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STABILITY OF STANDING ON AN UNSTABLE SURFACE

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ABSTRACT

Background: Side by side stance is a simple task for healthy adults. In order to challenge the postural control system, studies have often used unstable surfaces of support. ***Purpose:*** The focal point of this current research is to examine the influence of reduced base of support area on weight distribution and postural stability**.** ***Methods:*** Twelve healthy right-footed college students were recruited for the study. The participants stood on two boards with selective beam widths that had direct contact with two adjacent force platforms. On the left force platform, the beam was oriented longitudinally with a width of 2.5 cm. On the right force platform, the beam was oriented horizontally with three possible beam widths (2.5 cm, 4.0 cm, 8.5 cm). ***Results:*** .There was a non-significant effect of beam width on body weight distribution. There was a main effect for beam width on ApEn in the AP direction. The ApEn of the 2.5cm beam was significantly lower than that of the ApEn of the 4.0 cm and 8.5 cm beams. ***Conclusion:*** As the width of the horizontal beam under the right foot reduces (8.5 cm, 4.0 cm, 2.5 cm), we hypothesized more weight to be distributed in the left foot. Additionally, we predicted the complexity of COP to increase as the width of the right beam decreases. Our results failed to show significance in COP variability when testing for beam widths. When the right beam was 2.5 cm, the complexity was significantly lower than that of the beam widths 8.5 cm and 4.0 cm. One of our major findings was that the complexity in the AP direction of the 2.5 cm beam width was the smallest of the three widths. Our results provide additional evidence of the search strategies of the postural control system and the feedback and feedforward control processes in this process.

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Introduction

Upright human posture is an interesting phenomenon that has been studied extensively due to the centrality of posture in action and the complex mechanisms of the posture control system. A central issue is how about two-thirds of our body mass is located two-thirds of the body height above ground; therefore, sustaining a higher center of mass at a height over a small base of support, our feet, can be inherently difficult (Winter, 1995; Riccio, 1993). In spite of this, healthy adults require little to no attention directed to the control of posture in side-by-side stance.

In order to challenge the postural control system, studies have often used unstable surfaces of support (Mochizuki, Duarte, Amadio, Zatsiorsky, & Latash, 2006; Mochizuki, Duarte, Zatsiorsky, Amadio, & Latash, 1999; Krishnamoorthy, Yang, & Scholz, 2005). For example, Mochizuki et al. (2006) required participants to stand still on wooden boards that had beams attached underneath. The beams, which had direct contact with the force platforms, reduced the area of the base of support (i.e. 0.086 x 0.086 m (square), 0.043 x 0.086 (narrow-and-short), 0.043 x 0.172 m (narrow-double length), 0.043 x 0.500 m (narrow-and-long), and 0.086 x 0.500 m (wide-and-long)). Reducing the area of the base of support can have a large impact on as simple of a postural task as side-by-side stance. The results led to the proposal that the central nervous system (CNS) uses a "searching" mechanism during upright posture. The searching process refers to the postural sway that occurs to test the limitations of stability in quiet stance. For example, when someone stands on a base of support that has a smaller area than their feet, the center or pressure (COP) range of motion is larger than the base of support. Postural sway is a common term used to describe the random variations of COP position. The general hypothesis predicts that postural sway is a search process used to determine one's stability.

Studies have suggested that maintaining stance on unstable surfaces requires feedback and feedforward control processes (Massion, 1992). Feedback control processes include sensory feedback signals from visual, proprioceptive, and vestibular systems, whereas feedforward processes are used to stabilize COP in preparation of an expected action. The role of anticipatory postural adjustments (APAs) is to compensate expected perturbations in a feedforward manner. Aurin, Forrest, and Latash (1998) found that increasing postural instability decreases APAs. The authors hypothesized that the CNS suppresses APAs to prevent the potential destabilizing effects. These findings suggest an important link between the CNS and postural control system.

To study postural control processes, most research has examined postural instability in the sagittal plane (Gavrilenko, Gatev, Gantchev, & Popivanov, 1991; Aruin, Forrest, & Latash, 1998; Krizkova, Hlavacka, & Gatev, 1993; Ivanenko, Levik, Talis, & Gurfinkel, 1997; Trimble & Koceja, 2001; Streepey, Kenyon, & Keshner, 2007; Slobounov, Cao, Jaiswal, & Newell, 2009). One major finding of the study by Mochizuki et al. (2006) was that sagittal plane instability produced significantly more sway than frontal plane instability. Other studies have looked at and examined the frontal plane instability.

Wang, Molenaar, and Newell (2013) conducted a study that used beams to induce frontal plane instability and sagittal plane instability. It also tested for width (2.5 cm, 4.0 cm, and 8.5 cm) of the unstable support surfaces to investigate the influence it had on inter- and intra-coordination foot dynamics. The authors found that the largest influence on our postural control system was orientation of the unstable support surfaces. The greatest instability was present when the unstable support surfaces were positioned horizontally. Additionally, when the beams were horizontal and the most unstable (2.5 cm), the COP range of motion in the AP direction exceeded the width of support.

Similar findings were also presented in a study by Otten (1999). The author set up an experiment where participants balanced on an unstable ridge with one foot while focusing on the frontal plane. The center of mass of the participants' sway fell beyond the area of support surface. Furthermore, because of the sway of the participants, the direction of the ground reaction force often changed dramatically. In order to keep the center of mass within safe boundaries, participants used postural sway to help move their COP. These results provide additional evidence for the "searching" process in the postural control system.

