1.34650	1.31348	1.86256	1.78420	1.82240	2.78063	2.56216	2.92916	2.41881	2.02175	1.60860	1.84645

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.86368	0.61715	0.53251	0.51819	0.43937	0.56996	0.66267	1.89274	1.36555	1.23155	0.91112	1.22009	1.35654	1.06181
2	2.68688	1.47765	1.46357	1.28427	1.59782	1.88948	1.69658	3.01447	3.39709	3.59289	5.53656	4.64427	3.20434	2.32272
3	1.62550	1.51765	1.50153	1.59734	1.69585	1.80790	1.81026	1.39250	1.74668	1.41769	1.38269	1.67109	1.75820	1.52027
4	1.79361	0.85623	0.42760	0.58588	0.77787	1.07513	0.91021	2.04502	2.07071	1.82301	1.62949	1.68578	1.38343	1.42602
5	6.08276	4.78303	5.20404	5.39088	6.17148	5.80345	5.28914	6.01569	5.80652	4.78279	5.31104	4.50620	4.01469	4.10479
6	10.62732	9.86758	10.05926	8.52730	10.41030	9.20043	7.04869	3.79858	4.32175	4.22242	4.21047	4.94590	4.54494	5.11797
7	3.85448	2.60335	2.36895	2.14625	2.17538	2.13176	1.58898	2.45459	2.43957	2.31554	1.73945	1.78594	2.32887	1.91625
8	1.17432	0.76102	0.57471	0.64360	0.83726	0.89567	0.91642	1.80007	1.57573	0.92187	1.08646	1.38374	1.16600	1.01585
9	1.17432	0.76102	0.57471	0.64360	0.83726	0.89567	0.91642	1.80007	1.57573	0.92187	1.08646	1.38374	1.16600	1.01585
10	2.36305	2.36047	1.47648	1.08045	1.11243	1.41770	1.11622	1.95064	1.79077	1.58212	1.25529	1.58997	1.19518	1.51265
11	1.86098	2.01694	2.05269	1.25686	1.81177	1.71922	1.62885	3.08356	2.41543	2.00324	1.76776	1.45096	2.44906	1.16277
12	2.61526	1.90834	1.45976	1.63109	1.17269	1.05792	1.09306	2.76837	3.35216	3.18583	2.48247	2.34977	3.67956	2.48081

Trunk Angular Variability Table

Source	Sum of Squares	df	Mean Square	F	
FO	2.15000	1	2.15000	5.731	
OF	8.20500	6	1.36700	5.388	*
Surface	0.66100	1	0.66100	0.040	
FOxOF	5.59400	6	0.93200	5.071	*
FOxSurface	0.55200	1	0.55200	1.850	
OFxSurface	4.20300	6	0.70000	1.751	
FOxOFxSurface	1.72200	6	0.28700	1.392	
Subjects					
FOxS	4.12600	11	0.37500		
OFxS	16.75000	66	0.25400		
SurfacexS	181.09700	11	16.46300		
FOxOFxS	12.13400	66	0.18400		
FOxSurfacexS	3.28400	11	0.29900		
OFxSurfacexS	26.40400	66	0.40000		
FOxOFxSurfacexS	13.61000	66	0.20600		
Total		335			

* denotes p<.01

Cervical IMSD (Flexion-Extension) (degrees)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.71122	1.05691	0.60528	0.78904	0.83270	1.28239	2.02563	2.33138	1.95438	2.49670	1.99398	1.87918	2.11614	2.04884
2	1.90634	1.36685	1.55577	1.60984	1.95004	3.01125	3.71305	1.53662	1.98600	3.53406	3.36125	3.65520	3.51667	3.13071
3	0.89646	0.86875	0.85111	0.99918	1.49042	1.76753	1.91178	1.42983	1.42772	1.39687	1.06709	1.21123	1.39445	1.50145
4	0.68235	0.96479	1.31496	1.74492	1.37803	1.28592	1.66799	1.82233	1.99359	1.70905	1.43839	1.36927	1.56884	1.58664
5	4.43790	3.29119	2.99351	2.64265	2.88581	3.62757	5.85932	3.93796	4.90515	5.09140	4.06749	3.50927	3.35603	3.33341
6	7.28783	6.06266	5.20418	6.07669	6.45417	6.70399	7.33263	2.07477	3.20809	3.45354	4.84702	5.68954	5.84069	5.61445
7	1.54013	1.64732	1.12045	1.37829	1.72993	2.94693	3.29266	1.41135	1.58945	1.61250	1.52920	1.95778	1.94333	1.78837
8	0.81540	0.71650	1.01551	0.91960	1.07480	1.76752	2.08124	0.92514	0.97005	0.99953	1.03404	1.13812	1.10992	1.91447
9	1.19953	1.06364	0.89802	1.30559	1.31156	1.30213	1.55218	0.88235	0.82172	1.49586	0.95243	1.01812	0.86802	1.35430
10	0.95493	0.74573	0.70022	0.70491	1.13654	0.93042	1.82108	0.84376	1.32999	0.84563	0.89208	0.77675	1.23475	1.07709
11	1.65941	1.34690	1.43128	1.21840	1.60003	3.02521	3.27971	1.05539	1.09509	1.25286	1.71855	1.55290	1.75350	3.05575
12	4.26108	4.09318	2.27161	2.76135	2.59610	2.96804	3.89301	4.99440	2.90256	4.59886	2.60901	5.23167	3.66240	3.74322

