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POSTURE AFFECTS AFFORDANCE PERCEPTION OF REACHABILITY IN VIRTUAL REALITY

by

Hannah Lee Masoner

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for the Degree of Master of Arts

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ABSTRACT

Tasks such as standing and reaching require differing levels of postural stability. Postural equilibrium is necessary to perceive the location of objects (Lee, Pacheco, & Newell, 2018). This study compared affordance (Gibson, 1979) judgements of reachability between tasks that place different constraints on maintaining balance. Participants viewed a 3D virtual reality (VR) environment with a stimulus object placed at different egocentric distances. Using a within subjects design, participants were asked to make judgements on reachability while in a standard stance condition as well as two separate active balance conditions (yoga tree pose, and toe-to-heel pose). Feedback on accuracy was not provided, and participants were not allowed to attempt to reach. Response time, affordance judgments (reachable, not reachable), and head movements were recorded on each trial. Specifically, head movement time series were recorded by harnessing position data from Oculus Rift VR goggles. Consistent with recent research (Weast & Proffitt, 2018), the reachability boundary occurred around 120% of arm length, indicating overestimation of perceived action capability. Response times increased with distance, and were smallest for the most difficult tree pose, suggesting that in order to maintain a difficult pose, responding had to be sped up. Head movement amplitude and total amount of movements increased with increases in balance demands. Surprisingly, the coefficient of variation was comparable in the two poses that had increased balance requirements, and was more extreme in the ostensibly easier pose for the most opposing distances, indicating a pose by distance interaction. The insights gathered from this study will provide a fuller understanding of the perception of affordances in everyday tasks such as reaching.

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VR	Virtual Reality
HMD	Head-Mounted Display
ISI	Inter-stimulus Interval
CV	Coefficient of Variation
MFW	Multifractal Spectrum Width
ANOVA	Analysis of Variance

CHAPTER I - INTRODUCTION

In order to successfully navigate daily tasks it is necessary to have the ability to perceive objects in the environment. Unfortunately, it is often the case that perception becomes hindered by various circumstances. This study is concerned with situations of postural instability. There is a rather substantial percentage of people that face balance disruption. According to the National Institute on Deafness and Other Communication Disorders (NIDCD), 15 percent of American adults (33 million) suffered from balance disturbances in 2008 (“National Institute on Deafness”, 2017). Because this is such a prominent occurrence, it is the goal of this thesis to gain insight into how disruption in balance influences a person’s ability to perceive their surroundings and possibilities for future actions. This was explored through the assessment of perception in healthy individuals performing balance tasks.

Balance and Cognition

Postural stability requires certain resources, including cognitive processing and orientation in space. It is suggested that failure of either or both of these resources will result in instability (Horak, 2006). If, in fact, issues in cognitive processing (e.g., attention and learning) and orientation in space (e.g., perception, gravity, verticality) lead to unbalanced posture and instability, then it is likely that postural instability also has an effect on cognitive processing.

Cognitive resources are utilized for both cognitive functions and postural stability functions. In cases of dual-task cognition (i.e., performing a postural task and cognitive task simultaneously) reaction times become slower, demonstrating an increase in cognitive load (Teasdale & Simoneau, 2001). Participants who are asked to perform spatial matching tasks while standing on a balance beam (of varying widths) performed worse on spatial tasks as the challenge to balance increased (the beam got more narrow) (Barra, Bray, Sahni, Golding, & Gresty, 2006). It has been concluded that there is an ongoing relationship between balance and cognition.

The above findings are in line with the principle of ‘posture first’. This principle suggests that when faced with maintaining balance and performing a cognitive task, postural stability is naturally prioritized (Shumway-Cook, Woollacott, Kerm, & Baldwin, 1997). For example, when participants were administered a short term memory task, postural control improved as the memory task got more difficult. As postural instability declined and balance was more regularly maintained, available cognitive resources were expended and there were more errors in memory as the difficulty of the memory task increased (Riley, Baker, & Schmit, 2003). Another example of this occurred when participants were asked to focus on a task of lightly touching a piece of fabric while standing on an unstable surface. Performance of light touch diminished as the task got more difficult (Lee, Pacheco, & Newell, 2018). Together these show that cognitive tasks (e.g., spatial matching, memory recall, and focus oriented motor skills) are compromised as balance maintenance becomes more difficult, and as cognitive demands increase, postural control becomes more automatic and more efficient. Undoubtedly, there is a need for further research in exploring the aspects of this relationship, particularly as tasks change.