The focal point of this current research is to examine the influence of the reduced base of support area on weight distribution and postural stability. By calculating the ground reaction force ratio (Fz ratio) and examining linear/nonlinear characteristics of COP-L, COP-R, COP-net, we can determine if the widths of the beams have a significant effect on these factors. The use of two force platforms allows us to determine the ground reaction forces of the two feet and therefore the weight distribution. Two force platforms also allow the assessment of the COP of each foot separately (Kilby & Newell, 2012; Wang et al., 2013).

In this present study, participants were asked to stand on two boards with narrowed beams attached underneath that were placed on top of two separate force platforms. The experiment was designed specifically for right footed people. Under the left board was a beam oriented longitudinally spanning the length of the board with a fixed width of 2.5 cm. Under the right board was a beam with potential widths of 2.5 cm, 4.0 cm, or 8.5 cm oriented horizontally spanning the width of the board. The left board remained constant at 2.5 cm due to the findings in the study conducted by Wang et al. (2013). When testing the longitudinal conditions, there was no difference in COP range of motion for conditions with widths of 4.0 cm and 8.5 cm; therefore, it would be unnecessary to test the left foot in these additional conditions. The 2.5 cm longitudinal beam was sufficient enough to stimulate instability in the left foot.

According to the Waterloo Footedness Questionnaire-Revised (WFQ-R) that assesses foot preference, all of the participants were classified as right-footed (Elias, Bryden, Bulman-Fleming, 1998). When standing upright, right footed people utilize their left foot for postural stabilization, hence the left beam oriented longitudinally. In past research, evidence has found that instability in the frontal plane is far less significant than instability in the sagittal plane (Winter, 1995; Riccio, 1993). In this particular study because our focus is on manipulating the stability of the right foot, the left beam is oriented longitudinally so that it is more stable. Right footers use their dominant foot for manipulation tasks, like kicking a soccer ball or balancing on one foot. As previously noted, the majority of research concludes that manipulations that decrease joint stability in anteroposterior direction have a larger effect than manipulations that decrease joint stability in the mediolateral direction (Winter, 1995; Riccio, 1993). Additionally, COP range of motion is significantly greater in the AP direction compared to the ML direction (Mochizuki et al., 2006). Because of these conclusions which state that generating instability in the sagittal plane shows more significant motion, we chose to keep the right beam oriented horizontally. The orientations of the beams are used to create a partially stable left foot while we can test for the unstable right foot.

When positioned in side-by-side quiet stance, healthy adults distribute their weight symmetrically on both the right and left foot. After introducing challenging postural tasks, people do not always place their weight evenly on each foot. Specifically, Wang and Newell

(2012) found a pattern of asymmetrical load when participants stood in staggered and tandem stances. Participants favored their rear foot and naturally placed more weight there because of its stability. In our study, we predict the same effect. The left foot, or stabilizing foot, is already more stable because of the longitudinal orientation of the beam. As the width of the horizontal beam under the right foot reduces (8.5 cm, 4.0 cm, 2.5 cm), we hypothesize more weight to be distributed in the left foot. The equation we are using for the ground reaction force ratio is $Fz = (Fz_L – Fz_R) / (Fz_L + Fz_R)$; therefore, we predict $Fz < 0$.

Wang and Newell (2012) investigated the synchronization of the COPs of each foot and the COP-net. When one foot carried more weight than the other, the COP of the foot holding more weight and COP-net had significantly longer duration of synchronization. Additionally, when body weight is distributed symmetrically like in quiet stance, due to sagittal plane instability, the COPs coupled longer in the AP direction. Given this information, we can make a few predictions for the experimental outcomes. As previously stated, we predict more weight to be placed on the left foot because it acts more as a stabilizer. Since COP-net and the COP of the more loaded foot have shown synchronization, we propose that the complexity of COP-L and that of COP-net will be similar. Furthermore, since the left foot is more unstable in the frontal plane, we hypothesize that the complexity of COP-L and the complexity of COP-net will be similar for a longer period of time at least in the ML direction. Lastly, we predict the complexity of COP to increase as the width of the right beam decreases.

Methods

Participants

Twelve healthy young college students were recruited after being pre-screened for foot preference using the Waterloo Footedness Questionnaire-Revised (WFQ-R). The WFQ-R assessed foot preference by evaluating the preference of the foot for manipulation tasks, such as kicking a motionless ball, as well as stabilizing tasks, such as balancing on one foot. The questionnaire was scored as responses of left-always, left-usually, equal, right-usually, and right-always on a scale from -2 to 2. Consequently, for the most left-footed case, there would be an overall score of -20, and for the most right-footed case, there would be an overall score of 20. According to Elias et al. (1997), foot preference is identified by: (i) left-footed, scores range from -20 to -7, (ii) mixed-footed, scores of -6 to 6 and (iii) right-footed, scores of 7 to 20.

The 12 participants who were recruited responded with scores between 7 and 20 and were classified as right-footed. Of the twelve participants, six were males and six were females. The average age for the participants was 20.4 years (range 18 to 24 years), the average height was 166.3 cm (range 149.9 cm to 185.4 cm), and the average weight was 135.7 lbs (range 105 lbs to 180 lbs). The participants provided written informed consent approved by the Institutional Review Board of the Pennsylvania State University.

