I, Scott H Bonnette, hereby submit this original work as part of the requirements for the degree of Master of Arts in Psychology.

It is entitled:
Exploratory Action in Affordance Perception: The Influence of Postural Sway on Judgments of Stand-on-able Slopes

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Exploratory Action in Affordance Perception: The Influence of Postural Sway on Judgments of Stand-on-able Slopes

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Abstract

The present thesis examined the perception of affordances for upright stance on a slanted surface. The specific aims were (1) to determine the sensitivity of people to changes in their ability to stand on an inclined surface and (2) to investigate if people produce exploratory movements to facilitate prospective perception of an affordance for upright stance. The first interest was explored by comparing participants’ perceptual reports to actual behavioral boundaries. The second interest was investigated by constraining half of the participants’ ability to generate optic flow by requiring them to rest the back of their head on a horizontal restraint bar. Additionally, the second interest was further investigated by comparing the postural sway of participants who made affordance judgments to participants who simply observed the platform for the duration of the experiment. The affordance for upright stance was manipulated by adding a backpack with differing amounts of weight (0%, 10%, and 20%) to either to front or back of participants’ torsos and by adjusting the slanted surface’s incline. The adjustable wooden surface moved continuously in two directions (ascending and descending) over a range of 18° to 45°. Results corroborate past investigations on participants’ sensitivity to affordances for upright stance on sloped surface; however, it extends past research by demonstrating the accuracy of reports diminished when the head was constrained. Additionally, participants who made judgments moved in a different manner than participants who simply observed the platform. The experiment also displayed that participants’ postural sway was influenced by the physical manipulations of the backpack and head restraint bar. Discussion focused on (a) the sensitivity of people to the affordance of upright stance, (b) exploratory movements used to facilitate prospective
perception of an affordance for upright stance, and (c) the postural system’s dependence on context and supra-postural task demands.
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CHAPTER 1: INTRODUCTION

Perception and action play a critical role in how people adaptively control their behavior in complex and changing environments. Consider the functional demands of a complex behavior such as rock climbing. In this unique form of locomotion, climbers travel vertically by lifting their body weight using combinations of hands and feet. Because of the consequences for mistakes made during climbing, rock climbers must prospectively and accurately plan their climbing routes by taking into account the geographical layout and their physical limitations. In simpler terms, a certain rock formation will only be climbable to those who can perceive and perform the necessary actions. Gibson (1986) proposed that the ability to perceive opportunities for actions like climbing contributes to the control of behavior, and that these opportunities for action, termed affordances, are determined by a person’s relation to properties of the environment.

Perceiving the environment in terms of affordances means that the perceiver views the environment in terms of his or her own action capabilities. For example, an influential investigation of stair climbing by Warren (1984) revealed that an invariant ratio of a participant’s leg length to a step’s riser height restricted when participants judged a step as climbable. Participants could correctly judge their maximum climbable riser height, which corresponded to 0.88 of their leg lengths. Since Gibson’s initial proposal of affordances, the study of environmental properties and their relation to action possibilities has been a productive area of research (for reviews see Chemero, 2009; Fajen, Riley, & Turvey, 2009). Although many studies have revealed perceptual
sensitivity to affordances, the underlying question of how people detect the structure of energy specifying an individual affordance remains unanswered in most cases.

The concept of affordances is one feature that distinguishes Gibson’s (1966, 1986) theory from perceptual theories based on information processing and representationalism (e.g., Marr, 1982; Marr & Nishihara, 1978; Pylyshyn, 1989). Another distinction is that according to most versions of the latter kind of theory, muscular action and resulting movements play no necessary part in the acquisition of information, and investigators approaching the study of perception from this perspective typically do not focus on action in their conclusions (e.g., Hayhoe, Mennie, Gorgos, Semrau, & Sullivan, 2004). Action is instead explained through internal models and passively acquired perceptual information is simply used to correct or update models of environmental properties.

Alternatively, as in Gibson’s (1986) theory, perception can be portrayed as an active process in which perception and action behave synergistically (Turvey, Carello, & Kim, 1990; Warren, 2006). Again rock climbing can help illuminate what is meant by a synergistic relation between perception and action. During climbing a person may perform several test moves in order to probe the level of provided support. In other words, only from the actual reaching out and application of force can climbers definitively know how their forces will be resisted. Although few studies (e.g., Pijpers, Oudejans, & Bakker, 2007) have investigated rock climbing specifically, the broader investigation of locomotion has demonstrated how movement provides information for control. For example, people are able to perceive their direction of movement (Li & Warren, 2002; Warren, Kay, Zosh, Duchon, & Sahuc, 2001) and their time-to-contact
with an object (Lee, 1976) as a result of the lawful structuring of the optic array produced by self-movement. The assumption of an action/perception synergy has implications for behavior in that action can be viewed as either *performatory* or *exploratory*; performatory in the sense that it can be in service of a behavioral goal and exploratory because it can facilitate perception (Turvey et al., 1990).

The objective of this research is to investigate how exploratory postural sway facilitates perception of an affordance for upright stance. An affordance for upright stance is determined by the tangible properties of the supporting surface (i.e., firmness, friction, extent, and inclination) and the person (i.e., the properties relevant to action execution) (Stoffregen & Riccio, 1988). It has been found that people are capable of successfully perceiving the affordance of a slope for upright stance with both visual and haptic perception (Fitzpatrick, Carello, Schmidt, & Corey, 1994), and several studies have additionally demonstrated that participants are sensitive to changes in postural affordances (e.g., Malek & Wagman, 2008; Regia-Corte & Wagman, 2008). The specific aims of this project are to (1) determine how sensitive people are to changes in their ability to stand on an inclined surface and (2) determine whether or not people produce exploratory movements to facilitate prospective perception of an affordance for upright stance.

*Exploratory Movements*

Exploratory movements may be further distinguished if three classes of perception are considered: exteroception, proprioception, and exproprioception (Turvey, et al., 1990). These three classes of perception provide a person with information about the external environment (exteroperception, e.g., the layout of surrounding geography,
events, and objects), the movements and location of body parts relative to the whole body (proprioception, e.g., the location of an arm), and the movements, position, or orientation of the body relative to the environment (exproprioception, e.g., the height of a step compared to the height of a person’s leg), respectively. While numerous studies have verified peoples’ ability to detect these classes of information (e.g., Johansson, von Hofsten, & Jansson, 1980; Shaw, Flascher, & Mace, 1996; Carello & Turvey, 2004; Fajen, Riley, & Turvey, 2009), little progress has been made in explaining how the information specifying a certain property or relation is detected. The investigation of haptic perception is one exception.

Literature on haptic (touch) perception (e.g., Gibson, 1966; Solomon & Turvey, 1988; Solomon, Turvey, & Burton, 1989; Turvey, 1996) exemplifies the mutual relationship between perception and action. During dynamic touch (a type of haptic perception involving grasping and wielding a hand-held object), information about an object’s properties arises because wielding the object produces a flux of mechanical energy, which stimulates specialized neurons (mechanoreceptors) in the skin and tissues. In this case, action (wielding) makes perception possible (by producing the information), but it is also true that the person wielding the object must perceive properties of the object that are related to how the object can be moved and manipulated by muscular force; that is, successful wielding can only occur under perceptual guidance. Research on haptic perception has revealed the existence of unique exploratory patterns: People use different types of exploratory actions to facilitate detecting information specific to the object properties they intend to perceive (Klatzky & Lederman, 1992; Lederman & Klatzky, 1993). For example, to perceive an object’s shape using haptic perception alone
(i.e., non-visually), one might follow the contours of the object with the fingertips, whereas to perceive the object’s heaviness, one might hold and wield the object. Exploratory movements can be further distinguished, such that, for example, patterns of the same exploratory pattern, such as wielding, might exhibit unique exploratory dynamics depending on the exact object dimension (e.g., length vs. width) a person intends to perceive (Riley, Wagman, Santana, Carello, & Turvey, 2002).

Similar to haptic (touch) perception, recent research in postural control has described the movement variability in postural sway as meaningful and informative in that it creates stimulation (optical, vestibular, and proprioceptive) that can then be used to control posture (Riccio, 1993; Riley, Mitra, Stoffregen, & Turvey, 1997; Riley, Mitra, Wong, & Turvey, 1997). However, achieving a similar understanding of postural sway is challenging because the postural system itself cannot be attributed to a single, permanent structure (Riley, Kuznetsov & Bonnette, 2011). Postural control is, instead, situated across the interactions of the person-task-environment system (Stoffregen & Riccio, 1988) and the dynamical characteristics of postural sway have been shown (through non-linear analysis of time series data) to be highly dependent on context. A large body of literature exists that highlights postural control’s contextual dependence on task (e.g., precision aiming, auditory memory, and digit-span tasks), environment (e.g., light level, surface firmness, and support surfaces [i.e., a curtain]) and participant characteristics (e.g., disease, age, and fatigue; for review see Riley et al., 2011).

Postural sway might also facilitate the perception of information relevant to behaviors other than postural control. Several studies have shown that movement – and the resulting optical transformations – is critical for perceiving information about the
environment and its relation to the perceiver (e.g., distance perception, Bingham & Stassen, 1994; perception of a stepping-across affordance, Cornus, Montagne, & Laurent, 1999; perception of stepping and sitting affordances, Hirose & Nishio, 2001; Mark, Balliett, Craver, Douglas, & Fox, 1990; Mark, Jiang, King, & Paasche, 1999). For example, recent research by Yu, Bardy, and Stroffregen (2011) demonstrated the importance of exploratory body and head movements for perceiving affordances. In their study participants were asked to judge the minimum height under which they could pass in a rolling wheelchair. Participants were either permitted to move their heads, or their head movements were almost completely eliminated by the use of a passive head restraint. Yu et al. found that when participants’ head movements were restricted they made a significantly higher number of errors in judging their action capabilities. This suggests head movements played an exploratory role, producing optical transformations that revealed information about the participants’ relationship to the environment. Mark (1987) also revealed that when participants’ body and head movements were restricted they were unable to recalibrate perception to successfully perceive what was newly afforded after their action capabilities were changed (i.e., blocks were attached to their feet). Exploratory postural sway in this experiment will be investigated by manipulating participants’ perceptual attention (i.e., by giving different intentions and therefore different perceptual focuses) and ability to uncover informational invariants (i.e., by permitting or constraining head movements).

Behavioral and Perceptual Boundaries of Affordances

Because possibilities for action depend on the relationship between the organism and the environment, changes to the organization of either the organism or environment
should result in the emergence of new affordances. Several studies have investigated how varying the organism-environment relationship in such a way as to change the behavioral boundary (the point separating when a behavior is or is not afforded) results in changes in affordance perception. For example, Regia-Corte and Wagman (2008) investigated how manipulating a person’s center of mass (COM) influenced the boundary between slopes that were “stand-on-able” and slopes that were not. They found that the behavioral boundaries of affordances were indeed influenced by the COM manipulation, and that participants were perceptually sensitive to this. Specifically, participants had lower behavioral boundaries when their COM was raised to a higher, biomechanically less stable position. The current study will similarly investigate how changes to the COM influence the perceptual and behavioral boundaries of affordances.

The perceptual boundaries of affordances will be determined in this study using a methodology similar to that used by Malek and Wagman (2008) and Regia-Corte and Wagman (2008). Participants in the current study will make prospective perceptual judgments concerning their ability to stand on a continuous range of slopes (from 18° to 45°). The slopes will be changed in two ways: ascending (from 18° to 45°) and descending (from 45° to 18°). Participants will be asked to report their perceptual boundaries by indicating when they could no longer stand flat-footed on the platform in the ascending condition and when they first could stand flat-footed on the platform in the descending condition. The behavioral boundaries of affordances will then be determined in a similar manner, except actual limits for stand-on-ability will be found.
Hypotheses

Of primary interest in this study is the process by which participants are able to adapt to changes in their action capabilities when prospectively perceiving an affordance for stand-on-ability. It is hypothesized that changes in participants’ action capabilities (altering their COM and therefore the behavioral boundaries for upright stance on sloped surfaces) will require them to produce exploratory postural activity that functions to reveal their new behavioral boundaries. In addition, the given intention to stand on the platform is expected to produce different patterns of postural activity than participants who simply observe the platform without the intention to stand (Turvey et al., 1990).