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.51138	1.14397	0.83190	0.80027	1.02778	1.11764	0.93098	2.70467	2.42500	2.29603	1.52004	1.93252	1.63868	1.37365
2	3.14439	1.54827	1.38417	1.89488	3.30101	3.38569	2.57538	2.61460	3.50805	3.57960	6.87908	5.78060	3.71797	3.23434
3	1.57601	0.97186	1.15132	1.06393	1.10708	1.14039	1.05369	1.15079	1.30698	1.25568	1.00832	1.17050	1.36973	0.95538
4	2.53000	1.35070	1.40180	1.31808	1.78064	1.72800	1.39414	2.00475	1.30180	1.63917	1.23261	1.05222	1.56553	1.35128
5	6.12592	4.37346	3.94615	4.52904	5.76677	4.75801	3.70888	4.42829	5.30222	4.85885	4.66950	5.37019	4.10880	4.09340
6	7.95802	7.15886	7.14395	5.94060	8.20223	7.76026	6.18302	3.81836	4.92507	5.58007	5.82453	6.42025	6.03183	5.38389
7	2.58919	1.63502	1.50320	1.58723	1.44285	1.56937	2.49676	2.45861	1.24183	1.31355	1.19597	1.51964	1.49635	1.38640
8	1.36733	0.82718	0.83192	0.80924	1.42995	1.15334	0.83515	1.46445	1.74219	1.15806	1.05890	1.32520	1.21303	1.04148
9	1.96320	1.52890	1.25028	1.46817	2.07133	2.56016	1.80522	1.41634	0.78906	0.75519	1.03383	1.50273	1.72908	1.74079
10	2.98294	0.99222	0.89508	1.00127	1.27131	1.11224	1.28410	0.88191	0.83448	0.74189	0.89865	1.25947	0.91153	1.07765
11	1.78464	1.43148	1.52836	1.53636	1.85581	2.04367	2.03521	1.35617	1.35806	1.42523	1.63717	1.02787	1.44349	1.68619
12	4.23051	2.44007	3.74836	2.56672	3.80442	2.49866	3.20948	5.47218	4.52824	3.92822	2.76235	3.37783	6.19131	5.20370

Cervical Angular Variability Table

Source	Sum of Squares	df	Mean Square	F	
FO	4.65800	1	4.65800	4.073	
OF	12.42800	6	2.07100	4.759	*
Surface	0.19200	1	0.19200	0.040	
FOxOF	10.91000	6	1.81800	7.406	*
FOxSurface	0.00081	1	0.00081	0.002	
OFxSurface	8.48900	6	1.41500	3.148	*
FOxOFxSurface	4.08600	6	0.68100	2.949	
Subjects					
FOxS	12.57900	11	1.14400		
OFxS	28.72700	66	0.43500		
SurfacexS	53.18600	11	4.83500		
FOxOFxS	16.20300	66	0.24600		
FOxSurfacexS	3.76100	11	0.34200		
OFxSurfacexS	29.65900	66	0.44900		
FOxOFxSurfacexS	15.23900	66	0.23100		
Total		335			

* denotes p<.01

Percentage of power for hip rotation at TF (Individual Means) (%)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.71065	0.70440	0.80400	0.84815	0.84765	0.75430	0.57845	0.88510	0.87780	0.90530	0.84070	0.89030	0.86985	0.63025
2	0.55330	0.48895	0.62530	0.82950	0.79115	0.64555	0.78805	0.78815	0.74240	0.77985	0.86030	0.86665	0.77860	0.56565
3	0.82765	0.84915	0.89860	0.91265	0.93750	0.91600	0.69560	0.81820	0.86000	0.79030	0.83810	0.91160	0.86470	0.41990
4	0.40095	0.50710	0.38905	0.68290	0.68885	0.68855	0.79500	0.82840	0.79915	0.84650	0.78025	0.83585	0.80460	0.64080
5	0.75800	0.80375	0.66580	0.61325	0.82995	0.64830	0.40425	0.30540	0.24780	0.60050	0.60300	0.62150	0.72630	0.59385
6	0.76825	0.78230	0.77665	0.84035	0.85785	0.82065	0.65045	0.87875	0.86650	0.76425	0.78315	0.84640	0.78920	0.66140
7	0.75885	0.76100	0.59860	0.71875	0.61540	0.47380	0.40960	0.72240	0.67680	0.61805	0.49230	0.41845	0.31155	0.27655
8	0.75185	0.82485	0.83585	0.90205	0.87970	0.82170	0.81865	0.85410	0.84055	0.83575	0.81390	0.80860	0.80395	0.57565
9	0.45180	0.48495	0.40180	0.53010	0.54430	0.45035	0.22750	0.47765	0.28100	0.14690	0.50375	0.39865	0.46565	0.12175
10	0.83745	0.87110	0.85670	0.92180	0.85500	0.88275	0.70070	0.80795	0.92670	0.88580	0.83480	0.90600	0.46060	0.69225
11	0.89510	0.88800	0.81730	0.91235	0.84865	0.87820	0.64940	0.88295	0.89100	0.86625	0.87735	0.89625	0.88320	0.75795
12	0.61305	0.65925	0.81200	0.57815	0.80735	0.86115	0.49460	0.60085	0.37275	0.29745	0.61690	0.39405	0.40265	0.43095