Balance and Perception

Since the relationship between balance and cognition has been established. The next area of discussion is the relationship between balance and perception specifically. In order to keep upright posture one must be able to detect and use visual, vestibular, and proprioceptive information (Redfern, Yardley, & Bronstein, 2001). It is necessary to be attuned to related environmental and internal sources of information appropriately.

The perceptual psychologist James Gibson (1979) argued that the detection of optical information about one's self (e.g., seeing one's hand, arm, or nose) occurs simultaneously with seeing changes and events in the environment. This information is obtained through several mechanisms of intake. Gibson says "information about the self is multiple and that all kinds are picked up concurrently" (p.108). He supplements this by also addressing the aspect of movement and how head movements, motor movements of limbs, and locomotion within the environment can benefit perception. In other words, by interacting with the environment and sampling what is available beyond a fixed point of view it is possible to gather more information. Gibson refers to this active interaction with the environment as "visual kinesthesis" (p.118). Multifractal research has shown that increased head movements led to more accurate judgements of ability to stand on an inclined surface (Hajnal, Clark, Doyon, & Kelty-Stephen, 2018). Complex head movements yield increased visual exploration and therefore increased environmental sampling, which in turn lead to more accurate judgment of action abilities. These findings are in line with Gibson's original theory that increased environmental information leads to more accurate environmental perception.

Micheal, Guilford, Fruchter, and Zimmerman (1957) originally argued, similarly to Gibson, that in order to perceive the environment, one must use their own location as a reference and make relative inferences. This is supported by findings that show a relationship between postural sway (i.e., shifting or swaying of a person's center of gravity that can result in bending and twisting at the shoulders and/or hips) and proximity of an object (Stroffregen, 1999; 2000). As the distance between an object of focus and the perceiver decreases so does postural sway; conversely, as the distance to target objects increases postural sway increases (Bonnet, Temprado, & Berton, 2017). Self-location awareness is necessary in order to accurately perceive the distance from oneself to an object, and is essential in enabling shifting and tilting in order to visually explore the environment and acquire necessary visual information (Micheal et al., 1957). The simple point remains: according to Gibson, by definition, perception is an active process of sampling ambient energy arrays. This activity creates complex optical and kinesthetic patterns rich in information that guide behavior and perception. If the ability to perceive environmental information is hindered, then necessarily the ability to interpret and make judgements from it will also be hindered, which could lead to excessive postural sway and balance disruption. Since a working association between interpretation of the environment and postural sway has been supported then it would be reasonable to suggest the possible directional relationship of impaired balance leading to disrupted environmental interpretation. This relationship is anticipated in the current study as the effects of balance may influence affordance judgments.

Affordances

Gibson (1979) describes his evolutionary theory as “direct” perception. He explains this as the ability to perceive things by what they can be used for, i.e., what they offer the perceiver in terms of “meaning” or “value”. To put this in perspective, daily life presents items or situations that may or may not be accessible for one to act upon. For instance, if one were to encounter a bicycle, they may perceive it as something that is ridable, a mode of transportation. However, if the bicycle does not have the unique properties to conform to the person's individual size, balance, and motor skills then it may not be perceived by them as a mode of transportation. A child who is just learning to ride a bicycle with training wheels would not be afforded transportation on a full size mountain bike. Affordances are specifically adherent to the individual.

Gibson states that "to perceive the world is to coperceive oneself" (p. 141). This is consistent with the line of thought mentioned earlier, that perception of the environment requires sense about our own location (Micheal et al., 1957). One cannot appropriately perceive their surroundings unless they have knowledge of themselves (e.g., their location, situation, or capabilities). In a study by Warren, and Whang (1987), participants who were asked to make visual judgements on the affordance of passage (e.g., passing through a doorframe with no shoulder rotation) were able to do so by using body-scale awareness; as the passageway's width changed from trial to trial, intrinsic knowledge of own physical properties (e.g. one's own shoulder width) allowed them to make proper judgements. The current study aims to consider how the process of affordance perception is altered in individuals having to maintain balance more or less actively.