Exploratory movements in the current study will be limited in some conditions by having participants simply rest the back of their heads on a horizontal bar restraint. The limitation of exploratory movement should result in less accurate perceptual judgments of affordances. This result would be in agreement with past studies (e.g., Mark, 1987; Yu et al., 2011). In addition, changes in the underlying dynamic organization of postural exploratory movements are hypothesized to reflect affordance perception. That is, postural exploratory periods will show a difference in linear and/or non-linear analyses when compared with trials in which participants are not given the intention of standing on the platform.

The results of this study are also expected to replicate findings of several past studies investigating the affordances of slopes (i.e., Fitzpatrick et al., 1994; Malek & Wagman, 2008; Regia-Corte & Wagman, 2008; Klevberg & Anderson, 2002). Consequently, it is hypothesized that changes to either the environment (incline of surface) or participant (COM location) will result in lawful changes in the behavioral
boundary, and that participants will be perceptually sensitive to these changes.

Specifically, it is expected that participants will perceive the greatest boundaries for action (i.e., steeper “stand-on-able” slopes) with manipulations that shift the COM in the anterior direction than COM shifts in the posterior direction.
CHAPTER 2: METHOD

Participants

Eighty-three undergraduate students (39 men and 44 women) participated in this study. The participants’ average age, height, and weight were 19.40 yrs. ($SD = 2.31$), 1.71 m ($SD = 3.91$) and 68.4 kg ($SD = 26.29$), respectively. Participants had no history of neurological disorders (including any neuromuscular disabilities), skeletal disabilities or disorders, or balance problems. Participants were also free of any recent injuries that impaired movement and had normal or corrected-to-normal (with contact lenses or eye glasses) vision.

Data from several participants were excluded from the study. One participant failed to follow task instructions and reported perceptual judgments of walk-on-ability instead of stand-on-ability. Another participant experienced dizziness during the experiment and voluntarily withdrew from the study. A third participant was excluded because the amount of weight needed to adjust the participant’s COM was too large to fit into the backpack. Accounting for these exclusions, data from a total of 80 participants were analyzed. The study was IRB-approved and all participants gave written informed consent prior to participation.

Materials and Apparatus

The adjustable platform apparatus (see Figure 1) consisted of a wooden surface (95 cm × 70 cm) that was hinged to a wooden frame (134 cm × 95 cm × 121 cm). The hinge was located at the platform edge closest to the participant. The wooden frame served as both a safety railing for participants and as structural support for the adjustable platform. Plywood was used to conceal any visual cues provided by the wooden frame at
the end farthest from the participant. Two adjustable car jacks (Roadmaster USA Corporation, Eatontown, NJ) were secured to the underside of the platform, allowing the slope to be continuously adjusted from a minimum of 18° to a maximum of 45° at a rate of 0.68°×s⁻¹. A level was attached underneath the platform, allowing experimenters to record the platform angle while concealing that angle information from participants.

Figure 1. The above diagram represents the experimental apparatus arrangement (not to scale). The black outline surrounding the figure represents the walls of the room. The adjustable platform is positioned at the highest slope (45°) used in the experiment. The model participant illustrates what a participant performed in the 0% weight condition and the constrained exploratory movement condition. The white horizontal bar, behind the model’s head, is the head restraint bar used in the experiment.

An adjustable head restraint and wooden frame were built surrounding a force plate (Bertec Corporation; Columbus, OH). The force plate was used to record the
postural sway of participants and was connected to a computer running a custom written MATLAB (The MathWorks, Inc.; Natick, MA) program. The front of the force plate was 120 cm away from the front of the adjustable platform. The head restraint was constructed of a padded, plastic horizontal bar that was adjusted to each participant’s height (a maximum adjustable height of 200 cm). The restraint was placed behind the participant’s head, and was therefore not visible during the experiment. The combined height of the adjustable head restraint frame and force platform raised the participants slightly above floor level (12 cm) but participants’ feet were at an equal height to the adjustable platform surface (12 cm). A small backpack (45.72 cm × 38.48 cm) was used to hold small, 0.25 kg bags filled with sand. Participants wore this backpack to adjust their COM. Statistical analysis was performed using MATLAB and R (R Development Core Team; Vienna, Austria).

**Design**

Participants’ COM was manipulated by a within-subjects factor of weight condition (0%, 10%-front [10% F], 10%-back [10% B], 20%-front [20% F], and 20%-back [20% B]). The weight conditions either displaced participants’ COM in the anterior (front) or posterior (back) directions, except for the 0% condition which did not alter participants’ COM in any direction. Exploratory movement (constrained vs. unconstrained) and intention (judge vs. not judge) were manipulated as between-subjects factors – the participants in the no-judgment condition served as a control group. This resulted in a 2 (intention) × 2 (exploratory movement) × 5 (weight condition) mixed factorial design. There were two trials (one ascending, one descending) per COM weight condition for a total of 10 perceptual boundary trials and 10 behavioral boundary trials.
These 10 trials for perceptual judgments and behavioral boundaries were later averaged across ascending and descending trials for all dependent variables.

Because the interest of the current study concerns affordances, differences in participants’ characteristics in the two exploratory movement groups are discussed. Only participants in the intention-to-judge condition were included in the comparison as they were the only participants who provided affordance judgments. Two independent-sample $t$-tests, with a Welch’s $df$ correction for unequal variances (Welch, 1947), were used to compare the heights and weights of participants in each exploratory movement condition. There were no significant differences in participants’ height or weight, $t(36.72) = 0.00, p > .05$ and $t(36.35) = 0.30, p > .05$, respectively. The proportion of males and females were not significantly different across exploratory movement condition, $\chi^2(1, N = 40) = 0.00, p > .05$, nor was the proportion of each sex’s level of athletic experience, $\chi^2(1, N = 40) = 0.23, p > .05$. The proportion of participants (of both sexes) in the unconstrained exploratory movement condition who had athletic experience was 0.90 whereas the proportion of participants who had athletic experience in the constrained condition was 0.40. This difference was significant, $\chi^2(1, N = 40) = 8.90, p < .01$, indicating that participants in the unconstrained condition had a higher level of athletic experience.

Procedure

Experimental sessions lasted no longer than 1 hour. Researchers introduced the experiment and administered an IRB-approved informed consent document upon participant arrival. Only after participants granted informed consent did the experiment begin. Participant demographic information (i.e., sex, age, ethnicity/race, height, weight, and athletic experience) was collected before the experimental trials and was used to
calculate the amount of weight needed for each COM condition. Athletic experience was operationally defined as having participated in any physically strenuous activity within the last year for duration of at least 30 minutes, three times a week. Participants were randomly placed into one of four conditions: No-judgment/constrained, judgment/constrained, no-judgment/unconstrained, or judgment/unconstrained. For the conditions in which no judgment was required, no information relating to the perceptual and behavioral boundaries of the slope was collected; however, all perceptual boundary trials were presented to the participants in the same experimental environment.

*Perceptual boundary procedure.* During the experiment, participants were asked to give perceptual reports with respect to their ability to stand upright, flat-footed, and bipedally on an inclined platform. Before each judgment, participants’ COM was manipulated using the backpack and weights described above. The initial slope of the platform was either at its highest (descending) or lowest (ascending) position and was raised or lowered, respectively, by an experimenter who remotely controlled the car jacks. Over the course of a trial, the platform incline was continuously decreased or increased until participants reported they could first stand on the platform (descending trials) or when they could no longer do so (ascending trials). In order to avoid participants adopting an “analytical” strategy in making perceptual judgments (Heft, 1993) a participant’s first vocalized perceptual report was taken as the final judgment. No adjustments were permitted. Perceptual judgments were averaged across ascending and descending trials, yielding five final perceptual judgments (one for each weight condition) per participant.
Prior to the onset of each trial, participants were instructed to stand flat-footed on a force platform and place their arms through the backpack straps so that the backpack was in position for participants to wear it; however, the experimenter held the backpack slightly above the shoulders so that the participant did not feel the weight until the trial began. This was performed so that participants had no opportunity to explore their action capabilities before the start of the trial. Trials started after the experimenter released the backpack and participants took control of the weight. The first portion of all trials consisted of an exploratory period lasting 20 s in which participants were asked to stand with their eyes closed as soon as they felt the full weight of the backpack. This period was instituted to investigate participants’ ability to engage in proprioception. Having participants close their eyes is significant because participants, especially those with the intention to judge, could not have the platform in view. If visual information about the platform was available it would confound any possible conclusions about proprioceptive behavior. After this period participants were instructed to open their eyes and the platform began to move as described above. It is during this time that participants’ are able to gather exproprioceptive information. Trials with constrained exploration still required participants to close their eyes during the exploratory phase, but in addition they were required to keep their head firmly rested on the head-restraint bar.

The second portion of a trial consisted of participants watching the platform continuously raise or lower until it reached the point at which they instructed the experimenter to stop adjusting the incline at the perceived maximum stand-on-able slope. The platform’s current slope and the time at which the judgment was made were recorded. This procedure was repeated for each perceptual judgment. Participants in the
no-judgment conditions were instructed to simply stand and focus on the platform while it was adjusted in a decreasing or increasing manner, but they were not instructed to make perceptual reports.

Behavioral boundary procedure. Behavioral boundaries were determined after all perceptual judgments were made in order to ensure that knowledge of actual boundaries did not influence the prospective perceptual estimates (participants in the no-judgment group did not complete this phase; behavioral boundary information was irrelevant since they did not provide any perceptual reports). This procedure consisted of simply having participants stand flat-footed on a platform starting at its highest and lowest positions (ascending and descending trials were used; behavioral boundaries for each participant were averaged across ascending and descending trials). Participants were permitted to hold on to the handrails for support as the platform’s slope changed to the point at which they could first stand without support. This point was considered the behavioral boundary if the participant could stand flat-footed and straight up (i.e., only the ankle joint was permitted to have any visible degree of flexion or abduction) for 5 seconds. If participants could not stand for 5 seconds the platform was re-adjusted to the point at which they were able.

Data Analysis and Reduction

Postural sway was operationalized as the participant’s center of pressure (COP). The COP was recorded at a rate of 100 Hz, yielding a single 6,000 sample COP time series for each perceptual trial. The first 2000 samples (20 s) of each trial were from the time period during which participants’ eyes were closed. The remaining 4,000 samples were recorded when participants’ eyes were open. The eyes open segment of the COP
time series were truncated to end at the time at which participants rendered their perceptual judgments (see Figure 2). After each time series was truncated, each time series was additionally down-sampled from 100 Hz to 20 Hz. This was performed to prevent the oversaturation or over-digitization of observations in the COP data.

![Figure 2](image_url)

*Figure 2.* The top time series is an example time series from a participant in the unconstrained intention to judge condition. For this particular trial the participant was in the 20% B weight condition and the platform was adjusted in the ascending direction. Time series A is the exploratory phase, i.e., the section of the trial when participants closed their eyes. Time series B consists of the COP during the perceptual report phase. The length of this section was determined by the amount of time that passed before a participant made a judgment. In this case, the participant made a judgment 45.02 seconds into the trial which resulted in time series B including samples 2001-4502. Time series C is composed of the remaining samples and was not included in any analysis.

Time series from control participants (i.e., the no-intention-to-judge condition) were treated with an additional step that time series from participants given the intention to judge were not. This additional data processing step was required because the control participants did not give any perceptual reports and were instead instructed to focus on the platform for the entire duration of a trial. Consequently, their COP time series
necessarily were longer than the COP time series of participants who gave perceptual reports, because COP data collection ceased upon obtaining the report from the latter participants. Time series length could affect several of the dependent measures described below. Therefore, each trial for a control participant was matched to every possible experimental participant in the same exploratory movement condition (e.g., constrained, control participants were matched only to constrained, experimental participants).

Control time series were matched by truncating their length to the time a perceptual report was made during a particular experimental trial. For example, a descending platform trial in which an unconstrained, control participant wore a 20% F backpack was matched in length to every unconstrained, experimental trial of the same condition (i.e., a descending trial and a 20% F COM manipulation). This resulted in the derivation of 20 time series for the control trial, each of a particular length that corresponded respectively to each of the experimental trials in that condition. Each matched time series was then analyzed by the subsequently described dependent measures and the 20 returned values (one from each match) were averaged to obtain a single value for each control trial.