Apparatus

The participants stood on two boards with selective beam widths that had direct contact with two adjacent synchronized AMTI (American Mechanical Technology, Inc., Watertown, MA) force platforms. Kinetic data, force and moment, were collected with a sampling frequency of 100 Hz. The boards that were attached to the beams were identical in width and length with dimensions of 20 cm by 40 cm. The only differences between the boards were the widths of the beam and the orientation of the beams. On the left force platform, the beam was oriented longitudinally with a width of 2.5 cm. On the right force platform, the beam was oriented horizontally with three possible beam widths (2.5 cm, 4.0 cm, 8.5 cm). The right and left boards were always positioned 25 cm apart and aligned symmetrically. Between each condition, the platforms were calibrated and synchronized for data collection. Figure 1 illustrates the setup of the experiment depicting the beam widths and orientations and platform set-up.

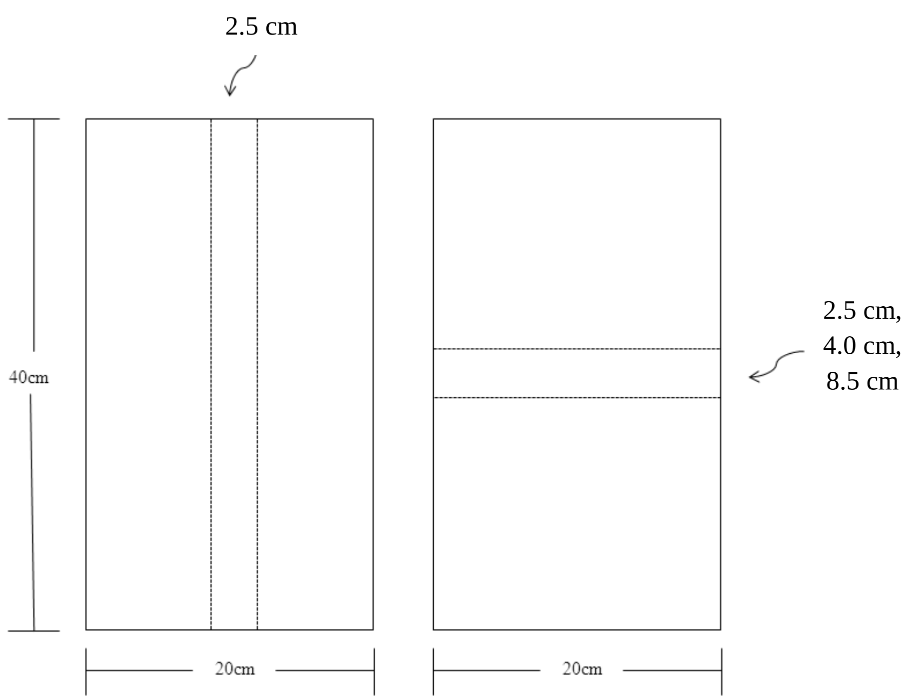


Figure 1 displays the board set up of the experiment. On the left side, the beam is placed longitudinally with a fixed beam width of 2.5 cm. On the right side, the beam is placed horizontally with varying beam widths of 2.5 cm, 4.0 cm, and 8.5 cm.

Tasks and procedures

Participants were asked to remain in quiet stance postures while standing on the left and right boards. They were required to stand as still as possible with their knees straight, arms by their sides, and toes pointing straight forward. Their eyes remained facing forward at a target directly in front of them. Data collection began 5 s after the trial was initiated and the participants were in a comfortable position. Each condition with a different beam width (2.5 cm, 4.0 cm, 8.5 cm) of the right board took 2 trials; therefore, there was a total of 6 trials. Each trial collected data for 60 s. If the edge of one of the boards touched the force platform, the trial would be discarded and the trial would be recollected. Breaks were given between each trial when needed. Figure 2 displays the stance each participant was asked to keep.

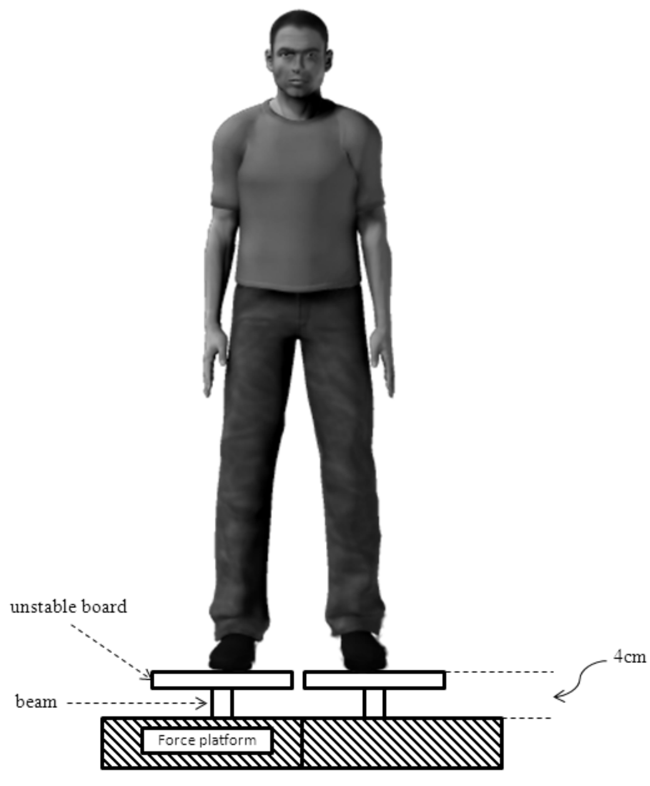


Figure 2 shows the experimental apparatus and the set-up. The subject has his hands by his sides and his head, eyes, and feet facing forward.