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.43765	0.68750	0.75985	0.79665	0.86920	0.78710	0.73370	0.79475	0.87960	0.90775	0.90710	0.86355	0.80625	0.81900
2	0.52380	0.43045	0.63485	0.83850	0.85970	0.82820	0.85030	0.73085	0.82130	0.75880	0.65810	0.56905	0.73355	0.79170
3	0.87050	0.94960	0.94870	0.89140	0.89090	0.87690	0.85940	0.86140	0.91770	0.91860	0.87380	0.79270	0.73560	0.75360
4	0.19440	0.15255	0.23345	0.54790	0.62410	0.70465	0.72705	0.66620	0.86045	0.82225	0.80995	0.85585	0.76315	0.66180
5	0.49435	0.75765	0.82495	0.73375	0.69915	0.72270	0.44285	0.26020	0.54000	0.58680	0.68820	0.69475	0.56620	0.35000
6	0.85525	0.90520	0.80305	0.76240	0.78800	0.73605	0.73095	0.90170	0.93480	0.86885	0.91115	0.92315	0.84225	0.63735
7	0.45540	0.77055	0.83580	0.77655	0.73980	0.83105	0.64220	0.67410	0.68635	0.56815	0.57975	0.70225	0.41630	0.53610
8	0.90300	0.89860	0.74940	0.82280	0.82585	0.78765	0.88335	0.88710	0.74605	0.82610	0.83810	0.69205	0.83035	0.74360
9	0.46600	0.52395	0.50810	0.57390	0.31590	0.34340	0.32405	0.24485	0.20360	0.23420	0.24675	0.55380	0.60635	0.66840
10	0.73025	0.82815	0.89545	0.81545	0.92980	0.87885	0.68600	0.79555	0.75620	0.81065	0.86375	0.82805	0.61965	0.60495
11	0.87190	0.86860	0.80580	0.91270	0.90295	0.86585	0.56240	0.86435	0.91000	0.92815	0.86205	0.91100	0.64640	0.80525
12	0.62245	0.46225	0.74195	0.66670	0.63215	0.67215	0.62080	0.50890	0.72200	0.71755	0.63665	0.50695	0.18380	0.44570

Percentage of power for ankle rotation at TF (Individual Means) (%)

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.63310	0.69710	0.51070	0.22230	0.15155	0.36030	0.25180	0.17900	0.07870	0.19350	0.03740	0.04945	0.09585	0.08375
2	0.22875	0.28130	0.32845	0.14705	0.11465	0.27340	0.54320	0.20535	0.14560	0.08000	0.11680	0.17715	0.09130	0.18215
3	0.62420	0.57905	0.57210	0.53530	0.78555	0.75405	0.63205	0.10090	0.21970	0.11050	0.17740	0.04570	0.03690	0.09990
4	0.69980	0.56565	0.48150	0.33625	0.34290	0.43985	0.30230	0.24020	0.23850	0.52225	0.07220	0.33050	0.29655	0.24405
5	0.52725	0.41875	0.08490	0.31580	0.79465	0.40365	0.23255	0.12250	0.06590	0.09670	0.08205	0.24570	0.12315	0.06515
6	0.32895	0.05080	0.27395	0.28685	0.28740	0.32700	0.27680	0.13425	0.08895	0.03160	0.07880	0.09365	0.04350	0.01810
7	0.24905	0.16705	0.10225	0.10725	0.06870	0.02455	0.02855	0.05230	0.04540	0.00885	0.02380	0.02300	0.03925	0.04795
8	0.24990	0.61635	0.75965	0.70190	0.75410	0.79990	0.70625	0.55295	0.38140	0.35655	0.33465	0.34065	0.19500	0.20020
9	0.86335	0.86850	0.83485	0.83175	0.66500	0.55415	0.12695	0.55050	0.71205	0.62525	0.61075	0.66780	0.61795	0.23790
10	0.50935	0.67185	0.79630	0.83135	0.86170	0.86535	0.67265	0.26570	0.13440	0.14200	0.23125	0.15855	0.09095	0.14925
11	0.84010	0.82685	0.77880	0.85020	0.82170	0.84190	0.64160	0.39060	0.09345	0.35435	0.22380	0.38205	0.23505	0.08435
12	0.22165	0.33975	0.45270	0.35590	0.60300	0.78260	0.62340	0.09675	0.15455	0.03380	0.05860	0.04065	0.03945	0.10100