COP time-series were quantified in terms of the amount of variability, using the standard deviation (SD) and local standard deviation (LSD, within-trial mean of SDs of non-overlapping, 1 s windows; Mitra & Frazier, 2004; Riley, Stoffregen, Grocki, & Turvey, 1999) of the time series in both the medial-lateral (ML) and anterior-posterior (AP) directions. The LSD of a time series is less affected by non-stationarity than the SD. Whereas the SD is computed over the entire time series, the LSD is computed by using a moving window and reflects more of the fine-grained structure of variation in the COP position.
Sample Entropy (SampEn; Richman & Moorman, 2000) analysis was used to capture the structure of variability in the COP time series. SampEn has demonstrated its ability to discriminate between experimental manipulations (e.g., vision, Ramdani et al., 2011; vision, expertise, and cognition, Stins, Michielsen, Roerdink, & Beek, 2009; and pathological states, Donker et al., 2008) of the postural system and it is effective even with short time series (Richman & Moorman, 2000). The SampEn calculations were performed using software available from PhysioNet (Lake, Richman, Griffin, & Moorman., 2002). SampEn is defined as the negative natural logarithm of the conditional probability that a dataset of length \( N \), having already repeated itself for \( m \) samples within a tolerance \( r \), will also repeat itself for \( m + 1 \) samples (not allowing for self-matches). A lower SampEn value indicates a more self-similar/regular signal, with a higher value indicating the opposite – a more complex/irregular signal. The current study’s selection of values for parameters \( r = 0.30 \) and \( m = 3 \) were based on suggestions by Ramdani et al. (2011).

Mean perceptual judgments of maximum stand-on-able slopes were compared to the actual behavioral boundaries to obtain measures of error in each condition. The first dependent measure of error is the ratio between participants’ perceptual judgments and the measured behavioral boundaries. A ratio greater than 1 indicates an overestimation of (perceived boundaries were greater than behavioral boundaries) and a value less than 1 indicates an underestimation (perceived boundaries were less than behavioral boundaries). The second dependent measure is known as the absolute ratio (AR; e.g., Weast, Shockley, & Riley, 2011). The AR gives a non-directional measure of error in
that it is defined as the absolute value of a ratio subtracted by 1. Lower values indicate more accurate perceptual judgments with a value of 0.0 signifying no error.
CHAPTER 3: RESULTS

Affordance Results

Statistical assumptions for analysis of variance (ANOVA) were tested (e.g., sphericity), and violations were treated with the appropriate method (i.e., Greenhouse-Geisser correction). The corrected statistics are presented below. The presence of statistical outliers in each level of the factorial design was also tested—data points more extreme than ±2.698 standard deviations (SDs) from the median were removed. A 2 (exploratory movement) × 5 (weight condition) mixed-design ANOVA was performed for each dependent variable of affordance related data.

Behavioral boundaries. There were significant main effects of weight condition, $F(2.96,56.20) = 58.15$, $p < .001$, $\eta_p^2 = .60$, and exploratory movement, $F(1,38) = 10.57$, $p < .05$, $\eta_p^2 = .68$, for participants’ behavioral boundaries. As shown by the main effect of weight condition, the 10% and 20% F conditions tended to increase the behavioral boundaries when compared to the 0% weight condition, while the 10% and 20% B conditions generally decreased the boundaries. The effects of the weight condition were also more pronounced in the 20% weight than the 10% conditions. The main effect of exploratory movement indicated that greater behavioral boundaries occurred in the unconstrained exploratory movement condition than the constrained condition. However, these effects were overshadowed by a significant exploratory movement × weight condition interaction, $F(2.96,112.39) = 2.78$, $p < .05$, $\eta_p^2 = .07$ (see Figure 3).

Simple-effects analysis subsequent to that interaction revealed that the boundaries in both the constrained, $F(2.35,44.64) = 39.91$, $p < .001$, $\eta_p^2 = .68$, and unconstrained,
$F(4,76) = 20.10, p < .001, \eta^2_p = .51,$ exploratory movement conditions were significantly affected by weight condition. Paired-sample $t$-tests with a Bonferroni-correction were then used to compare behavioral boundaries in each exploratory movement condition and revealed that the effect of weight condition depended upon exploratory movement condition as follows. As shown in Figure 3, the 20% F weight condition in both the constrained ($M = 29.88^\circ, SD = 3.41^\circ$) and unconstrained ($M = 31.88^\circ, SD = 2.30^\circ$) exploratory movement conditions resulted in the steepest stand-on-able slope (except in the unconstrained condition, the 10% F [ $M = 31.25^\circ, SD = 2.39^\circ$] boundary was not significantly different than the 20% F boundary). The 20% B condition in both exploratory movement conditions (constrained: $M = 24.78^\circ, SD = 3.31^\circ$; unconstrained: $M = 28.20^\circ, SD = 2.61^\circ$) resulted in significantly lower behavioral boundaries than in all other weight conditions; however in the constrained condition, the boundary in the 20% B weight condition was not significantly different than in the 10% B condition ($M = 25.90^\circ, SD = 3.83^\circ$). The remaining comparisons were not as straightforward as were the results for the most extreme COM adjustments (i.e., 20% F and 20% B), and varied considerably across exploratory movement condition. In the constrained exploratory movement condition the boundary in the 10% F condition was significantly higher than the 0% ($M = 27.23^\circ, SD = 3.69^\circ$) and 10% B weight conditions. The boundaries for the 0% and 10% B weight conditions were not significantly different from each other. In the unconstrained exploratory movement condition there were no significant differences in the boundaries for comparisons among the 0% ($M = 30.28^\circ, SD = 2.79^\circ$), 10% B ($M = 29.75^\circ, SD = 2.93^\circ$), and 10% F conditions.
Lastly, simple-effects analysis also showed that the effect of exploratory movement was significant in each weight condition: 0%, $F(1,38) = 8.68$, $p < .01$, $\eta_p^2 = .19$; 10% F, $F(1,38) = 5.76$, $p < .05$, $\eta_p^2 = .13$; 10% B, $F(1,38) = 12.76$, $p < .001$, $\eta_p^2 = .25$; 20% F, $F(1,38) = 4.73$, $p < .05$, $\eta_p^2 = .11$, and 20% B, $F(1,38) = 13.17$, $p < .001$, $\eta_p^2 = .26$. The unconstrained exploratory movement condition had a higher behavioral boundary than the constrained exploratory movement condition in all weight conditions. Furthermore, there was a tendency for smaller differences across exploratory movement conditions in the 10% and 20% F conditions.

![Figure 3](image-url)

*Figure 3.* Average behavioral boundaries for each weight condition in the unconstrained and constrained exploratory movement conditions. The error bars indicate one standard error of the mean.

*Perceptual judgments: Raw (extrinsic units) judgments.* There was a significant main effect of weight condition for raw perceptual judgments, $F(2.92, 110.94) = 22.86$, $p$
< .001, $\eta_p^2 = .38$ (see Table 1). The 0% weight condition had significantly higher judgments of maximum slopes than all other weight conditions. The 20% B condition produced significantly lower judgments than all other weight conditions. No other comparisons were significant. Neither the main effect of exploratory movement nor the interaction were significant, $F(1,38) = 0.01, p > .05$, and $F(2.92,110.94) = 1.23, p > .05$, respectively.

**Table 1**

*Descriptive Statistics of Perceptual Judgments and Bonferroni-Corrected Post-hoc Comparisons for the Main Effect of Weight Condition*

<table>
<thead>
<tr>
<th>Condition</th>
<th>$M$</th>
<th>$SD$</th>
<th>$p$ values</th>
<th>0%</th>
<th>10% F</th>
<th>10% B</th>
<th>20% F</th>
<th>20% B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>33.96°</td>
<td>2.96°</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10% F</td>
<td>32.99°</td>
<td>2.53°</td>
<td>.01*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10% B</td>
<td>32.91°</td>
<td>2.55°</td>
<td>.04* &gt;.99</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20% F</td>
<td>32.76°</td>
<td>2.51°</td>
<td>.05* &gt;.99</td>
<td>&gt;.99</td>
<td>&gt;.99</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20% B</td>
<td>31.04°</td>
<td>3.11°</td>
<td>.00** .00**</td>
<td>.00**</td>
<td>.00**</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note. * $p < .05$, ** $p < .01$.

**Perceptual judgments: Ratio of perceived: actual boundaries.** There were significant main effects of weight condition, $F(3.21,122.05) = 16.51, p < .01, \eta_p^2 = .30$, and exploratory movement, $F(1,38) = 7.58, p < .01, \eta_p^2 = .17$. However, these main effects were obscured by a significant interaction (see Figure 4) between those factors, $F(3.21,122.05) = 2.77, p < .05, \eta_p^2 = .07$. Simple-effects analysis revealed that the ratios in both the constrained, $F(2.79,53.08) = 12.47, p < .01, \eta_p^2 = .40$, and unconstrained, $F(4.76) = 4.52, p < .01, \eta_p^2 = .19$, exploratory movement conditions were significantly affected by weight condition. These significant simple main effects were explored further.
by conducting a series of paired-sample \(t\)-tests (with a Bonferroni-correction) to compare the weight conditions within each of the exploratory movement conditions.

For the unconstrained exploratory movement condition, participants judged their action capabilities in each weight condition with similar accuracy. The only significant pairwise comparison in the unconstrained condition was between the 20% F (\(M = 1.04, SD = 0.10\)) and 10% B (\(M = 1.12, SD = 0.14\)) conditions, with the 20% F condition having more accurate perceptual judgments. No other comparisons among or involving the weight conditions of 0% (\(M = 1.12, SD = 0.15\)), 10% F (\(M = 1.06, SD = 0.13\)), and 20% B (\(M = 1.11, SD = 0.16\)) were significant.

Conversely, the comparisons in the constrained condition revealed that participants judged their action capabilities in varying degrees of accuracy with the tendency for the 10% and 20% F conditions to exhibit higher accuracy. The ratio in the 20% F condition (\(M = 1.08, SD = 0.10\)) was significantly lower (i.e., more accurate) than all other weight conditions. The 10% F condition (\(M = 1.15, SD = 0.14\)) was significantly lower than the 10% B condition (\(M = 1.27, SD = 0.17\)). No other comparisons involving the 0% (\(M = 1.23, SD = 0.14\)), the 10% F, the 10% B, and the 20% B (\(M = 1.24, SD = 0.17\)) weight conditions were significant.

Turning to the simple effect of exploratory condition at each level of weight condition, the unconstrained group exhibited significantly lower ratio values (and thus more accurate perceptual judgments) than the constrained group in all weight conditions (0% \([F(1,38) = 5.17, p < .05, \eta^2_p = .12]\), 10% F \([F(1,38) = 4.91, p < .05, \eta^2_p = .11]\), 10% B \([F(1,38) = 9.87, p < .01, \eta^2_p = .21]\), and 20% B \([F(1,38) = 6.29, p < .05, \eta^2_p = .14]\)) except the 20% F weight condition (\(p > .05\)).
Finally, a series of one-sample t-tests were performed comparing each weight conditions’ ratio, in both the constrained and unconstrained exploratory movement conditions, to the accurate value of 1.0 described in the data analysis and reduction section. Results are presented in figure 4.

Figure 4. Average ratios for each weight condition in the unconstrained and constrained exploratory movement conditions. The solid black horizontal line indicates an accurate ratio value of 1.0. The error bars designate one standard error of the mean. # signifies that the weight condition was not significantly different than 1.0, $p > .05$.

**Perceptual judgments: Absolute ratio.** There was a significant main effect of weight condition on the absolute values of the ratios, $F(3.22,122.48) = 12.92$, $p < .001$, $\eta_p^2 = .25$ (see Table 2). The 20% F weight condition had significantly lower absolute ratios (i.e., more accurate perceptual judgments) than all other weight conditions except for the 10% F condition. No other comparisons were significant. The main effect of exploratory movement was significant as well, $F(1,38) = 6.62$, $p < .05$, $\eta_p^2 = .15$. Participants in the
constrained condition \((M = 0.20, SD = 0.13)\) had significantly higher absolute ratios than participants in the unconstrained condition \((M = 0.13, SD = 0.10)\), \(F(1,38) = 6.62, p < .05, \eta^2_p = .14\), indicating greater accuracy for the unconstrained condition. The interaction was not significant, \(F(3.22,122.48) = 1.96, p > .05\). One-sample t-tests were performed comparing each weight conditions’ AR to the accurate value of 0.0. All weight conditions were significantly different 0.0, all \(p\)’s < .05.