Data analysis

There were several variables of postural control that were analyzed. The force and moment data collected from the force platforms were filtered using a 4th-order zero-lag Butterworth low-pass filter with a 6 Hz cutoff frequency. Postural variability was quantified by computing the ellipse of COP data that is derived from the force and moment time series recorded from the force platforms.

The complexity of COPnet time series in both AP and ML directions was examined using Approximate Entropy (ApEn). ApEn is a regularity measure that quantifies the complexity of fluctuations over a times-series data in both AP and ML directions (Pincus, 1991). It is the negative natural logarithm of the conditional probability that two m-dimensional templates that are similar within a tolerance r remain similar at the next (m + 1) – dimensional state space. The range for ApEn is 0 to 2, with 2 being the most complex and 0 being least complex. For example, white noise is considered extremely irregular; therefore, its ApEn would tend to 2. While a sine wave is extremely predictable and, therefore, would have an ApEn tending to 0.

Lastly, the Fz ratio was calculated to determine the body weight distribution over both feet using the equation: $Fz = (Fz_L – Fz_R) / (Fz_L + Fz_R)$. If the Fz ratio was equal to 0, then this would mean the participant distributed their body weight on both feet equally. If the Fz ratio was greater than 0, then the participant would be placing more body weight over the left leg; and if the Fz ratio was less than 0, the participant placed more body weight over the right leg.

Results

Fz Ratio – Weight Distribution

The descriptive statistical analyses in the three width conditions, when the right beam width = 2.5 cm, 4.0 cm, and 8.5 cm, are shown in Table 1. A one-way ANOVA was conducted to compare the effect of the beam widths (2.5 cm, 4.0 cm, 8.5 cm) on body weight distribution in the three different conditions. There was a non-significant effect of beam width variable on body weight distribution at the α=.05 level for all three conditions [F(2,33) = .956, p = .395].

Beam Width (cm)	N	Mean	Std. Deviation	Std. Error
2.5	12	.0525	.08981	.02593
4.0	12	.0449	.06833	.01973
8.5	12	.0117	.07035	.02031

Table 1: Descriptive statistical analysis of the Fz ratio in the three beam width conditions.

ApEn (ML) – Regularity in ML direction

A two-way ANOVA showed several significant effects of Approximate Entropy (ApEn) in the mediolateral (ML) direction. The null hypothesis was that there are no differences in ApEn in the mediolateral direction across beam width and center of pressure type (i.e., COP-L, COP-R, and COP-net). Beam width and COP types were tested as the main effects. We also tested the interaction effect between the beam width and COP type. The two-way analysis of variance yielded a main effect for the COP type main effect in the ML direction, $F(2, 22) = 16.546$, $p=.000$. The pairwise comparison showed that the ApEn of the COP-net was significantly higher ($M=.141$, $SD=.013$) than that of the ApEn of COP-L and COP-R (COP-L : $M=.089$, $SD=.010$; COP-R: $M=.114$, $SD=.011$). The main effect of beam width was non-significant, $F(2, 22) =.436$, $p >.05$. Additionally, the interaction effect was non-significant, $F(4, 44) = 1.498$, $p=.219$. Figure 3 shows the non-significant interaction effects in the ML direction.

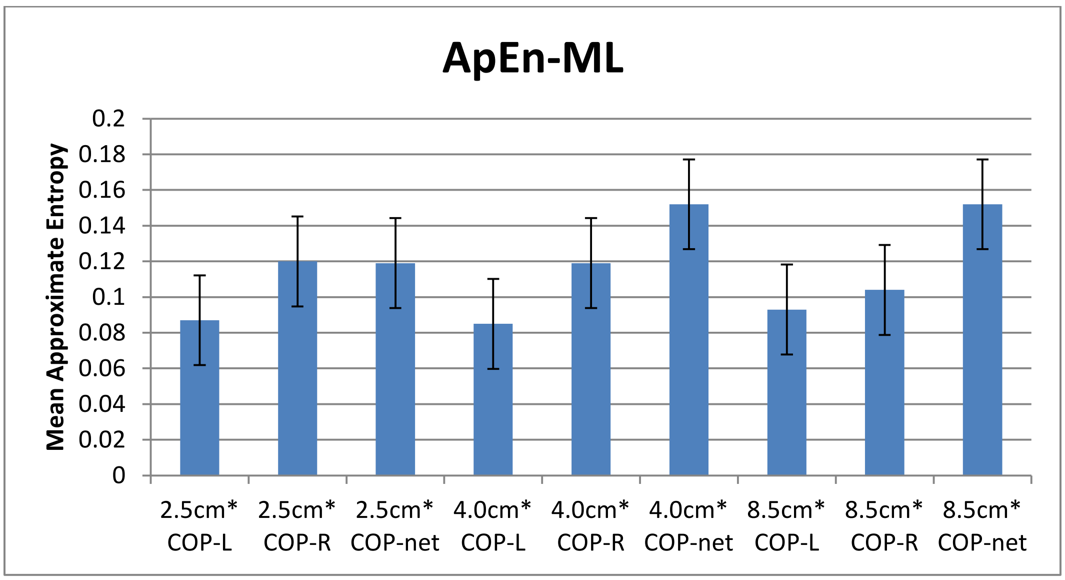


Figure 3: Mean ApEn of the interaction effects between COP type (COP-L, COP-R, COP-net) and beam width (8.5cm, 2.5cm, 4.0cm) in the ML dimension. Error bars are standard deviation.