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.59380	0.64965	0.62150	0.31020	0.21525	0.34065	0.34820	0.15730	0.07505	0.15955	0.17205	0.05095	0.04360	0.04150
2	0.48615	0.30285	0.29965	0.26355	0.50935	0.57390	0.64705	0.04995	0.14480	0.10020	0.13225	0.11305	0.38470	0.21225
3	0.84885	0.86305	0.86270	0.36505	0.41760	0.54740	0.58720	0.11015	0.27420	0.17495	0.09990	0.11345	0.03530	0.04925
4	0.12995	0.24570	0.18865	0.24535	0.55095	0.39390	0.59645	0.10945	0.03595	0.22865	0.06950	0.10240	0.31945	0.08415
5	0.12835	0.10835	0.53710	0.67945	0.70535	0.24720	0.38775	0.03195	0.08235	0.18205	0.17115	0.05485	0.04390	0.03425
6	0.64020	0.49870	0.31015	0.26810	0.19790	0.29920	0.27810	0.07365	0.10370	0.14400	0.21950	0.16135	0.13265	0.02760
7	0.31395	0.30525	0.36345	0.22155	0.29645	0.11875	0.03110	0.04235	0.01810	0.00795	0.08345	0.10600	0.08540	0.04095
8	0.87730	0.82635	0.38330	0.59445	0.46070	0.28400	0.64630	0.26155	0.45680	0.64475	0.52975	0.30125	0.30685	0.19255
9	0.66725	0.84015	0.85350	0.71650	0.62535	0.41965	0.17100	0.76025	0.62225	0.51235	0.76075	0.49970	0.66850	0.47010
10	0.62705	0.73965	0.67710	0.62400	0.87195	0.87045	0.77465	0.36525	0.06590	0.08685	0.11170	0.03485	0.03395	0.04315
11	0.76435	0.80515	0.73530	0.89020	0.86470	0.85940	0.53225	0.18725	0.23460	0.32630	0.17410	0.12145	0.09205	0.08585
12	0.31435	0.35130	0.45170	0.36900	0.37285	0.40460	0.36740	0.13070	0.08810	0.18415	0.10125	0.05240	0.00660	0.01570

Hip/ankle IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	2.17356	2.16201	3.62404	4.75630	5.80933	5.80196	3.62769	1.72921	1.81037	1.99071	1.50539	1.31492	2.01985	1.87894
2	1.92672	2.30482	3.42795	3.78320	3.81034	2.41467	1.76331	0.58158	0.70842	0.64414	0.47425	0.39205	0.39532	0.56485
3	3.74202	3.10118	4.32114	4.54670	3.79056	3.24851	2.72529	0.67485	0.59016	0.76797	0.93649	1.08711	0.62098	0.95335
4	0.31783	0.72081	2.48669	1.80475	1.88136	1.67477	1.51310	2.12977	0.93757	2.45190	1.28831	1.24785	1.25979	1.49778
5	1.44505	1.56919	0.91094	1.19795	2.05519	1.65412	1.23065	0.72497	0.88984	0.90062	0.74509	0.98074	0.61305	1.14532
6	3.88344	3.59626	4.24964	4.25095	3.95172	4.48979	2.25363	0.94808	1.01618	0.85002	0.99255	0.86469	0.71908	1.00764
7	2.18423	2.59655	2.06412	3.22965	3.03754	3.12883	2.43670	0.66877	0.57914	0.36558	0.35144	0.30925	0.35834	0.27703
8	1.20071	0.96147	0.68769	0.80875	0.76064	0.75618	0.77674	0.29800	0.26521	0.28125	0.29121	0.27634	0.27848	0.24514
9	0.40489	0.39912	0.53077	0.56950	0.77591	1.05060	1.50965	0.12100	0.09890	0.13669	0.11892	0.15584	0.13264	0.34714
10	2.93349	3.22698	2.91584	2.61195	2.35457	2.39415	2.31339	1.27236	1.44378	1.31584	1.15316	1.25343	0.68660	0.89010
11	3.69076	3.60506	3.45834	3.11120	3.07038	3.19567	3.24193	2.72868	2.78374	2.25854	2.32376	1.66642	2.07685	1.85307
12	3.06855	2.91659	3.28082	2.52150	2.01973	2.14799	2.71583	0.47635	0.61253	0.59348	0.41985	0.40721	0.35303	0.55356

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	3.26512	2.22096	2.22762	4.37362	8.17691	8.49253	4.72143	1.58657	1.15048	1.05900	1.70068	1.17833	1.30635	1.18078
2	2.08279	1.98521	1.62132	2.73267	3.17936	2.66107	2.50608	0.52845	0.65197	0.49876	0.52356	0.46947	0.48582	0.43967
3	3.17773	3.60063	3.90257	3.41828	5.34789	6.03627	5.26642	1.18672	1.00008	0.91889	1.07064	1.01635	0.82529	0.98783
4	0.86122	0.70690	0.54535	0.65450	1.01365	1.07196	1.89035	1.56041	1.78598	3.38452	1.62628	2.19577	2.77743	2.01513
5	1.73357	1.27176	1.82080	2.09692	2.40364	1.11802	1.64540	0.47289	0.52757	1.09636	1.71606	1.50278	1.47790	1.65751
6	3.52454	3.76217	3.94198	4.30573	3.72562	3.19597	2.50897	1.48677	1.23363	1.03970	1.20216	1.22320	1.01756	0.78434
7	2.10457	1.86691	1.91914	2.55731	3.61483	4.68715	4.10830	0.49336	0.52494	0.68909	0.45336	0.57386	0.72440	0.68242
8	0.83034	0.85977	0.92896	0.93596	1.06160	1.16659	1.38330	0.43143	0.30287	0.25863	0.32985	0.25577	0.34470	0.24536
9	0.52333	0.43845	0.44920	0.70925	0.73397	1.39329	1.97217	0.23275	0.12509	0.09508	0.12123	0.19128	0.17650	0.23607
10	2.67619	2.77385	2.98734	2.60896	2.52889	2.44622	2.46180	1.17663	0.80721	1.03594	0.97835	0.86491	0.73806	0.85573
11	4.45031	4.01943	3.90394	3.65386	3.26084	3.30304	3.38467	2.83495	2.89135	3.09382	2.53873	1.96876	1.61955	1.33193
12	2.65067	1.83862	2.09239	2.50898	2.73289	2.44872	2.45148	0.66926	0.51226	0.60554	0.45485	0.36357	0.66910	0.57412