Table 2

Descriptive Statistics for AR and Bonferroni-Corrected Post-hoc Comparisons for the Main Effect of Weight Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>(M)</th>
<th>(SD)</th>
<th>(p) values</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>0%</td>
<td>0.20</td>
<td>0.12</td>
<td>-</td>
</tr>
<tr>
<td>10% F</td>
<td>0.15</td>
<td>0.10</td>
<td>.07</td>
</tr>
<tr>
<td>10% B</td>
<td>0.19</td>
<td>0.13</td>
<td>&gt;.99</td>
</tr>
<tr>
<td>20% F</td>
<td>0.09</td>
<td>0.07</td>
<td>.00**</td>
</tr>
<tr>
<td>20% B</td>
<td>0.20</td>
<td>0.14</td>
<td>&gt;.99</td>
</tr>
</tbody>
</table>

*Note. * \(p < .05\), ** \(p < .01\).*

Summary of affordance results. The affordance for the stand-on-ability of a slope was found to be systematically influenced by manipulations of the spatial location of participants’ COM. Specifically, when the COM was shifted by 20% in the anterior direction (20% F), participants were able to stand on a steeper slope than when the COM was shifted in the posterior direction (20% B). The 10% weight conditions (10% F and 10% B) did not influence participants’ behavioral boundaries to the same extent as the 20% weight conditions. This pattern occurred in both the unconstrained and constrained exploratory movement conditions; however, as noted earlier, the behavioral boundaries
for participants in the constrained condition were lower than for participants in the unconstrained condition. Participants’ perceptual judgments were not fully consistent with the changes in behavioral boundaries. Perceptual judgments occurred at lower inclinations when any change to the COM was made, indicating that a deviation from baseline COM (i.e., 0%) renders participants’ judgments more cautious. As indicated by the ratio and absolute ratio results (both of which control for the difference in the groups’ behavioral boundaries), participants in the unconstrained exploratory movement condition were more accurate in perceiving the affordance of stand-on-ability than participants in the constrained condition. Additionally, the one-sample t-tests indicated that the only condition that was not significantly different than the accurate ratio value of 1.0 was the 20%F, unconstrained exploratory movement condition.

*Postural Sway Results*

A 2 (exploratory movement) × 2 (intention) × 5 (weight condition) mixed-design ANOVA was performed on each postural sway measure. Due to the large variations in COP data, a discovered outlier (using the same criteria as the affordance related data) was only removed if experimental notes made during data collection indicated obvious deviations from the experimental protocol (e.g., shuffling the feet while on the force platform, noticeable gross body movements not related to the study [e.g., adjustment of backpack straps during a trial], and/or not focusing on the platform during a trial).

*SD of AP sway during the eyes closed period.* There was a significant main effect of weight condition for SD of AP sway, $F(2.12,161.21) = 15.90$, $p < .001$, $\eta^2_p = .17$ (see Table 3). Post-hoc analysis (paired-sample, Bonferroni-corrected $t$-tests) revealed that the 0% weight condition had significantly lower SD than all other weight conditions. Any
COM manipulation resulted in a systematic increase in postural sway variability regardless if it was in the anterior or posterior direction. Neither the 10% F and B or 20% F and B weight conditions were significantly different from each other. The 20% F condition had significantly higher SD values than the 10% F condition, but it was not significantly different than the 10% B weight condition. The 20% B weight condition was significantly higher than the 10% B and 10% F conditions. The main effect of exploratory movement was also significant, $F(1,76) = 36.25, p < .001, \eta^2_p = .32$, with the unconstrained condition ($M = 0.82 \text{ cm}, SD = 0.37 \text{ cm}$) having significantly higher SD than the constrained condition ($M = 0.40 \text{ cm}, SD = 0.46 \text{ cm}$). The main effect of intention was not significant, $F(1,76) = 3.28, p > .05$, nor were any interactions (all $p > .05$).

Table 3

<table>
<thead>
<tr>
<th>Condition</th>
<th>$M$ (cm)</th>
<th>$SD$ (cm)</th>
<th>$p$ values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
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</tr>
<tr>
<td>10% F</td>
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<td>.00**</td>
</tr>
<tr>
<td>10% B</td>
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<td>20% F</td>
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<td>.00** .04* .08</td>
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<tr>
<td>20% B</td>
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<td>0.47</td>
<td>.00** .00** &gt;.99</td>
</tr>
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</table>

Note. * $p < .05$, ** $p < .01$.

SD of ML sway during the eyes closed period. There was a significant main effect of weight condition for SD in the ML direction, $F(2.27,209.28) = 10.59, p < .001, \eta^2_p = .12$. Similar to the general trend displayed in AP sway, post-hoc analysis (paired-sample, Bonferroni-corrected $t$ tests) revealed that the 0% weight condition had a significantly
lower SD than the 10% B, 20% F, and 20% B weight conditions. Although the pattern of increased sway variability for increased amount of weight exists in ML sway, the results are not as distinct as in AP sway. The only remaining differences between weight conditions was that the 20% B weight condition had significantly higher SD than the 10% F and 10% B conditions. No other comparisons were significant (see Table 4). The main effect of exploratory movement was also significant, $F(1,76) = 12.21, p < 0.001, \eta_p^2 = 0.14$. The unconstrained exploratory movement condition ($M = 0.42$ cm, $SD = 0.29$ cm) had a significantly higher SD than the constrained condition ($M = 0.25$ cm, $SD = 0.27$ cm). The main effect of intention was significant as well, $F(1,76) = 4.13, p < .05, \eta_p^2 = .05$. Participants in the intention to judge condition ($M = 0.38$ cm, $SD = 0.37$ cm) had significantly higher SD values than those in the no intention to judge condition ($M = 0.29$ cm, $SD = 0.15$ cm). No interactions were significant (all $p > .05$).

Table 4

<table>
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<th>Weight Condition</th>
<th>M (cm)</th>
<th>SD (cm)</th>
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<th>10% F</th>
<th>10% B</th>
<th>20% F</th>
<th>20% B</th>
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<td>0%</td>
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</tr>
<tr>
<td>10% F</td>
<td>0.32</td>
<td>0.25</td>
<td>.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% B</td>
<td>0.33</td>
<td>0.28</td>
<td>.00**</td>
<td>&gt;.99</td>
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</tr>
<tr>
<td>20% F</td>
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<td>.00**</td>
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<td>.80</td>
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</tr>
<tr>
<td>20% B</td>
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<td>0.33</td>
<td>.00**</td>
<td>.02*</td>
<td>.05*</td>
<td>&gt;.99</td>
<td></td>
</tr>
</tbody>
</table>

Note. * $p < .05$, ** $p < .01$. 

30
LSD of AP sway during the eyes closed period. There was a significant main effect of weight condition for LSD in the AP direction, $F(1.80,136.96) = 12.75, p < .001, \eta^2_p = .14$. The pattern of results for this effect are similar to those provided by SD. Post-hoc analysis (paired-sample, Bonferroni corrected $t$-tests) revealed that the 0% weight condition had significantly lower LSD than all other conditions (see Table 5 for all comparisons and $p$-values). Both the 20% F and 20% B conditions had significantly higher LSD than all other weight conditions, but they were not significantly different from each other. The 10% F and 10% B weight conditions were not significantly different. The main effect of exploratory movements was also significant, $F(1,76) = 32.42, p < .001, \eta^2_p = .30$. The unconstrained exploratory movement condition ($M = 0.58$ cm, $SD = 0.26$ cm) had a significantly higher LSD than the constrained condition ($M = 0.26$ cm, $SD = 0.34$ cm). The main effect of intention was significant as well, $F(1,76) = 4.56, p < .05, \eta^2_p = .06$. Participants in the intention to judge condition ($M = 0.48$ cm, $SD = 0.44$ cm) had significantly higher LSD values than those in the no intention to judge condition ($M = 0.36$ cm, $SD = 0.21$ cm). No interactions were significant (all $p > .05$).
Table 5

*Descriptive Statistics for LSD in AP Sway and Post-hoc Comparisons for the Main Effect of Weight Condition During the Eyes-closed Period*

<table>
<thead>
<tr>
<th>Condition</th>
<th>M (cm)</th>
<th>SD (cm)</th>
<th>p values</th>
</tr>
</thead>
<tbody>
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<td>0%</td>
<td>0.32</td>
<td>0.31</td>
<td>-</td>
</tr>
<tr>
<td>10% F</td>
<td>0.41</td>
<td>0.30</td>
<td>.03*</td>
</tr>
<tr>
<td>10% B</td>
<td>0.39</td>
<td>0.29</td>
<td>.05*</td>
</tr>
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<td>.00**</td>
</tr>
<tr>
<td>20% B</td>
<td>0.49</td>
<td>0.34</td>
<td>.00**</td>
</tr>
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</table>

*Note. *p* < .05, **p** < .01.*

LSD of ML sway during the eyes closed period. There was a significant main effect of weight condition for LSD in the ML direction of postural sway, $F(2.63,199.75) = 8.27$, $p < .001$, $\eta^2_p = .14$. Comparable to the SD results for ML sway, the effect of weight condition was again not as strong as the differences in AP sway. Post-hoc analysis (paired-sample, Bonferroni corrected $t$-tests) revealed that the only differences in LSD among weight conditions were that the 0% condition was significantly lower than 10% B, 20% F, 20% B conditions (see Table 6). No other comparisons were significant. The main effect of exploratory movements was also significant, $F(1,76) = 14.67$, $p < .001$, $\eta^2_p = .16$. The unconstrained exploratory movement condition ($M = 0.31$ cm, $SD = 0.23$ cm) had a significantly higher LSD than the constrained condition ($M = 0.17$ cm, $SD = 0.17$ cm). The main effect of intention was significant as well, $F(1,76) = 5.98$, $p < .05$, $\eta^2_p = .07$. Participants in the intention-to-judge condition ($M = 0.28$ cm, $SD = 0.28$ cm) had significantly higher LSD values than those in the no-intention-to-judge condition ($M = 0.20$ cm, $SD = 0.10$ cm). No interactions were significant (all $p > .15$).
Table 6

Descriptive Statistics for LSD of ML Sway and Post-hoc Comparisons for the Main Effect of Weight Condition During the Eyes-closed Period

<table>
<thead>
<tr>
<th>Condition</th>
<th>$M$ (cm)</th>
<th>$SD$ (cm)</th>
<th>$p$ values</th>
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<td>0.19</td>
<td>-</td>
</tr>
<tr>
<td>10% F</td>
<td>0.23</td>
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<td>.25</td>
</tr>
<tr>
<td>10% B</td>
<td>0.24</td>
<td>0.23</td>
<td>.00**</td>
</tr>
<tr>
<td>20% F</td>
<td>0.27</td>
<td>0.22</td>
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</tr>
<tr>
<td>20% B</td>
<td>0.28</td>
<td>0.20</td>
<td>.00**</td>
</tr>
</tbody>
</table>

Note. * $p < .05$, ** $p < .01$.

SampEn of AP sway during the eyes closed period. There were significant main effects of weight condition, $F(3.11,236.41) = 44.39$, $p < .01$, $\eta^2_p = 0.37$, and exploratory movement, $F(1,76) = 33.87$, $p < .01$, $\eta^2_p = 0.31$. The main effect of intention was not significant, $F(1,76) = 0.00$, $p > .05$. The 0% condition had the highest values of SampEn, as supported by the main effect of weight condition, with a slight trend of decreasing SampEn values as the percentage of weight is increased. However, this trend is not as clear in the constrained exploratory movement group. Additionally, the main effect of exploratory movement indicated that the unconstrained condition had lower SampEn values than the constrained condition. Nevertheless, these effects were masked by a significant exploratory movement and weight condition interaction, $F(3.11,236.41) = 16.78$, $p < .01$, $\eta^2_p = .18$. No other interactions were significant (all $p > .05$).

The interaction seemed to be driven largely by the presence of a larger effect of weight condition in the unconstrained exploratory movement condition (or, alternatively, by a larger difference between exploratory movement conditions in the 0% weight
condition than in the other weight conditions). Simple-effects analysis of the exploratory movement by weight condition interaction revealed that the SampEn of AP sway during the eyes-closed period in both the constrained, $F(3.01,117.22) = 34.98, p < .01, \eta^2_p = .47$, and unconstrained, $F(3.16,123.32) = 10.93, p < .01, \eta^2_p = .22$, exploration conditions were significantly affected by weight condition (see Figure 5). In the constrained condition, a series of paired sample, Bonferroni-corrected $t$-tests revealed that the 0% weight condition ($M = 0.70, SD = 0.28$) had significantly higher SampEn values than all other weight conditions. The unconstrained condition followed a similar pattern of results. The 0% condition ($M = 0.34, SD = 0.12$) was significantly higher than the 20% F ($M = 0.27, SD = 0.11$) and 20% B ($M = 0.24, SD = 0.10$) conditions; however, the 0% condition was not significantly different than the 10% F ($M = 0.30, SD = 0.12$) and 10% B ($M = 0.30, SD = 0.11$) conditions. In the constrained condition, the 20% B condition ($M = 0.32, SD = 0.18$) had significantly lower SampEn values than the 0%, 10% B ($M = 0.44, SD = 0.21$), and 20% F ($M = 0.41, SD = 0.18$) weight conditions but not the 10% F condition ($M = 0.41, SD = 0.18$). Likewise, in the unconstrained condition, the 20% B condition had significantly lower SampEn values than the 0%, 10% F ($M = 0.30, SD = 0.12$), and 10% B ($M = 0.30, SD = 0.11$) weight conditions. No other comparisons in either exploratory movement condition were significant (all $p > .05$).