ApEn (AP) – Regularity in AP direction

A two-way ANOVA was also used to analyze ApEn in the anteroposterior (AP) direction. The null hypothesis was that there are no differences in ApEn in the anteroposterior direction across beam width and center of pressure type (i.e., COP-L, COP-R, and COP-net). As in the calculations for ApEn in the ML direction, beam width and COP type were tested as main effects, and the interaction effect between COP type and width were tested for ApEn in AP direction.

The two-way analysis of variance yielded a main effect for the beam width of ApEn in the AP direction, $F(2, 22) = 3.697$, $p=.041$. The pairwise comparison verified that ApEn of the 2.5cm beam was significantly lower (M=.073, SD=.008) than that of ApEn of the 8.5cm and 4.0cm beams (8.5cm beam : M=.076, SD=.006; 4.0cm beam: M=.090, SD=.007). Additionally, the main effect for COP type of ApEn in the AP direction was significant, $F(1.220, 13.425) = 9.403$, $p=.006$. The post-hoc analysis confirmed that the ApEn of the COP-R was significantly lower (M=.067, SD=.006) than that of both COP-L (M=.088, SD=.008) and COP-net (M=.084, SD=.007).

The interaction effect of beam width and COP type was also significant, $F(2.621, 28.834) = 3.464$, $p=.034$. Post-hoc analysis showed that the complexity of the COP-L was significantly larger than that of the two other COPs when the width of the beam was 2.5cm (COP-L M=.086; COP-R M=.054 and COP-net M=.080). Additionally, according to the post-hoc analysis, when the beam width was 2.5cm, the ApEn of COP-net was significantly larger than the ApEn of COP-R (COP-net M=.080; COP-R M=.054). Lastly, the analysis also showed that the complexity of COP-L was significantly larger than that of COP-R when beam width was 4.0cm (COP-L M=.098; COP-R M=.077). Figure 4 portrays the significant interaction effects in the AP direction.

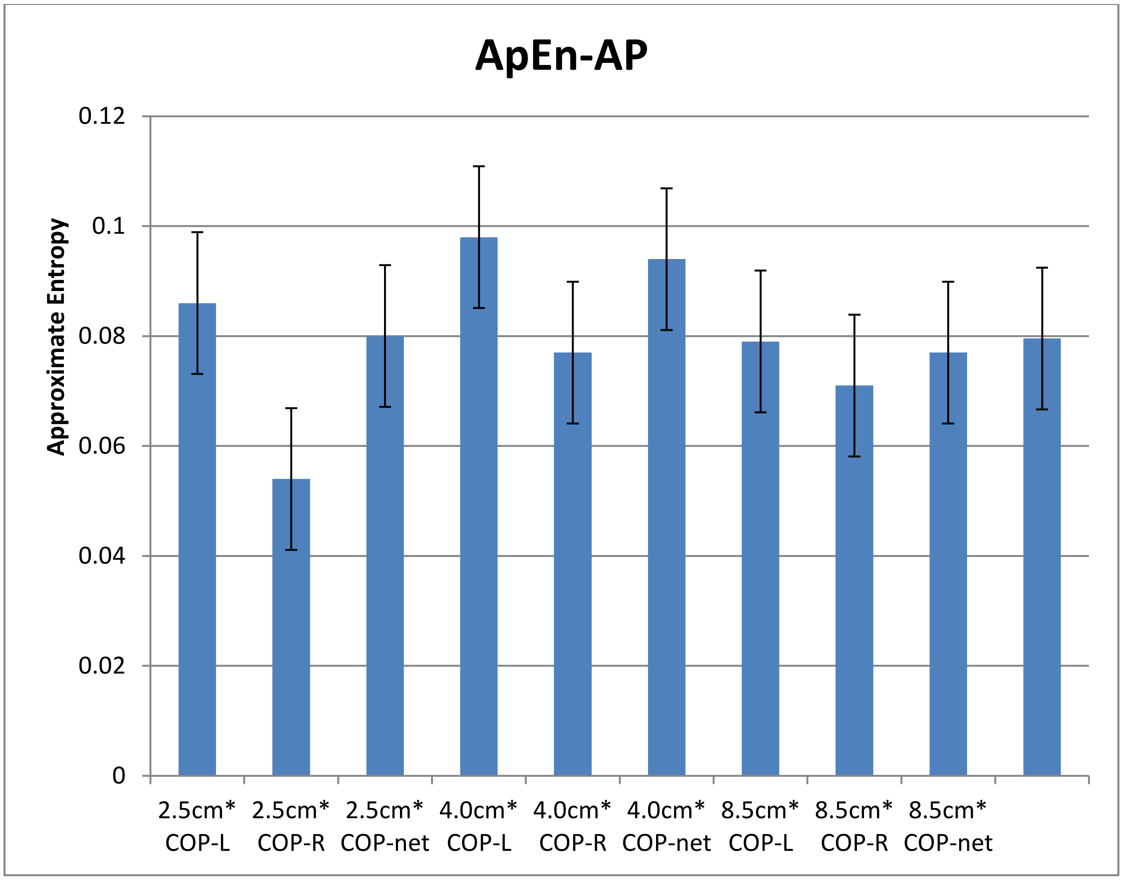


Figure 4: Mean ApEn of the interaction effects between COP type (COP-L, COP-R, COP-net) and beam width (8.5cm, 2.5cm, 4.0cm) in the AP dimension. Error bars are standard deviation.