Cervical/trunk IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	1.13110	1.73764	1.11841	2.02690	1.81660	1.90437	1.26157	1.07939	1.17080	2.52385	2.10856	1.70359	2.12100	2.78375
2	1.21791	1.43800	1.45841	1.19805	1.53901	1.62731	1.04468	0.66743	0.77036	1.01087	1.12680	1.05039	1.19540	1.20332
3	0.66183	0.69279	0.66897	0.69545	0.90775	0.98843	0.69189	1.00846	0.97012	0.99327	0.78811	0.87576	0.92365	0.98843
4	1.29560	1.63956	1.23884	2.72700	1.90808	1.70203	1.42078	0.96443	1.03812	0.86489	0.88243	1.00912	1.20636	1.29527
5	0.66481	0.60411	0.52091	0.56375	0.72655	0.75407	1.17452	1.01517	1.00026	1.15636	1.03596	1.02671	0.91601	1.00994
6	0.64221	0.67236	0.77415	0.80905	0.78064	0.87300	0.85869	0.56762	0.91967	0.98509	1.00059	1.04959	1.15720	1.25010
7	0.43954	0.57381	0.44913	0.61710	0.83811	1.39727	1.47730	0.53287	0.74563	0.71591	0.96243	1.02181	0.76048	0.80587
8	1.56421	1.24537	1.27948	1.34995	0.87463	1.69233	1.52920	1.00908	0.85050	0.87270	0.92446	1.00986	1.08506	1.38710
9	2.24513	1.84832	1.11898	1.92085	1.05947	1.24098	1.11646	0.98154	0.72223	1.27871	0.83214	0.90421	0.85471	0.97244
10	0.69125	0.88632	0.78704	0.76905	0.87493	0.70646	1.16917	0.46465	0.99483	0.72533	0.56163	0.71831	0.68931	0.57042
11	0.92345	0.59030	0.64254	0.61830	0.94517	1.39418	1.66941	0.45127	0.57401	0.59920	0.97872	1.06008	1.08717	1.52478
12	2.69306	4.51253	1.76045	2.10420	1.41859	1.70649	2.12718	1.80331	1.13324	1.57168	1.10183	2.59759	2.23625	2.03006

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.41295	2.07912	1.74882	1.59037	2.32696	1.94668	1.42034	1.43997	1.87095	2.00007	1.68333	1.60292	1.23633	1.29156
2	1.34278	1.02651	0.94532	1.46012	2.08427	1.79180	1.53059	0.87204	1.09068	0.99675	1.22628	1.41664	1.18723	1.38720
3	0.97351	0.64175	0.76309	0.66345	0.65277	0.63892	0.59738	0.82777	0.74732	0.87968	0.73268	0.71893	0.78690	0.61999
4	1.40241	1.64055	3.40086	2.50923	2.51177	1.74911	1.56681	0.97713	0.62994	0.87858	0.75772	0.62441	1.13034	0.93414
5	1.25833	1.10648	0.70972	0.83771	0.95127	0.85391	0.70842	0.74893	0.91293	1.02908	0.89336	1.20916	1.02344	1.05391
6	0.76181	0.74133	0.72764	0.70004	0.78820	0.84947	0.88210	1.00438	1.14052	1.34801	1.41135	1.33080	1.32670	1.04643
7	0.68348	0.74342	0.60624	0.70586	0.65109	0.73971	1.50036	1.00676	0.53834	0.56740	0.71237	0.85645	0.65547	0.73411
8	1.16640	1.13660	1.44365	1.24943	1.71155	1.28765	0.92781	0.80348	1.04731	1.27188	1.00310	0.95425	1.05719	1.03058
9	1.67383	2.01816	2.14819	2.26362	2.47159	2.85552	1.99694	0.78529	0.55221	0.80237	1.02062	1.10086	1.51093	1.73382
10	1.33372	0.48680	0.67022	0.99179	1.20986	0.80325	1.19980	0.44053	0.46334	0.44902	0.69215	0.91425	0.74769	0.72661
11	0.94677	0.75309	0.75441	1.23061	1.02519	1.20518	1.24011	0.46281	0.56184	0.71214	0.94007	0.70771	0.67406	1.42165
12	1.58604	1.29349	2.55819	1.58253	3.27543	2.37941	2.93583	1.95807	1.35430	1.36273	1.13220	1.42852	1.76298	2.36136

Cervical/trunk variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	0.13000	1	0.13000	0.836
OF	2.61400	6	0.43600	4.620 *
Surface	4.43900	1	4.43900	3.869
FOxOF	0.82300	6	0.13700	1.069
FOxSurface	0.64900	1	0.64900	5.043
OFxSurface	0.68700	6	0.11400	1.016
FOxOFxSurface	1.47900	6	0.24700	1.874
Subjects				
FOxS	1.71700	11	0.15600	
OFxS	6.22300	66	0.09429	
SurfacexS	12.62200	11	1.14700	
FOxOFxS	8.46800	66	0.12800	
FOxSurfacexS	1.41500	11	0.12900	
OFxSurfacexS	7.43700	66	0.11300	
FOxOFxSurfacexS	8.68300	66	0.13200	
Total		335		