Lastly, simple effects analysis also indicated that there were significant simple main effects of exploratory movement in each weight condition. The constrained condition had significantly higher SampEn values than the unconstrained condition in each weight condition: 0%, $F(1,78) = 57.53, p < .01, \eta^2_p = .42$; 10% F, $F(1,78) = 9.52, p < .01, \eta^2_p = .11$; 10% B, $F(1,78) = 14.33, p < .01, \eta^2_p = .16$; 20% F, $F(1,78) = 17.43, p < .01, \eta^2_p = .
.18; and 20% B, $F(1,78) = 6.94, p < .05, \eta_p^2 = .08$. The difference between the unconstrained and constrained exploratory movement conditions in the 0% weight condition was especially large.

Figure 5. Average SampEn of AP sway during the eyes closed period for each weight condition in the unconstrained and constrained exploratory movement conditions. The error bars indicate one standard error of the mean.

SampEn of ML sway during the eyes closed period. The SampEn results of ML postural sway during the eyes-closed period followed a similar pattern as the AP results. There were significant main effects of weight condition, $F(2,60,197.97) = 69.56, p < .01, \eta_p^2 = .48$, and exploratory movement, $F(1,76) = 48.75, p < .01, \eta_p^2 = .39$. The main effect of intention was not significant, $F(1,76) = 0.64, p > .05$. The 0% condition, equivalent to the result in AP sway, had the highest values of SampEn. Again, there was a similar trend of decreasing SampEn values as the percentage of weight was increased.
and, equivalent to AP sway, the trend was not as clear in the constrained exploratory movement condition. Furthermore, the main effect of exploratory movement indicated that the unconstrained condition had lower SampEn values than the constrained condition. However, as in AP sway, the exploratory movement and weight conditions significantly interacted, $F(2.60, 197.97) = 11.66, p < .01, \eta^2_p = .13$, overshadowing the main effects. No other interactions were significant (all $p > .05$).

Simple-effects analysis of the significant interaction revealed that the SampEn values in both the constrained, $F(2.77, 107.90) = 54.78, p < .01, \eta^2_p = .58$, and unconstrained, $F(2.34, 91.32) = 17.09, p < .01, \eta^2_p = .30$, exploratory movement conditions were significantly affected by weight condition; although, as was the case for AP sway, the effect was more pronounced for the constrained condition as indicated by the substantially larger effect size (see Figure 6). In both the constrained and unconstrained conditions, Bonferroni-corrected pairwise comparisons revealed that the 0% weight condition (constrained: $M = 0.84, SD = 0.27$; unconstrained: $M = 0.49, SD = 0.22$) had significantly higher SampEn values than all other weight conditions. The similarities in results between the two exploratory movement conditions ceased after the 0% condition.

In the unconstrained condition there were no other significant comparisons among the 10% F ($M = 0.35, SD = 0.15$), 10% B ($M = 0.34, SD = 0.12$), 20% F ($M = 0.30, SD = 0.11$), and 20% B ($M = 0.30, SD = 0.11$) weight conditions. Alternatively, the constrained condition did exhibit significant differences in the remaining comparisons. Both the 20% B ($M = 0.37, SD = 0.14$) and 20% F ($M = 0.37, SD = 0.14$) conditions had significantly lower SampEn values than the 10% B ($M = 0.54, SD = 0.18$) and 10% F ($M = 0.49, SD = 0.18$)
0.16) weight conditions. No other comparisons in the constrained condition were significant (all $p > .05$).

Lastly, simple-effects analysis indicated that there were significant simple main effects of exploratory movement in all weight conditions: 0%, $F(1,78) = 39.13$, $p < .01$, $\eta_p^2 = .33$; 10% F, $F(1,78) = 16.15$, $p < .01$, $\eta_p^2 = .17$; 10% B, $F(1,78) = 33.60$, $p < .01$, $\eta_p^2 = .30$; 20% F, $F(1,78) = 10.50$, $p < .01$, $\eta_p^2 = .12$; and 20% B, $F(1,78) = 6.30$, $p < .05$, $\eta_p^2 = .07$, weight conditions. The unconstrained condition had significantly lower values of SampEn than the constrained condition, with the largest difference again lying in the 0% weight condition.

![Graph](image.png)

*Figure 6.* Average SampEn of ML sway during the eyes closed period for each weight condition in the unconstrained and constrained exploratory movement conditions. The error bars indicate one standard error of the mean.
**PL of COP sway during the eyes closed period.** There were no significant effects or interactions for PL (all $p > .15$).

**Summary of COP results during the eyes closed period.** The main effect of weight condition had a significant effect on all but one of the dependent measures (PL). Changes to participants’ COM in either the anterior or posterior direction resulted in a systematic increase in SD values. In other words, when weight was added to participants’ torsos, they displayed greater postural sway variability. This effect was greater in AP sway than in ML sway and it was more evident in AP sway for LSD than SD. Also, the manipulation of participants’ COM resulted in lower SampEn values, indicating a more regular pattern of postural sway. Moreover, the exploratory movement conditions affected participants’ postural sway with participants displaying lower SD and LSD values, on average, and higher SampEn values when their postural sway was constrained. This effect was found more so in AP than ML sway. The only dependent measures to demonstrate an effect of intention were LSD in AP and ML sway and SD in ML sway. Participants who had the intention to judge the stand-on-ability of a slope displayed greater variability (i.e., higher SD and LSD values) in their postural fluctuations than participants who were not given the intention to judge. The results, in short, showed that physical manipulations (i.e., the weight and exploratory movement conditions) and behavioral goals (i.e., intention) affected the overall amount and structure of postural sway during the time period in which participants stood with the eyes closed before viewing the slopes they were about to judge.

**SD of AP sway during the eyes open period.** There were significant main effects of weight condition and exploratory movement for the SD of AP postural sway during the
eyes open period, $F(3.31,251.42) = 6.30, p < .001, \eta_p^2 = .08$ and $F(1,76) = 33.85, p < .001, \eta_p^2 = .31$, respectively. The main effect of intention was not significant, $F(1,76) = 0.34, p > .05$. The pattern of results from the two significant main effects generally followed the pattern from the eyes closed period—increases to the COM of participants resulted in higher SD values and the unconstrained exploratory movement condition had higher SD values than the constrained condition. However, the main effects are difficult to interpret because there was also a significant three-way interaction (intention $\times$ exploratory movement $\times$ weight condition) presented in Figure 7, $F(3.31,251.42) = 4.25, p < .01, \eta_p^2 = .05$.

Subsequent to the significant three-way interaction, simple-effects analysis revealed that the simple main effect of exploratory movement was significant in all weight conditions: 0%, $F(1,76) = 25.83, p < .001, \eta_p^2 = .25$; 10% F, $F(1,76) = 28.49, p < .001, \eta_p^2 = .27$; 10% B, $F(1,76) = 39.16, p < .001, \eta_p^2 = .34$; 20% F, $F(1,76) = 20.69, p < .001, \eta_p^2 = .21$; and 20% B, $F(1,76) = 10.71, p < .01, \eta_p^2 = .12$. The pattern of results was the same across all weight conditions—the unconstrained exploratory movement condition had significantly greater SD than the constrained condition. This follows the significant main effect of exploratory movement and is comparable to other effects of exploratory movement. There were no significant differences between intentions within any weight condition, nor did intention interact with exploratory movement in any weight condition (all $p > .05$).

Additional simple-effects analyses indicated that the simple effects of weight condition and intention differed between the unconstrained and constrained exploratory movement conditions. Within the constrained exploratory movement condition the simple
main effect of weight condition was significant, $F(2.43, 92.32) = 3.76, p < .02, \eta^2_p = .09$. The sole significant comparison was between the 0% ($M = 0.30$ cm, $SD = 0.25$ cm) and 20% B ($M = 0.47$ cm, $SD = 0.45$ cm, $p < .01$) weight conditions with the 0% condition having significantly lower SD than the 20% B condition. No other comparisons were significant involving the remaining weight conditions: 10% F ($M = 0.37$ cm, $SD = 0.23$ cm), 10% B ($M = 0.34$ cm, $SD = 0.25$ cm), and 20% F ($M = 0.43$ cm, $SD = 0.38$ cm). The simple effect of intention was not significant in the constrained condition nor did it interact with weight condition (both $p > .05$).

The results of the simple-effects analyses within the unconstrained exploratory movement condition showed a different pattern than the constrained condition. Within the unconstrained condition the simple main effect of weight condition was significant and it also interacted with intention, $F(3.45, 131.13) = 3.99, p < .05, \eta^2_p = .09$ and $F(3.45, 131.13) = 5.18, p < .01, \eta^2_p = .12$, respectively. Subsequent to the significant interaction, additional simple-effects tests indicated there were no significant differences between the intention-to-judge and no-intention-to-judge conditions in the 0%, 10% F, 10% B, and 20% F weight conditions (all $p > .05$). The only significant difference, which is not in agreement with other effects of intention, was in the 20% B condition where the intention-to-judge condition ($M = 0.63$ cm, $SD = 0.29$ cm) had a significantly lower SD than the no-intention-to-judge condition ($M = 0.90$ cm, $SD = 0.38$ cm), $F(1, 38) = 6.37, p < .05, \eta^2_p = .14$. Lastly, within the unconstrained exploratory movement condition, both the intention-to-judge and no-intention-to-judge conditions showed significant simple main effects of weight condition, $F(3.25, 61.79) = 3.03, p < .05, \eta^2_p = .14$ and $F(3.20, 60.74) = 6.37, p < .01, \eta^2_p = .25$, respectively; however, in the intention-to-judge
condition no pairwise comparisons reached significance after Bonferroni-corrections (all $p > .15$). In the no-intention-to-judge condition the 0% weight condition ($M = 0.59$ cm, $SD = 0.23$ cm) had significantly lower SD values than the 10% F ($M = 0.71$ cm, $SD = 0.27$ cm), 10% B ($M = 0.76$ cm, $SD = 0.26$ cm), 20% F ($M = 0.79$ cm, $SD = 0.29$ cm), and 20% B ($M = 0.90$ cm, $SD = 0.38$ cm) weight conditions (see Figure 8). The 10% F and 10% B weight conditions also had significantly lower SD values than the 20% B condition. No other comparisons were significant (all $p > 0.10$).

In the intention-to-judge condition (see Figure 7A), simple-effects analysis showed a significant exploratory movement $\times$ weight condition interaction, $F(3.04,115.38) = 3.23, p < .05, \eta_p^2 = .08$. Within the constrained condition there were no significant differences among weight conditions for participants given the intention to judge, $F(2.08,39.44) = 2.14, p > .05$. For the unconstrained condition there were significant differences among weight conditions for participants given the intention to judge, $F(3.25,61.79) = 3.03, p < .05, \eta_p^2 = .14$; however, after Bonferroni corrections of $p$-values no comparisons reached significance (all $p > .05$). Additionally, in the intention-to-judge condition the unconstrained condition had significantly greater SD than the unconstrained condition in all weight conditions (all $p < .05$) except for the 20% B weight condition which was not significantly different ($p > .05$).
Figure 7. Average SD of AP sway during the eyes-open period for each weight condition in the unconstrained and constrained exploratory movement conditions. A is for participants who had the intention to judge and B is for participants who did not have the intention to judge. The error bars indicate one standard error of the mean.