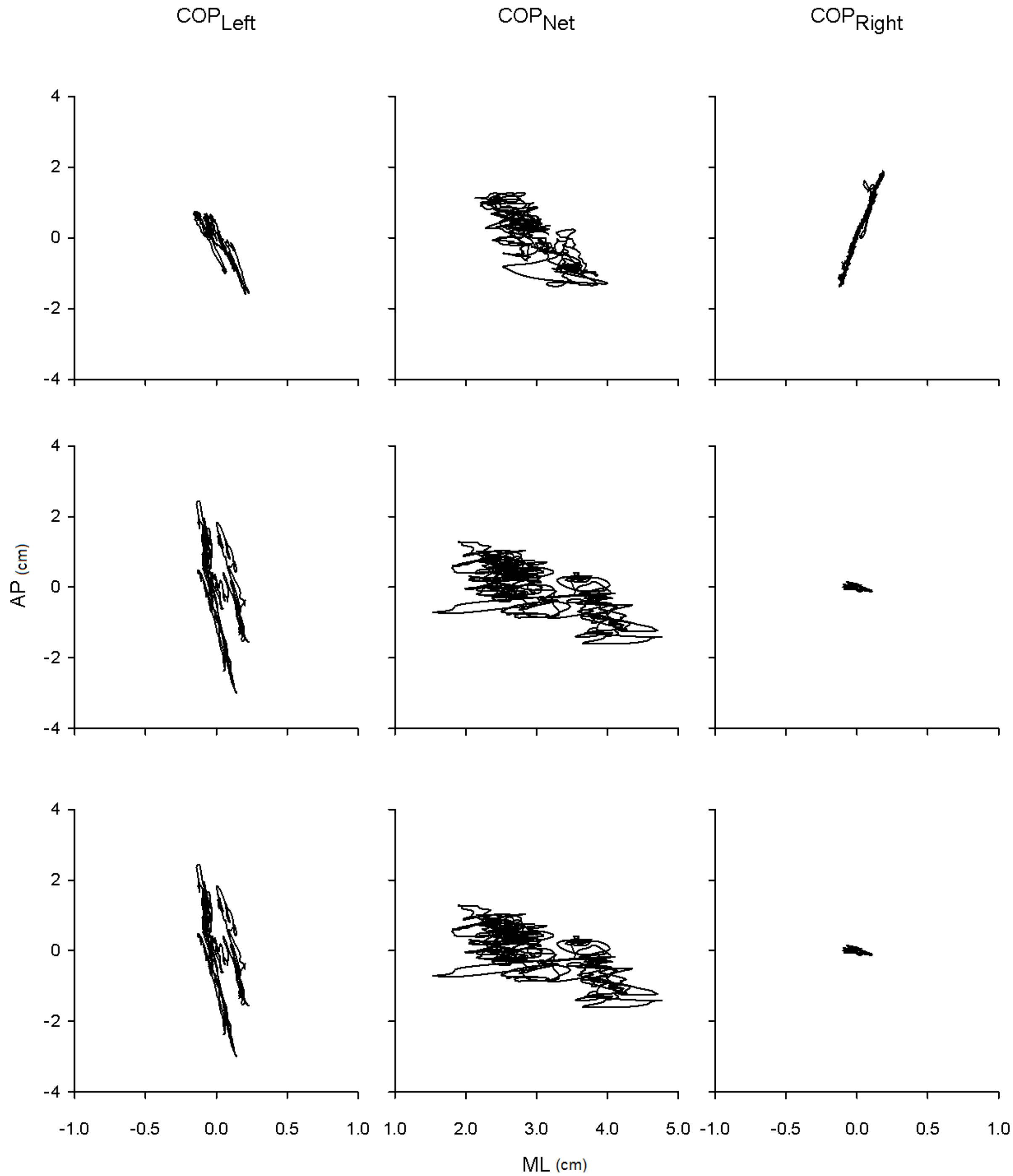
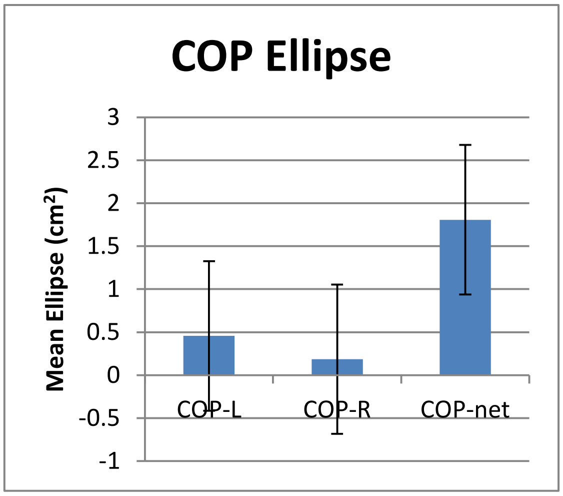


Figure 5: The sample COP plot shows the three COP types from left to right: COP-L, COP-net, COP-R, along with the three beam widths from top to bottom 8.5cm, 4.0cm, 2.5cm.