* denotes p<.01

Trunk/hip IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.38089	0.41705	0.41025	0.25195	0.26249	0.25434	0.54204	0.61636	0.46871	0.28102	0.30883	0.36140	0.31799	0.23536
2	1.07634	0.77823	0.78545	0.70565	0.67225	0.74202	1.41747	0.77666	0.84015	1.11729	1.10670	1.41518	1.31461	1.10047
3	0.37316	0.36384	0.38001	0.42200	0.39312	0.45016	0.80225	0.45452	0.42567	0.37541	0.28939	0.33696	0.40673	0.43890
4	1.21001	1.06019	1.25970	0.98400	1.02239	0.68408	0.72003	0.65408	0.60980	0.65163	0.76047	0.66847	0.63977	0.67161
5	2.45366	1.86248	1.92635	2.02760	1.40230	1.54651	1.75844	0.86069	1.13371	1.04654	1.16367	0.96671	1.13535	0.88695
6	3.87968	3.12993	2.25895	2.51030	2.70638	2.42322	4.25278	0.73872	0.64741	0.79044	1.01749	1.15520	1.05661	1.18966
7	2.13992	1.70116	1.89112	1.72595	2.07144	2.28453	2.64458	1.17485	1.00558	2.08479	1.39280	1.78502	1.99937	2.55875
8	0.57252	0.53425	0.61515	0.54875	0.92699	0.92389	1.15019	0.88153	1.08544	1.20076	1.36579	1.25288	1.30859	1.60611
9	0.91116	1.24853	1.62493	1.42860	1.98672	1.74051	2.01075	1.01684	1.63196	1.22556	1.33627	1.06197	1.23884	0.69779
10	0.87713	0.72393	0.41299	0.43080	0.52154	0.48843	0.88513	0.56157	0.38484	0.36883	0.51211	0.36314	0.57204	0.76092
11	0.29564	0.37063	0.39130	0.44125	0.37945	0.49025	0.61317	0.31438	0.30338	0.37937	0.39237	0.31656	0.38134	0.54014
12	0.85109	0.53498	0.52419	0.65065	0.86048	0.74426	0.73649	1.43253	0.87082	1.09388	1.30619	1.22191	1.38743	0.88509

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	0.66233	0.37907	0.39576	0.29623	0.18591	0.24513	0.27857	0.48578	0.40585	0.33629	0.26953	0.36072	0.45529	0.42711
2	1.54624	0.63347	1.06031	0.63048	0.49145	0.58585	0.67657	1.24276	0.95378	1.06822	1.77580	1.39212	1.09176	1.05368
3	0.32641	0.35967	0.36002	0.40415	0.37340	0.40441	0.49959	0.31566	0.43987	0.38124	0.33826	0.36191	0.38793	0.41719
4	1.27301	0.74640	0.63025	0.76143	0.69558	0.84386	0.66247	0.85912	0.86995	0.76115	0.79194	0.80517	0.65399	0.79986
5	2.82185	1.72531	1.82533	1.99332	1.58418	1.47976	1.69412	1.57120	1.35991	1.07873	1.44819	0.94116	0.94830	0.95034
6	2.34775	2.29228	2.95040	3.52419	3.92540	3.08212	3.15213	0.69212	0.78048	0.70056	0.74452	0.87436	0.87102	1.23821
7	2.72107	1.95223	1.67754	1.52066	1.02799	1.08815	1.15374	1.36664	1.43746	1.05700	1.08934	1.06062	1.09246	1.20223
8	0.83920	0.55412	0.51859	0.85830	0.94687	0.93860	1.10406	1.23528	1.02468	0.81019	0.97078	1.17770	1.13111	1.13280
9	1.86405	1.52396	1.19039	1.06854	1.47544	1.09598	1.05032	1.56606	2.15509	1.21027	1.56068	1.03518	1.01351	0.79129
10	1.05427	1.27755	0.80646	0.51477	0.41821	0.57043	0.63078	0.83861	0.80555	0.57122	0.42445	0.48698	0.43252	0.60543
11	0.26895	0.30839	0.31412	0.20711	0.29212	0.33557	0.43873	0.52059	0.44821	0.34081	0.33506	0.27653	0.39579	0.25696
12	0.95226	0.82919	0.69636	0.63318	0.46182	0.43175	0.83123	1.06872	1.38243	1.39007	1.21003	1.27230	0.82336	0.84632

Trunk/hip variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	0.17900	1	0.17900	1.085
OF	1.19400	6	0.19900	2.305
Surface	4.04500	1	4.04500	1.211
FOxOF	1.83500	6	0.30600	3.490 *
FOxSurface	0.08924	1	0.08924	1.536
OFxSurface	1.11600	6	0.18600	3.158 *
FOxOFxSurface	0.37300	6	0.06222	1.190
Subjects				
FOxS	1.81600	11	0.16500	
OFxS	5.69900	66	0.08635	
SurfacexS	36.73100	11	3.33900	
FOxOFxS	5.78400	66	0.08764	
FOxSurfacexS	0.63900	11	0.05811	
OFxSurfacexS	3.88500	66	0.05887	
FOxOFxSurfacexS	3.45200	66	0.05230	
Total		335		