Unlike in the intention-to-judge condition, the simple main effects of exploratory movement and weight condition did not interact in the no-intention-to-judge condition ($p > .05$). However, both simple main effects of exploratory movement, $F(1,38) = 26.81, p < .001$, $\eta^2_p = .41$, and weight condition, $F(3.47,131.84) = 8.50, p < .001$, $\eta^2_p = .18$, were significant. The significant effect of exploratory movement indicated that the unconstrained condition ($M = 0.75$ cm, $SD = 0.30$ cm) had higher SD than the constrained condition ($M = 0.41$ cm, $SD = 0.22$ cm). Bonferroni-corrected, pairwise comparisons revealed that the 0% weight condition ($M = 0.46$ cm, $SD = 0.23$ cm) had significantly lower SD than the 10% F ($M = 0.58$ cm, $SD = 0.28$ cm), 20% F ($M = 0.62$ cm, $SD = 0.31$ cm), and 20% B ($M = 0.68$ cm, $SD = 0.38$ cm) weight conditions, but it was not significantly different than the 10% B condition ($M = 0.57$ cm, $SD = 0.33$ cm). No other pairwise comparisons were significant (all $p > .15$).
**SD of ML sway during the eyes open period.** The only significant result for SD of ML sway during the eyes open period was the main effect of exploratory movement, \( F(1,76) = 12.64, p < .01, \eta_p^2 = .14 \). The unconstrained exploratory movement condition \((M = 0.44 \text{ cm}, SD = 0.49 \text{ cm})\) had significantly higher SD than the constrained condition \((M = 0.23 \text{ cm}, SD = 0.19 \text{ cm})\).

**LSD of AP sway during the eyes open period.** There was a significant main effect of exploratory movement on the LSD of AP sway during the eyes open period, \( F(1,76) = 20.97, p < .001, \eta_p^2 = .22 \). The unconstrained exploratory movement condition had more variable sway than the constrained condition. Both main effects of intention and weight condition were not significant (both \( p > .05 \)). However, the three-way interaction, depicted in Figure 8, between intention, exploratory movement and weight condition was significant, \( F(2.76,209.53) = 3.24, p < .05, \eta_p^2 = 0.22 \).

In line with the significant main effect of exploratory movement, simple-effects analysis revealed that within the intention-to-judge condition there was a significant simple main effect of exploratory movement, \( F(2.55,48.46) = 7.01, p < .01, \eta_p^2 = .27 \), with the unconstrained condition \((M = 0.50 \text{ cm}, SD = 0.30 \text{ cm})\) displaying higher LSD values than the constrained condition \((M = 0.26 \text{ cm}, SD = 0.34 \text{ cm})\). Again, in line with the pattern of results for the main effects, the simple main effect of weight condition was not significant nor did it interact with the simple main effect of exploratory movement (both \( p > .05 \)).
Figure 8. Average LSD of AP sway during the eyes-open period for each weight condition in the unconstrained and constrained exploratory movement conditions. A is for participants who had the intention to judge and B is for participants who did not have the intention to judge. The error bars indicate one standard error of the mean.

In the no-intention-to-judge condition there were significant simple main effects of weight condition and exploratory movement as well as a significant interaction between the two, $F(3.08,116.96) = 7.40, p < .001$, $\eta_p^2 = .16$, $F(1,38) = 25.39, p < .001$, $\eta_p^2 = .40$, and $F(3.08,116.96) = 3.10, p < .05$, $\eta_p^2 = .08$, respectively. Additional simple-effects tests following this interaction showed that there was a significant effect of weight condition in the unconstrained exploratory movement condition, $F(3.08,116.96) = 7.40, p < .001$, $\eta_p^2 = .12$, but not in the constrained condition ($p > .05$). Pairwise comparisons of weight condition within the unconstrained exploration condition revealed that the 20% B condition ($M = 0.46$ cm, $SD = 0.16$ cm) had significantly greater LSD values than the 0% ($M = 0.33$ cm, $SD = 0.10$ cm) and 10% B ($M = 0.37$ cm, $SD = 0.13$ cm) weight conditions, but it did not significantly differ from the 10% F ($M = 0.38$ cm, $SD = 0.13$ cm) and 20% F ($M = 0.40$ cm, $SD = 0.12$ cm) conditions. This pattern of results is in
agreement with other effects of weight condition. No other comparisons were significant (all $p > .05$). Furthermore, there were significant simple main effects of exploratory movement in each weight condition that were all in line with the main effect. The unconstrained condition had higher LSD values than the constrained condition in all weight conditions: 0%, $F(1,38) = 8.28, p < .05, \eta^2 = .18$; 10% F, $F(1,38) = 11.91, p < .01, \eta^2 = .24$; 10% B, $F(1,38) = 30.00, p < .001, \eta^2 = .44$; 20% F, $F(1,38) = 22.07, p < .001, \eta^2 = .37$; and 20% B, $F(1,38) = 29.38, p < .001, \eta^2 = .44$.

Moreover, simple-effects analysis revealed there was a significant simple effect of exploratory movement, that was in accordance with the main effect, in every weight condition: 0%, $F(1,76) = 12.40, p < .001, \eta^2 = .14$; 10% F, $F(1,76) = 25.32, p < .001, \eta^2 = .25$; 10% B, $F(1,76) = 29.28, p < .001, \eta^2 = .28$; 20% F, $F(1,76) = 11.04, p < .01, \eta^2 = .13$; and 20% B, $F(1,76) = 7.19, p < .01, \eta^2 = .09$. The unconstrained exploratory movement condition had significantly higher values of LSD than the constrained condition in every weight condition. Similar to the SD of AP sway results during the eyes-open period, there were no significant simple main effects of intention in any weight condition, nor did exploratory movement and intention interact (all $p > .05$).

Within the unconstrained exploratory movement condition simple effect analysis revealed that the effects of intention and weight condition were not significant (both $p > .05$). However, there was a significant interaction between intention and weight condition, $F(3.33,129.79) = 3.95, p < .01, \eta^2 = .09$. Further simple effects tests after the interaction indicated that there were no significant differences between intention among the weight conditions of 10% F, 10%B, and 20% B: $F(1,38) = 3.02, p > .05$; $F(1,38) = 3.57, p > .05$; and $F(1,38) = 0.07, p > .05$, respectively. There were significant differences
between the intention and no intention to judge condition in the 0%, $F(1,38) = 4.53, p < .05$, $\eta_p^2 = .11$, and 20% F, $F(1,38) = 4.19, p < .05$, $\eta_p^2 = .10$, weight conditions, with the intention to judge having greater LSD in both conditions. This result is in line with the other effects of the intention condition. Additionally, in the no intention to judge unconstrained condition there was a significant simple main effect of weight condition, $F(2.55,48.46) = 7.01, p < .01$, $\eta_p^2 = .27$. Pairwise Bonferroni-corrected comparisons revealed that the 20% B weight condition ($M = 0.46$ cm, $SD = 0.16$ cm) had significantly greater LSD than the 0% ($M = 0.33$ cm, $SD = 0.10$ cm) and 10% B ($M = 0.37$ cm, $SD = 0.13$ cm) conditions, but it was not significantly different than the 10% F ($M = 0.38$ cm, $SD = 0.13$ cm) or 20% F ($M = 0.40$ cm, $SD = 0.12$ cm) conditions. No other comparisons were significant (all $p > .05$). The intention-to-judge condition in the unconstrained exploratory movement condition had no significant differences among the weight conditions, $F(3.09,58.76) = 1.26, p > .05$.

Lastly, in the constrained exploratory movement condition, there were no significant simple main effects of intention or weight condition, nor was there an interaction between those factors (all $p > .05$).

*LSD of ML sway during the eyes open period.* Similar to the LSD results in AP sway, the main effect of weight condition was not significant, $F(2.13,161.93) = 2.03, p > .05$. There were significant main effects of intention, $F(1,76) = 4.78, p < .05$, $\eta_p^2 = .06$, and exploratory movements, $F(1,76) = 13.06, p < .001$, $\eta_p^2 = .15$, for LSD of ML sway during the eyes open period. As indicated by the significant main effects, the unconstrained exploratory movement condition and the intention-to-judge condition displayed more variable sway than the constrained and no-intention-to-judge conditions.
However, these main effects were overshadowed by a significant interaction between the two factors, $F(1,76) = 4.78, p < .05, \eta_p^2 = .05$.

The significant two-way interaction seems to be driven by the simple main effect of intention not being significant in the constrained condition ($p > .05$). The simple main effect of intention was significant in the unconstrained condition, $F(1,38) = 5.81, p < .05, \eta_p^2 = .13$; participants with the intention to judge ($M = 0.35 \text{ cm}, SD = 0.37 \text{ cm}$) had significantly greater LSD values than participants with no intention to judge ($M = 0.20 \text{ cm}, SD = 0.08 \text{ cm}$). The simple main effect of exploratory movement was significant in both the intention-to-judge and the no-intention-to-judge conditions, $F(1,38) = 8.72, p < .05, \eta_p^2 = .19$ and $F(1,38) = 6.91, p < .05, \eta_p^2 = .15$, respectively. Like the main effect of exploratory movement, the unconstrained condition had higher LSD values than the constrained conditions. Specifically, within the intention-to-judge condition, the unconstrained exploratory movement condition ($M = 0.35 \text{ cm}, SD = 0.37 \text{ cm}$) had significantly higher LSD values than the constrained condition ($M = 0.15 \text{ cm}, SD = 0.17 \text{ cm}$). Likewise, in the no-intention-to-judge condition the unconstrained exploratory movement condition ($M = 0.20 \text{ cm}, SD = 0.08 \text{ cm}$) had significantly higher LSD values than the constrained condition ($M = 0.14 \text{ cm}, SD = 0.09 \text{ cm}$). The effect size of exploratory movement was similar in the intention-to-judge and no-intention-to-judge conditions.

*SampEn of AP sway during the eyes-open period.* There were significant main effects of exploratory movement, $F(1,76) = 28.93, p < .01, \eta_p^2 = 0.28$, weight condition, $F(3.45,134.38) = 11.48, p < .01, \eta_p^2 = 0.13$, and intention $F(1,76) = 10.93, p < .01, \eta_p^2 = 0.13$. Participants given the intention to judge ($M = 0.45, SD = 0.30$) had significantly
higher SampEn than participants not given the intention ($M = 0.32, SD = 0.30$).

Equivalent to the SampEn results of AP sway during the eyes-closed period, there was also a significant interaction between the exploratory movement and weight conditions, $F(3.45, 134.38) = 4.48, p < .01, \eta^2_p = 0.06$.

Subsequent to the significant interaction, simple-effects analysis revealed that SampEn in the constrained exploratory movement condition was significantly affected by weight condition, $F(3.27, 127.69) = 9.81, p < .01, \eta^2_p = 0.58$, (see Figure 9), but SampEn in the unconstrained condition was not, $F(4, 156) = 2.38, p > .05$. In the constrained condition, Bonferroni-corrected pairwise comparisons revealed that the 0% weight condition ($M = 0.62, SD = 0.29$) had significantly higher SampEn than the 10% F ($M = 0.46, SD = 0.28$), 20% F ($M = 0.48, SD = 0.30$), and 20% B ($M = 0.41, SD = 0.28$) conditions, but it was not significantly difference than the 10% B weight condition ($M = 0.62, SD = 0.29$). No other pairwise comparisons were significant (all $p > .05$). Lastly, simple effects analysis indicated that there were significant simple main effects of exploratory movement in every weight condition with the unconstrained condition having significantly lower values of SampEn than the constrained condition: 0%, $F(1, 78) = 35.61, p < .01, \eta^2_p = 0.31$; 10% F, $F(1, 78) = 14.76, p < .01, \eta^2_p = 0.16$; 10% B, $F(1, 78) = 17.88, p < .01, \eta^2_p = 0.19$; 20% F, $F(1, 78) = 19.58, p < .01, \eta^2_p = 0.20$; and 20% B, $F(1, 78) = 8.08, p < .01, \eta^2_p = 0.09$. 


Figure 9. Average SampEn of AP sway during the eyes open period for each weight condition in the unconstrained and constrained exploratory movement conditions. The error bars indicate one standard error of the mean.

SampEn of ML sway during the eyes open period. There were significant main effects of exploratory movement [$F(1,76) = 35.32, p < .01$, $\eta_p^2 = .32$], intention [$F(1,76) = 11.95, p < .01$, $\eta_p^2 = .14$], and weight condition [$F(3.44,261.79) = 16.38, p < .01$, $\eta_p^2 = .18$]. There were also two significant interactions, between intention and weight [$F(3.44,261.79) = 2.66, p < .05$, $\eta_p^2 = .03$] and between intention and exploration [$F(1,76) = 9.45, p < .01$, $\eta_p^2 = .11$].