Ellipse – Postural Variability

To quantify postural variability, we computed the ellipse of COP type (i.e., COP-L, COP-R, and COP-net) and beam width. In order to investigate the null hypothesis that there are no postural variability differences with beam width and center of pressure type, we calculated the ellipse at the $p = .05$ level. The three beam widths and the three COP types were tested as the main effects. We also tested the interaction effect between the width and COP type. We used a two-way ANOVA to determine the influence of the independent variables on the measure of ellipse.

The two-way analysis of variance yielded a main effect on the ellipse for the COP type, $F(1.052, 11.574) = 19.543$, $p=.001$. The post-hoc analysis found that the ellipse of the COP-net was significantly higher ($M = 1.808$, $SD = .375$) than that of the ellipses of COP-L ($M=.456$, $SD=.083$) and COP-R ($M=.186$, $SD=.051$). However, the main effect for the ellipse for beam width was non-significant, $F(2, 22) = .773$, $p>.05$. Furthermore, the interaction effect was also non-significant, $F(1.740, 19.138) = 2.282$, $p=.134$. Figures 6 and 7 show the mean ellipses of COP and beam width, respectively.



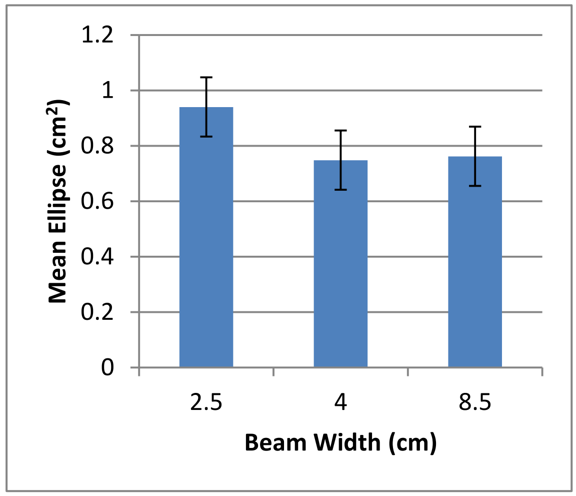


Figure 6 and 7: Mean ellipse of AP and ML dimensions is shown above in each condition of COP type (COP-L, COP-R, and COP-net) and beam widths (8.5cm, 2.5cm, 4.0cm), respectively. The error bars are standard deviation.

Discussion

The focus of this present study was to investigate how unstable beam widths and orientation affect body weight distribution and COP variability, together with the COP complexity under each foot and their relation to the COP-net. In our study, we used two boards with beams attached to the bottom; the left beam was fixed longitudinally while the right beam was fixed horizontally. The setup was specifically made for right-footers (Peters, 1988). Therefore, we hypothesized more weight would be placed on the left foot rather than the right foot. Since we anticipated that more weight will be distributed on the left foot, we hypothesized the complexity of COP-L will be more similar to that of COP-net (Wang & Newell, 2012). And lastly, we predicted COP variability to be greater as beam widths decreased. To test these predictions, we calculated the body weight ratio, approximate entropy of COP, and the standard deviation of COP ellipse.

The null hypothesis that beam width induced an asymmetrical body weight distribution was not rejected. For the COP ellipse, we observed a significant COP type main effect; the ellipse of COP-net was significantly larger than that of COP-L and COP-R. For COP ApEn, we observed a significant COP type main effect in the ML direction whereas in the AP direction, we found significant main and interactive effects of both COP type and beam width.

Our results failed to show significance in COP variability when testing for beam widths. We had predicted a higher COP variability as the beam width decreased. Most studies have shown that participants standing on an unstable shortened support surface have greater COP range of motion (Mochizuki et al., 2006). Unlike previous studies, we found that beam width was not a significant factor that influenced COP variability. The significant effect that COP-net variability was greater than that of COP-R and COP-L is consistent with previous studies

(Winter, 1995). This conclusion is logical because the variability of COP-net is made up of both the variability of COP-R and of COP-L. Also, the magnitude of COP variability in the anteroposterior direction exceeded the width of the 2.5 cm beam. This pattern relates to the "searching" mechanism that the CNS uses to keep upright posture (Mochizuki et al., 2006). As mentioned previously, the searching method refers to the motion of the COP patterns of postural sway. Postural sway increases when the beam width decreases in size because of the instability. Our results provide additional information in the search strategies of postural sway.

ApEn in both ML and AP directions was calculated to determine the effect that the unstable boards had on postural stability. The Approximate Entropy is a measure used to quantify randomness and predictability of a system (Pincus, 1991). The larger the ApEn, the more random and irregular the system is and vice versa. We had anticipated that there would be a lower COP complexity as the task constraint became more difficult because reduced COP trajectories are available.

In our case, we predicted low COP ApEn when the right beam width decreased. The ApEn in the ML direction resulted in a significantly larger complexity of COP-net than the complexity of COP-R and COP-L. We were unable to determine any differences in ApEn in the ML direction across beam width. Conversely, our findings showed significant effects in the AP direction. When the right beam was 2.5 cm, the complexity was significantly lower than that of the beam widths 8.5 cm and 4.0 cm. Furthermore, the complexity of COP-R was significantly lower than that of COP-net and COP-L. As for the interaction effect between COP and beam width, when the right beam width was 2.5 cm, the complexity of COP-L was larger than the other COPs and COP-net was significantly larger than COP-R. When the right beam was 4.0 cm, the ApEn of COP-L was significantly larger than the ApEn of COP-R. Because the ankle joint's primary function is movement in the AP direction, it is reasonable that there were more significant main and interactive effects in the AP direction rather than in the ML direction (Krishnamoorthy, Yang, & Scholz, 2005).