* denotes $p<.01$

Hip/knee IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	2.54325	2.44735	2.27105	2.20395	3.06978	5.16036	5.23425	5.68994	3.34533	7.71439	7.88955	6.03234	5.93489	7.27877
2	2.37536	2.12661	2.33636	2.78455	2.00090	1.66560	1.39115	1.24265	1.21688	1.10677	1.17261	1.43978	1.26647	1.23329
3	1.90020	1.61299	2.40048	2.82635	2.82766	2.49761	1.82891	1.06765	1.20548	1.70334	3.51463	4.32446	3.63029	2.53367
4	0.63955	0.88192	1.46037	1.81400	2.08073	1.51410	1.16237	3.45320	2.20822	4.81443	4.17392	3.58892	3.56488	2.44982
5	1.68512	1.70710	0.61460	1.36540	2.22818	1.01515	0.71591	0.55040	0.52190	1.08297	0.88643	1.16473	0.87407	1.49282
6	2.63068	1.72127	2.53665	2.86085	1.93589	2.27009	1.17662	1.58825	1.74431	1.36541	2.16366	3.22648	3.84613	3.23605
7	1.78275	2.04515	1.42039	2.80915	2.23579	1.79608	0.91517	1.36997	1.56334	1.32403	1.64908	1.50507	2.10301	0.66743
8	0.46525	0.44292	0.41140	0.48575	0.49846	0.49767	0.49589	0.29059	0.25375	0.26659	0.39604	0.35459	0.35475	0.46058
9	1.10973	1.00144	1.21200	1.05490	1.29422	1.38674	0.96016	0.62544	0.48329	0.78622	0.80519	0.96249	0.73164	0.74441
10	1.73380	1.86085	2.00432	2.38375	1.97475	2.32783	2.15462	2.19391	2.67328	2.93149	2.76940	2.90077	1.59761	2.26093
11	5.37810	5.73605	5.32202	4.72530	4.21459	4.01973	3.93974	4.59402	6.47918	4.11589	3.97636	1.98705	2.39520	2.79784
12	1.84016	1.54330	1.76873	1.58170	1.75865	2.09637	3.08446	1.14543	1.29151	1.53150	1.53274	0.99028	0.99446	1.32580

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	3.33439	1.92818	1.63022	2.17398	2.87006	2.98446	2.52735	5.91447	4.20458	6.84291	8.30403	5.95306	4.57069	8.09878
2	1.58733	1.99176	1.54767	1.77981	2.19029	2.24814	2.27793	1.11345	1.22873	1.18177	0.97422	0.90031	0.49312	0.52039
3	2.05259	2.07460	1.95430	1.79943	3.43825	5.46655	5.17431	1.77884	1.67591	1.93486	2.05536	2.99809	3.50531	4.11466
4	0.63553	0.77798	0.47641	0.60772	1.01145	1.05081	1.42315	3.31600	4.81855	4.89533	3.09687	4.57421	5.26853	2.44185
5	0.89900	0.91520	2.01591	2.46305	3.29617	1.56541	1.52202	0.48104	0.60589	0.93076	2.06533	3.25434	2.13692	2.98636
6	3.48285	3.56061	2.32573	1.85684	1.84741	2.73466	1.90899	2.15360	2.43827	1.92922	2.50619	2.87505	2.70402	3.09392
7	1.68304	1.96517	1.90643	1.81036	2.91546	2.51702	2.93392	1.81210	1.99863	1.48869	2.11608	2.25296	2.60611	2.51651
8	0.44058	0.43223	0.47576	0.62429	0.50302	0.63208	0.77380	0.42704	0.31619	0.30006	0.35414	0.36814	0.39822	0.40012
9	0.91644	0.87015	0.91398	0.83457	1.04516	1.32061	1.19467	0.75130	0.80844	0.78931	0.88637	1.22894	1.09974	0.97695
10	3.54524	3.00886	2.34770	2.31753	2.22787	2.22122	2.29794	2.24379	1.93680	2.49735	2.44171	2.09238	2.29180	2.11832
11	5.21538	5.72958	5.48294	5.64216	5.40999	5.33146	5.01947	3.45520	5.30292	5.37379	5.16936	4.39521	5.16013	2.52445
12	2.29163	2.16643	2.20461	2.12567	2.08639	2.43239	2.32261	1.62165	1.52612	2.26505	0.85623	1.10932	0.91317	0.90985

Hip/knee variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	3.15700	1	3.15700	4.050
OF	6.40000	6	1.06700	1.158
Surface	3.63000	1	3.63000	0.276
FOxOF	2.56800	6	0.42800	0.899
FOxSurface	0.04908	1	0.04908	0.086
OFxSurface	3.11100	6	0.51800	0.944
FOxOFxSurface	0.37900	6	0.06310	0.246
Subjects				
FOxS	8.57400	11	0.77900	
OFxS	60.80100	66	0.92100	
SurfacexS	144.76300	11	13.16000	
FOxOFxS	31.41000	66	0.47600	
FOxSurfacexS	6.27100	11	0.57000	
OFxSurfacexS	36.24400	66	0.54900	
FOxOFxSurfacexS	16.93100	66	0.25700	
Total		335		