Simple-effects analysis of the intention × weight condition interaction revealed that the SampEn values in both the intention-to-judge and no-intention-to-judge conditions were significantly affected by weight condition, $F(4,156) = 4.44, p < .01$, $\eta_p^2 = .10$ and $F(2.93,114.39) = 21.28, p < .05$, $\eta_p^2 = .35$, respectively (see Figure 10), but the effect was
larger in the no-intention condition. In the intention-to-judge condition, Bonferroni-corrected pairwise comparisons revealed that the 0% weight condition \((M = 0.66, SD = 0.38)\) was significantly higher than the 10% B weight condition \((M = 0.48, SD = 0.32)\). No remaining comparisons among 0%, 10% F \((M = 0.56, SD = 0.31)\), 10% B, 20% F \((M = 0.53, SD = 0.37)\), and 20% B \((M = 0.54, SD = 0.39)\) weight conditions were significant. For the no-intention-to-judge condition, Bonferroni-corrected pairwise comparisons revealed that the 0% weight condition \((M = 0.55, SD = 0.25)\) had significantly higher SampEn values than all other weight conditions. The 10% B condition \((M = 0.40, SD = 0.18)\) was not significantly different than the 10% F condition \((M = 0.41, SD = 0.18)\), but it did have significantly lower SampEn values than the 20% F \((M = 0.55, SD = 0.25)\) and 20% B \((M = 0.55, SD = 0.25)\) weight conditions. The 10% F weight condition also had significantly lower SampEn values than the 20% F condition but not the 20% B condition. The 20% F and 20% B conditions were not significantly different.

The simple main effect of intention was significant in the 10% F, 20% F, and 20% B weight conditions, \(F(1,78) = 6.63, p < .05, \eta^2_p = .08; F(1,78) = 11.15, p < .01, \eta^2_p = .13; \) and \(F(1,78) = 10.52, p < .01, \eta^2_p = .12\), respectively (see Figure 13). The intention-to-judge condition had significantly greater SampEn values than the no-intention-to-judge condition. The simple main effect of intention was not significant in the 0% and 10% B weight conditions (both \(p > .05\)).

Simple-effects analysis of the intention \(\times\) exploratory movement condition interaction revealed that the simple main effect of exploratory movement was significant in both the intention and no-intention-to-judge conditions, \(F(1,38) = 26.14, p < .01, \eta^2_p = .40\) and \(F(1,38) = 9.25, p < .01, \eta^2_p = .20\), respectively, though the effect was somewhat
larger in the intention to judge condition. In the intention to judge condition, the unconstrained exploratory movement condition ($M = 0.36$, $SD = 0.18$) had significantly lower SampEn values than the constrained condition ($M = 0.75$, $SD = 0.38$). The no-intention-to-judge condition followed the same pattern of results as the intention to judge condition – the unconstrained exploratory movement condition had a mean value of 0.34 ($SD = 0.17$) and the constrained condition had a mean value of 0.47 ($SD = 0.21$). The simple main effect of intention was significant in the constrained exploratory movement condition, $F(1,38) = 13.57$, $p < .01$, $\eta^2_p = .26$. The intention-to-judge condition had significantly higher SampEn values than the no-intention-to-judge condition. Lastly, the simple main effect of intention was not significantly different in the unconstrained exploratory movement condition, $F(1,38) = 0.17$, $p > .05$. 
Figure 10. Average SampEn of ML sway during the eyes-open period for each weight condition in the intention and no-intention-to-judge conditions. The error bars indicate one standard error of the mean.

PL of COP during the eyes-open period. The main effect of intention had a significant effect on PL of the COP during the eyes-open period, $F(1,76) = 5.14$, $p < .05$, $\eta^2_p = 0.06$. Participants not given the intention to judge ($M = 27.61$ cm, $SD = 6.41$ cm) exhibited significantly longer PL than participants given the intention to judge ($M = 17.76$ cm, $SD = 30.35$ cm). No other effects or interactions were significant (all $p > .15$).

Summary of postural sway results during the eyes-open period. The effects of exploratory movement and weight condition were largely equivalent to the effects found in the eyes closed period. Increases to participants’ COM in either the anterior or posterior direction resulted in a systematic increase in SD and LSD values and a decrease in SampEn values. The exploratory movement condition also affected participants’
postural sway with participants displaying lower SD and LSD values and higher SampEn values in the constrained condition than the unconstrained condition. However, as compared to the eyes-closed period of a trial, there were a greater number of dependent variables affected by the factor of intention. The intention-to-judge condition produced patterns of postural sway that were more variable (i.e., higher SD and LSD) and complex (i.e., higher SampEn values) than the no-intention-to-judge condition. Also, as shown by the PL results, participants who had the intention to judge the affordance for upright stance swayed less overall than participants who did not. Intention interacted with the physical manipulations of weight condition and exploratory movement for every variable except SampEn of AP sway.

The effect of intention was accompanied by changes in the effect of weight condition on postural sway. Differences among weight conditions were diminished when participants had the intention to judge (i.e., SampEn of ML sway and LSD of AP sway in the unconstrained condition). The effects of weight condition in the no-intention-to-judge condition followed the same general trend displayed during the eyes-closed period—COM displacements in either the posterior or anterior direction resulted in more variability, as indicated by SD and LSD, and a more regular pattern of postural sway, as indicated by SampEn. Participants who had the intention to judge did not display as many systematic differences among weight conditions.

The exploratory movement condition produced results consistent with the eyes closed period. However, as previously mentioned, there were dependent measures for which the factor of exploratory movement impacted the effect of intention. For the measures of variability (i.e., SD and LSD), the participants in the constrained condition
did not exhibit differences in the intention condition, excluding a single effect of intention in the SD of AP sway that was the opposite pattern of results displayed by every other intention effect. The effects of intention were mainly found in the unconstrained condition, where the participants with the intention to judge displayed more variable postural sway than those who did not have the intention to judge. However, there was a single dependent measure that revealed a pattern consistent with the effects of intention but was not in agreement with the interaction effect of exploratory movement and intention just discussed. The SampEn of ML sway showed differences between intention in the constrained condition but not in the unconstrained condition. Nonetheless, the overall results indicate that participants in the intention-to-judge condition organized their postural sway differently than those who simply observed the platform.
CHAPTER 4: DISCUSSION

The aims of this project were to (1) determine how sensitive people are to changes in their ability to stand on an inclined surface and to (2) determine whether or not people produce exploratory movements to facilitate prospective perception of an affordance for upright stance, particularly when the affordance was changed by changing participants’ action capabilities. The discussion is organized by addressing the outcome of the experiment pertinent to each aim followed by an examination of the study’s general implications, shortcomings, and possible future directions for research.

Perceptual Sensitivity to the Affordance for Upright Stance

Behavioral boundaries. Participants’ actual behavioral boundaries (maximum stand-on-able slopes) were, as predicted, higher (i.e., participants could stand on a higher slope) when the COM was shifted in the anterior direction and lower when shifted in the posterior direction. However, this only occurred in the most extreme COM displacement conditions (i.e., 20% F and 20% B). The 10% F and 10% B manipulations did not cause a significant change in the action capabilities for upright stance, although they produced nominal changes in the expected direction. The overall pattern of results is largely consistent with the findings of Malek and Wagman (2008), who used added masses equal to 15% of the participant’s body weight to change the COM location.

The significant interaction between exploratory movement condition and weight condition indicated that the constrained participants had lower behavioral boundaries than unconstrained participants. This difference may be explained by the previously noted discrepancy in levels of athletic experience between the two groups. It is plausible that participants with athletic experience were in better physical condition (i.e., they were able
to produce greater levels of muscular output) and were therefore able to stand on steeper slopes. The pattern of results for the behavioral boundaries of the unconstrained participants lends evidence that this may be the case. In the unconstrained condition, there was no difference in behavioral boundaries for the 0%, 10% F, and 10% B weight conditions (see Figure 3), suggesting that these participants were able to overcome the smaller COM modulations experienced in the 10% F and 10% B conditions and stand effectively unchanged on the sloped platform. Additionally, the mean difference between the highest stand-on-able slope (i.e., 20% F) and the lowest stand-on-able slope (i.e., 20% B) was 3.68° for participants in the unconstrained group. This is a smaller difference than the range between the constrained participants’ highest and lowest stand-on-able slope, which was 5.10°. Consequently, it is feasible that the athletic experience of the unconstrained condition provided them with advantages in strength or balance that participants in the constrained condition did not have, allowing participants in the former group to stand on a more steeply sloped platform. When compared to the behavioral boundaries reported in past research, both the constrained and unconstrained groups had behavioral boundaries for the 0% weight condition that were within the range of the highest (36.5° in Regia-Corte & Wagman, 2008) and lowest (22.8° in Klevberg & Anderson, 2002) reported boundaries. There are a few methodological differences between past research and the current experiment that should be mentioned before further discussing participants’ behavioral boundaries and their relation to perceptual judgments. First, behavioral boundaries in the current experiment were obtained in a different manner than research in the past. Behavioral boundaries in past research (i.e., Fitzpatrick et al., 1994; Klevberg & Anderson, 2002; Malek & Wagman, 2008; Regia-Corte &
Wagman, 2008) were only obtained for slopes presented in an ascending manner. The current study used both ascending and descending trials which were then averaged to obtain a behavioral boundary. This procedure was implemented due to the possibly of hysteresis and/or enhanced contrast effects affecting the boundaries (Fitzpatrick et al., 1994; Richardson, Marsh, & Baron, 2007; see also Tuller, Case, Ding, & Kelso, 1994). Second, the current study used a continuously adjustable platform (comparable to the platform used by Regia-Corte & Wagman, 2008) whereas the previous study by Malek and Wagman (2008), for example, used a platform that was adjusted in various set increments—the platform’s range was adjustable from 15-45° in steps of 5°. The current procedure permitted a much finer resolution for detecting the behavioral boundaries. Lastly, due to the use of a continuously adjustable platform, participants were able to remain on the platform (with the help of support railings and a “spotter” in case of a fall) even when they could not stand upright (i.e., at the beginning of descending behavioral trials). This may have influenced participant behavior by allowing greater opportunity for discovering behavioral boundaries.

**Perceptual boundaries.** In the current study participants did not perceive their true action capabilities with absolute accuracy. Participants overestimated their ability to stand on a slope (i.e., perceptual boundaries occurred at higher slopes than behavioral boundaries) by, on average, 14.2% according to the ratio measure and by 16.6% for the AR measure. This outcome was the same regardless of exploratory movement condition. Specifically, the 0% weight condition yielded the highest perceived stand-on-ability of a sloped surface with an average perceived boundary of 33.96°. The 0% condition also had the highest perceptual boundaries when comparing the present results to the results of
prior studies: 29.6° in Fitzpatrick et al. (1994), 31.4° in Klevberg and Anderson (2002), and 25.9° in Malek and Wagman (2008). No other weight condition comparisons to past results were possible because the majority of other studies did not manipulate participants’ COM; only Wagman and his colleagues (i.e., Malek & Wagman, 2008; Regia-Corte & Wagman, 2008) investigated the influence of altering the COM on affordance judgments. However, their weight conditions were not equivalent to those used in the current experiments. In the present study, the 20% B condition did yield the lowest judgments of stand-on-ability of a slope and this result is in line with the finding of Malek and Wagman, who found that participants judged slopes while wearing a 15% mass added in the posterior direction as the least stand-on-able. However, participants in the current study were not sensitive to their new action capabilities in the 10% F, 10% B, and 20% F weight conditions.

Participants in both exploratory movement conditions produced about the same pattern of perceptual judgments across conditions. However, because the behavioral boundaries of the two exploratory movement conditions were considerably different, the relative accuracy of the two groups must be assessed using the ratio and AR measures. According to those measures, participants in the unconstrained exploratory movement condition exhibited greater accuracy and generally judged each slope afforded by a certain weight condition with equivalent precision (with a sole exception between the 10% B and 20% F conditions). Participants in the constrained exploratory movement condition did not perceive their action capabilities with the same level of accuracy. This result may be explained by two possibilities.
Past affordance research has suggested that athletes are more accurate and sensitive to certain affordances (for a review see Fajen et al., 2009). If this is the case, the athletic experience of participants in the unconstrained group could have driven the more accurate affordance judgments. However, it is highly probable that the opportunity for those participants to produce exploratory movement was a greater factor in their more accurate judgments.