One of our major findings was that the complexity in the AP direction of the 2.5 cm beam width was the smallest of the three widths. These results are supported by previous literature. In Wang, Molenaar, and Newell (2013), COP range of motion was the largest when the beams were oriented horizontally at 2.5 cm widths. Aging and sickness is often associated with lower ApEn, while normative physiology is associated with larger ApEn (Pincus & Goldberger, 1994). This is because there is greater regularity and less complexity when one's physiology is compromised. In our current study, the 2.5 cm beam is the most difficult condition. Unlike the other two conditions, in the 2.5 cm condition participants have fewer options to move around without losing balance causing COP trajectories to look more regular. In the 8.5 cm condition, participants are unlikely to fall no matter how shaky and unsteady they are, so COP trajectories look more complex.

Another major finding was that complexity of COP-R in the AP direction was significantly smaller than the other COPs. The orientation of the beams played a major role in this discovery. Wang, Molenaar, and Newell (2013) conducted a study to test the effect of beam width and orientation on COP motion. It was found that the horizontal conditions stimulated the most COP range of motion. Since the orientation of the right beam is fixed horizontally to cause the most instability and difficulty, the complexity of COP-R is the smallest. It is more regular due to the few options of maintaining balance. Furthermore, when the right beam was 2.5 cm, the complexity of COP-L was greater than that of COP-net and COP-R, and the complexity of COP-net was greater than COP-R. The complexity of COP-L was largest because of the left beam's stability. The beam was oriented longitudinally, and therefore was more stable than the right beam. The feedback and feedforward information are easily transferred when the body is in a more stable state (Pincus & Goldberger, 1994).

It was important to calculate both the ellipse and ApEn to determine variability and complexity of postural stability. Most researchers use COP variability to quantify postural stability, but Newell, van Emmerik, Lee, and Sprague (1993) conducted a study which suggests COP variability is insufficient to determine stability of posture. The study focused on participants with tardive dyskinesia, a movement disorder, compared to those without the disease. Some participants with the disorder showed the same results of COP variability as the 'normal' participants, while other participants with a tardive dyskinetic profile showed a more rhythmic COP variability. To further investigate postural stability, one must do additional tests that will consider the postural dynamics. ApEn is an additional measure that can enhance the findings of the dispersion ellipses. ApEn focuses on the order of data rather than the magnitude of variation (Pincus & Goldberger, 1994).

As for our hypothesis regarding weight distribution, we found no significant effect on weight distribution due to beam width. Usually in side-by-side stance, weight distribution is symmetrical (Wang & Newell, 2012). Since we added instability, we proposed that there would be an asymmetrical body weight pattern. For example, Wang and Newell (2012) found that while participants stood in staggered and tandem stances, about 65-75% body weight was placed on the rear foot. The rear foot is considered more stable, so the participants felt more comfortable placing body weight on that foot. In our present study, the left foot is considered more stable due to the longitudinal orientation of the beam; the right foot is less stable because it is oriented horizontally and induces anteroposterior instability. In the end, our prediction was not supported by our results. One reason for this could be because of the side-by-side stance. The Wang and Newell (2012) study found symmetrical weight distribution in side-by-side stances and asymmetrical weight distributions in other stances. It is possible weight distribution does not change in side-by-side stance even when you induce instability.

The purpose of requiring participants to stand on narrowed support surfaces was to challenge and create instability to the postural control system. People rely on three sensory systems: visual, proprioceptive, and vestibular, to maintain balance (Gaerlan, Alpert, Cross, Louis, & Kowalski, 2012). In order to sustain side-by-side stance and to complete the many activities of daily living, individuals depend largely on proprioceptive and cutaneous input. The mechanoreceptors, that play a prime role in proprioception, relay information about muscle length and speed of contraction to the central nervous system. The relaying of information gives the individual the ability to recognize joint movement and its position. Without our understanding of where our body is related to space, it is difficult to uphold side-by-side stance. The feedback and feedforward control processes allow the necessary information to be sent to the CNS to correct any postural instability.

With this study, there were some limitations. Due to the length of sessions and short amount of time to use the lab before another experiment was set up, we were only able to test 12 students. By increasing the amount of participants, the added data could have impacted our results. To fix and investigate our results, there are a few suggestions for future studies. It would be interesting to further investigate weight distribution using the different beam widths. Because we saw no differences in weight distribution in side-by-side stance, it might be fitting to see if there is different weight distribution and if so, the extent of asymmetrical weight load, in staggered and tandem stances. Using the same protocol of the study but requiring different stances can help explain why weight distribution of side-by-side stance was unaffected by the beam widths and setup of the experiment. Additionally, another future suggestion for a study is to reverse the setup. The beam orientations were designed for right footed people. If we reverse the orientations and instead had the right beam fixed longitudinally and the left beam fixed horizontally, we could compare the results of the present study to see if foot dominancy has a big impact on the results.

In summary, our findings in the present study show that unstable bases of support induce postural instability. The postural control system is complex in many ways. It gathers and relays information using different mechanisms to keep balance. Our results provide additional evidence of the search strategies of the postural control system and of feedback and feedforward control processes in this search. Our study builds on previous research in providing results that support concepts and mechanisms of the postural control system.

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