Knee/ankle IMVRs

Participant	do.16flat	do.23flat	do.31flat	do.47flat	do.54flat	do.63flat	do.75flat	do.16fb	do.23fb	do.31fb	do.47fb	do.54fb	do.63fb	do.75fb
1	0.83270	0.87661	1.39814	2.31430	2.11586	1.53080	0.72142	0.30612	0.63770	0.26066	0.18999	0.22552	0.38369	0.25823
2	0.77612	0.90234	1.29257	1.41075	1.84763	1.47082	1.27132	0.47927	0.56272	0.58842	0.43542	0.38897	0.41792	0.75494
3	1.96674	1.91814	1.79371	1.60950	1.34091	1.30724	1.50809	0.63209	0.48956	0.45086	0.26645	0.25139	0.17105	0.37627
4	0.62331	0.73566	1.29506	0.89175	0.95347	1.10513	1.30072	0.59522	0.39855	0.48224	0.30757	0.34807	0.35033	1.04445
5	0.87479	1.03556	1.49333	1.09090	0.92244	1.61301	1.69888	1.33820	1.75195	1.04434	0.91664	0.79205	0.75379	0.90400
6	1.86717	2.18231	1.97226	1.61815	2.08163	2.08639	1.90876	0.62191	0.70559	0.63838	0.54209	0.25125	0.20503	0.24623
7	1.28952	1.32561	1.53929	1.19660	1.35614	2.21479	2.87074	0.49301	0.37120	0.26755	0.23742	0.21684	0.16546	0.41468
8	2.58157	2.16995	1.67142	1.66560	1.53028	1.51950	1.56517	1.02344	1.04817	1.05518	0.80393	0.78131	0.79683	0.53688
9	0.36888	0.40010	0.48264	0.53845	0.60549	0.75947	1.61192	0.19192	0.20194	0.18319	0.16962	0.16641	0.18283	0.47109
10	1.75321	1.72478	1.45453	1.09285	1.19219	1.02980	1.07336	0.59614	0.58046	0.45759	0.43190	0.44429	0.68297	0.39056
11	0.68720	0.62981	0.65470	0.66360	0.73000	0.80299	0.83835	0.59199	0.43705	0.78538	0.70897	0.89067	0.96684	0.83566
12	1.66799	1.87474	1.82843	1.58550	1.15472	1.03225	0.89707	0.41814	0.47505	0.37928	0.30530	0.39796	0.33974	0.43019

Participant	up.16flat	up.23flat	up.31flat	up.47flat	up.54flat	up.63flat	up.75flat	up.16fb	up.23fb	up.31fb	up.47fb	up.54fb	up.63fb	up.75fb
1	1.02926	1.19440	1.40226	1.92997	2.84854	2.82776	1.97714	0.26897	0.30669	0.15478	0.20631	0.22310	0.65392	0.16685
2	1.37110	0.96057	1.10501	1.52678	1.45160	1.18489	1.10134	0.46944	0.52121	0.42285	0.59299	0.55921	0.98513	0.86849
3	1.54583	1.74579	2.02490	1.90377	1.55420	1.10198	1.03912	0.66483	0.59678	0.47536	0.51901	0.34004	0.23671	0.24189
4	1.38533	1.00770	1.15190	1.07369	0.99904	1.03193	1.34898	0.49568	0.36638	0.62460	0.50100	0.44537	0.47715	0.78332
5	1.84821	1.43728	0.89625	0.85633	0.73237	1.07266	1.23536	0.98523	0.88955	1.15768	0.88038	0.48152	0.71310	0.55829
6	1.23488	1.50484	1.92678	3.08177	2.21293	1.25730	1.31154	0.68240	0.50635	0.54225	0.48615	0.42280	0.37505	0.25526
7	1.56569	0.99569	1.02057	1.55782	1.24015	1.85275	1.41808	0.26969	0.26208	0.52096	0.22193	0.26119	0.31142	0.31269
8	1.88586	1.97477	1.95306	1.58295	2.10027	1.80816	1.81255	1.03102	0.96291	0.86994	0.91166	0.69669	0.87210	0.60939
9	0.57275	0.51091	0.49896	0.83870	0.69243	1.05942	1.64957	0.31040	0.15292	0.12884	0.13649	0.15889	0.16045	0.23784
10	0.75635	0.96595	1.27858	1.12483	1.13225	1.09997	1.07139	0.50232	0.41771	0.41080	0.40017	0.41375	0.32018	0.38804
11	0.89678	0.70561	0.71645	0.64751	0.60916	0.61907	0.67801	0.82477	0.57030	0.59394	0.53443	0.49606	0.32432	0.54194
12	1.16883	0.83080	1.00188	1.19290	1.34071	0.99908	1.06773	0.40762	0.32494	0.27022	0.57158	0.33252	0.71921	0.68245

Knee/ankle variability ratio Table

Source	Sum of Squares	df	Mean Square	F
FO	0.10000	1	0.10000	0.901
OF	0.10300	6	0.01712	0.122
Surface	56.24800	1	56.24800	43.880 *
FOxOF	0.56400	6	0.09394	1.533
FOxSurface	0.00154	1	0.00154	0.013
OFxSurface	0.84100	6	0.14000	1.544
FOxOFxSurface	0.14900	6	0.02491	0.357
Subjects				
FOxS	1.22200	11	0.11100	
OFxS	9.28600	66	0.14100	
SurfacexS	14.10000	11	1.28200	
FOxOFxS	4.04300	66	0.06126	
FOxSurfacexS	1.35400	11	0.12300	
OFxSurfacexS	5.98900	66	0.09074	
FOxOFxSurfacexS	4.61000	66	0.06986	
Total		335		

* denotes p<.01