Even though this study was not designed to investigate athletic expertise and is therefore unable to explicitly address any possible effects resulting from it, there have been a few studies that investigated perception of affordances and athletic experience. Oudejans, Michaels, Bakker, and Dolné (1996) investigated the “catchableness” of fly balls, and found an effect for active-perception conditions but not for athletic experience. In their experiment, athletes and non-athletes alike grossly overestimated their ability to catch a ball when their ability to generate information through locomotion was removed (i.e., by having participants remain in a stationary, upright posture). When participants were given an opportunity to move about for a short period (one second), their judgments still overestimated the “catchableness” of a fly ball, but the judgments were significantly more accurate than those made in the stationary condition. Only through action were the participants able to make more accurate perceptual judgments.

Additional research by Weast, Shockley, and Riley (2011) investigated sports expertise in basketball and its influence on perception of affordances for other actors. They reported that basketball players were more sensitive to the basketball-specific, action-scaled affordance of interest in the study—maximum reach with jump—than non-basketball players. However, the basketball players were no more sensitive to body-
scaled, non-sports specific affordances (i.e., maximum standing reach and maximum sitting height) than the non-players. These results seem to suggest that athletes are more sensitive to sport-specific affordances, but not at perceiving affordances, in general. It is questionable that the sports experience of participants, which could make them more accurate in affordance perception, was task-specific to the certain affordance under consideration in the current study. No participants reported any experience that was obviously in direct relevance to the stand-on-ability of a slope, such as rock climbing, skiing, or hiking.

The difference in the two groups’ accuracy in making perceptual judgments could alternatively be explained as support for action and perception existing in a synergistic relationship. If perception and action are integrally reliant upon each other then it is possible that perceptual judgments can be hindered by a lack of available exploratory behavior, especially if it prevents information specifying a person’s relationship to the environment from being detected (Mark et al., 1990). In the case of the current study, when optical and mechanical (proprioceptive) transformations were reduced by the restriction of postural sway, perceptual judgments were markedly more inaccurate. The importance for postural movement (action) and the resulting optical and mechanical transformations (perception) in making affordance judgments is additionally supported by the COP results discussed next.

*Exploratory Movements for Perceiving an Affordance for Upright Stance*

The hypothesis that participants given the intention to judge an affordance would produce different patterns of postural sway than participants not given the intention was supported. During the eyes-closed period of a trial, differences between intention
conditions were found in the variability measures LSD (for AP and ML sway) and SD (for ML sway). Specifically, participants who had the intention to judge displayed more variable postural sway. For the eyes-open period, participants not only showed differences in the variability of postural sway, but they also displayed differences in the complexity (i.e., SampEn) and overall amount of postural sway (i.e., PL). Participants who had the intention to judge had more variable and complex postural sway, but they swayed less overall.

A general examination of how the experimental manipulations (i.e., the weight and exploratory movement conditions) affected participants’ COP is needed before the effect of intention on postural sway can be explained. First, the COP results give evidence beyond the affordance results that the constrained exploratory movement condition effectively altered the opportunity to reveal perceptual invariants specifying the stand-on-able affordance. Constrained participants had less variable (as indicated by the SD and LSD results) and more complex (as indicated by the SampEn results) postural sway than the unconstrained participants. These results indicate that participants who rested their heads against the horizontal head-restraint bar had both qualitative and quantitative differences in their body movements compared to unconstrained participants. Also, the effect of exploratory movement on sway was found in many dependent measures and, as indicated by the relatively large partial eta-squared values, the effect was strong. The current study’s support surface (i.e., the horizontal, head-restraint bar) and point of contact with the body (i.e., the head) produced results that are in line with previous research on light touch’s (usually with a single finger) effect on postural sway (Jeka & Lackner, 1994; Riley, Wong, Mitra, & Turvey, 1997; Clapp & Wing, 1999),
although there were many methodological differences between the current study and those studies.

Postural sway was also altered by the manipulation of participants’ COM. With the added weight, additional muscular forces had to be produced and controlled in order to overcome the inherently unstable upright stance. It is important to note that postural sway was measured on a level surface and that the advantages provided by the 10% and 20% F conditions exist for stance only on a sloped surface (and more specifically, only when the front of the body faces the slope). When weight was added in either direction, participants displayed greater postural variability (i.e., higher SD and LSD values), but participants swayed in a more regular manner, as indicated by the lower SampEn values. This finding corroborates past research on the effects of added mass to the torso and postural control (e.g., Heller, Challis, & Sharkey, 2009; Ledin, Fransson, & Magnusson, 2004; Schiffman, Bensel, Hasselquist, Gregorczyk, & Piscitelle, 2006).

Tasks that place functional demands on the postural system, like maintaining light contact with a surface, are called supra-postural tasks (Riccio & Stoffregen, 1988). Supra-postural tasks require that the body coordinate itself in such a way as to preserve not only upright stance but concurrently achieve the behavioral goal at hand. Specifically, much research has demonstrated the organization of postural sway in service of visual performance (e.g., Stoffregen, Smart, Bardy, & Pagulayan, 1999; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000; Riley, Mitra, Stoffregen, & Turvey, 1997). The finding of postural modulation in service of a supra-postural, visual task may have important implications for interpreting the COP data during the eyes-open period, which is discussed subsequent to the eyes-closed period.
During the eyes-closed period participants first encountered the COM manipulation. The added weight changed participants’ postural capabilities and the necessary forces required to maintain stable, upright stance. It may be the case that during this period participants were obtaining information about these required forces and, therefore, moved in order to test their new action capabilities. This is not to exclude the possibility that participants (even in the no-intention-to-judge condition) did not experience a transient period during which their postural system adapted to the mechanical perturbation caused by the COM manipulation. This scenario is probable as evidenced by the SD and LSD results in AP sway. While there was no effect of intention found for the SD measure, there was one found for LSD (which may exhibit greater sensitivity than SD when analyzing nonstationary data; Riley et al., 1999). In other words, although participants with the intention to judge may have had more variable postural sway, it is likely that gross variability measures (i.e., SD) could not distinguish between experimental manipulations. Furthermore, the effect of intention did not interact with any other factor, indicating that participants, regardless of exploratory movement condition and weight condition, swayed more variably when they had the intention to judge. This pattern was not the same for the eyes-open period, during which the effect of intention interacted with the exploratory movement condition and weight condition for several measures.

Differences in postural sway between intention conditions were mainly found in the unconstrained exploratory movement condition during the eyes-open period. Participants with the intention to judge generally displayed postural sway that was more variable (i.e., higher SD and LSD) and complex (i.e., higher SampEn values) than the no-
intention-to-judge condition. This outcome was most likely a result of the functional demands placed on participants in the constrained exploratory movement condition. During the constrained condition, the operational demand of maintaining contact with the head restraint bar had a larger influence over postural control than any other supra-postural task (evidence for this can be found in the large effect sizes of the exploratory movement condition). This is most likely due to the current study’s experimental design and is not an explicit assumption for how a particular supra-postural task may influence postural control. In other words, participants were instructed to maintain contact with the head-restraint bar and if contact was lost the trial would be restarted. Thus, this task placed critical performance demands on the organization of postural sway.

Participants in the constrained exploratory movement condition performed significantly worse in judging their action capabilities than the unconstrained participants. The COP results during the eyes-open period substantiate the claim that exploratory movements (i.e., postural sway) serve a purpose of generating information about a person’s relation to the environment (Mark et al., 1990; Oudejans et al., 1996; Stoffregen, Yang, & Bardy, 2005; Riley et al., 2002). The combined results of this thesis seem to indicate that that the constrained condition sufficiently altered participants’ ability to detect information specifying their relation to the environment. Furthermore, the increase in complexity of postural sway by participants with the intention to judge may have been adopted to reveal information about the stand-on-ability affordance. The visual system has previously been demonstrated to affect postural functioning (e.g., Stoffregen, Pagulayan, Bardy, & Hettinger, 2000), and the visual system is argued to be one of the most powerful sources of information specifying movement relative to the
environment (Lee, 1980; Warren, 1976). The influence of vision may help explain the interaction between the exploratory movement, weight condition, and intention factors.

During the eyes-open period, in the unconstrained exploratory movement condition, it was commonly found that participants with the intention to judge had noticeably fewer differences among weight conditions than participants with no intention to judge. One explanation can be found in the idea of postural stabilization facilitating affordance perception. Two previous studies have noted analogous results of a supra-postural task stabilizing visual performance. Stoffregen, Yang, and Bardy (2005) found that head and torso movement in the AP direction of postural sway was dependent on whether participants were making affordance judgments or not. When participants were judging their maximum sitting height, their postural sway was significantly more variable (i.e., SD) than the postural sway displayed during the control trials. Furthermore, it was found that sway during judgment intervals was significantly less variable relative to sway during the time between judgment intervals. An additional study by Pagulayan, Hayes, and Stoffregen (2001) found a parallel pattern of results when they asked participants to perform a hard and an easy visual task. During the hard visual task, postural variability remained stable throughout the experiment; however, during the easy task, postural variability increased as the experiment progressed. These studies, along with the current finding of postural stabilization across weight conditions, suggest that there may be stable patterns of postural sway that are utilized depending on the constraints of supra-postural tasks (Stoffregen et al., 2005). The stable pattern of postural sway displayed in the current experiment may have played a role in detecting macroscopic, cross-modal (visual and haptic) information specifying the stand-on-ability of a slope (Turvey et al., 1990).
The results found in this study also corroborate past research on exploratory haptic exploration. For example, Riley, Wagman, Santana, Carello, and Turvey (2002) demonstrated, through the use of recurrence quantification analysis (Webber & Zbilut, 1994), that different perceptual intentions give rise to different exploratory dynamics. Specifically, they found that the intention to perceive the length of a rod gave rise to more complex but less variable haptic wielding. Participants in the current study displayed exploratory dynamics that were different depending on their intention; however, the exact pattern of results was not the same. Participants with the intention to judge commonly displayed more complex and variable postural sway. This difference between the current study and past work by Riley et al. (2002) can most likely be explained through the simple fact that they were not the same task. Despite their differences, the interesting result is that participants in both studies moved differently depending on the information they intended to detect. Both of these studies lend support to the co-specificity hypothesis (Turvey et al., 1990), which predicts that there are different exploratory dynamics displayed as a function of the intended property to be perceived.

Although there is some evidence for the co-specificity hypothesis, additional work is needed to determine the precise relation between exploratory movement and affordance perception. Specifically, studies that investigate the informational basis of affordance perception should focus on how the body moves (action) to generate information (perception). This task can be accomplished through a variety of methods but, extending the current project, additional research could investigate haptic exploration of the stand-on-ability of a slope. Past literature has shown perceptual equivalency
between visual and haptic exploration of a sloped surface (Regia-Corte & Wagman, 2008; Malek & Wagman, 2008; Fitpatrick et al., 1994). Based on these findings and the current thesis, it is expected that participants would display different exploratory dynamics depending on the intended property to be perceived (e.g., the affordance for upright stance, length versus width, or no intention to perceive).

Another study that controls for the sampling bias in athletic ability across the exploratory movement condition could strengthen the findings of the current thesis. This additional study should explicitly investigate the influence of sports expertise on affordance judgments. It is expected that a group of experts thought to have experience in discriminating postural stabilities afforded by differing landscapes and terrains (e.g., hiking or mountain climbing) would make more accurate perceptual reports concerning the stand-on-ability of a slope when compared to novices. Furthermore, the experts would be expected to display exploratory activity that may be optimal for the generation of information relative to the affordance. Evidence for this may be found in differences between the COP of participants (i.e., experts versus novices) and the accuracy of their affordance judgments. If experts move differently and provide more accurate affordance reports, there would be reason to believe that experts do not hold in memory their action capabilities, but instead, it is likely that experts have become sensitive to an optimal pattern of information (e.g., Stoffregen et al., 2005; Boschker, Bakker, & Micheals, 2002).

Summary and Conclusions

First, participants in the current thesis were generally sensitive to the affordance of upright stance on a sloped platform. This result supports past research on affordances for
upright stance, but it extends these findings in two ways. Participants who were judging an affordance had different postural sway than participants who were not judging an affordance and when the ability to detect information was constrained the accuracy of affordance judgments decreased. These results suggest that perception and action exist in a synergetic relationship where information detection is possible through action, and action is guided through information detection. In other words, there is a circular causality between action and perception (Turvey et al., 1990) where the two are integrally reliant on each other. Future research is needed to explore the interaction between exploratory movements and perception.
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