Balance and Affordances

There are very few studies that investigated the influence of active balance on judgments of action capabilities. Walter, Wagman, Stergiou, Erkmen, and Stroffregen (2016) evaluated affordance judgements influenced by environmental motion. Experienced mariners were sensitive to dynamic changes when asked to judge walkable distances on a moving ship. They were able to interpret the different motions of the ship (depending on direction, either fore-aft or athwart) and adjust affordance judgements accordingly. This demonstrates evaluation of bodily motion brought on by external factors and the ability to make affordance judgements accordingly. The mariners had to estimate their own balance capabilities in order to adapt to the moving ship and walk in a single direction. However, this does not directly address the current research question of whether or not impaired balance affects affordance judgments. Therefore we hope to contribute to this area of research.

Perception and Affordances in Virtual Reality

Virtual reality has become a widely used tool in several areas of research, particularly perception. Due to the ease of manipulating task demands and stimuli within the environment and convenience for running experiments, researchers are utilizing it regularly. One of the main concerns when using virtual reality (VR) for perceptual research is that it does not fully match what one sees in the real world. It has been argued that egocentric distances are compressed in VR as compared to real-world perception (Bakker, Werkhoven, & Passenier, 2001; Messing & Durgin, 2005). In other words, the distance between a person's own location and some object in the environment appears smaller in VR. Contrary to this there is evidence to support that perception of a virtual space, identical to the real space which the participant occupies, show no condensing properties (Interrante, Ries, & Anderson, 2006).

VR has become a useful tool in measuring affordance judgments. Affordance research using virtual reality has had different foci as well as different outcomes. Guess, Stefanucci, Creem-Regehr, and Thompson (2010) explored accuracy of affordance judgements in the real-world versus a virtual world. They modeled the virtual environment after the real-world environment and observed the affordance of passage, similar to the previously discussed real-world study (Warren et al., 1987). Judgments of passage between two poles were compared at matching distances in each environmental setting. It was found that accuracy in participants’ responses was not significantly different between the real-world and the VR. On the other hand, Lin, Rieser, and Bodenheimer (2015) did not find congruent results between real-world and virtual settings when judgements were based on visual assessment alone; similarities were found only when additional proprioceptive information was present, such as the presence of an avatar which mimicked real-world movement within the virtual environment. In a virtual environment study looking at affordances for stepping over or under a pole and stepping off of a ledge, they found similar results in each setting only when an avatar was present or when the action was performed. These findings suggest a need for more affordance judgment research using VR.

Affordance Judgements of Reachability

Reachability affordances have been explored in both real-world (Carello et al., 1989) and virtual environments and have shown similar tendencies. In real-word judgments of reachability, overestimation of reaching capabilities typically occurs, even when action is present (Weast & Proffit, 2018). This also occurs in VR. Participants who are asked to judge whether a virtual object is within reach tend to overestimate their actual reaching abilities (Doyon, 2018). It is likely that results of reachability will persist and overestimation will take place in the current study. However, it is possible that the reverse take place in this study because of the added factor of balance. Participants may underestimate their reachability threshold in fear of losing balance and falling.

Nevertheless, this study aims to explore affordance judgments of reachability, using a virtual stimulus, while participants are required to actively maintain balance.

Based on the gathered literature and the intended methods outlined below, there are general hypotheses for the dependent variables of response time, affordance judgments, and head movement. Mainly, response times will become longer as the balance task becomes more difficult. This is expected due to the increase in the postural task demands and the need for further cognitive resources. Second, affordance judgments are anticipated to be less accurate as the postural task increases in difficulty because participant's main focus will be maintaining balance ("Posture First Principle"). Due to the instability caused by the postural task, their environmental perception will not be accurate. Lastly, it is expected that head movements will increase with more difficult balance tasks in order to meet the demands of maintaining stable posture.

CHAPTER II - METHOD

Participants

Students were recruited through the Sona participant pool at the University of Southern Mississippi. Data was collected from a total of 38 participants. Five participants were excluded due to misinterpretation of experimental instructions (N = 33). This is a sufficient sample size based on an approximate power analysis performed using the G*Power software package (Version 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007) in order to obtain a medium to large effect size, and is consistent with what has been obtained in similar research (Doyon, 2018). Participants included 29 women and 4 men, ranging from ages 18 to 26 (*M* = 18.97, *SD* = 1.69). Individuals were required to be 18 years of age or older and have normal or corrected-to-normal vision as well as no existing physical injuries (e.g. broken bones, sprained joints).

Materials and Apparatus

This study employed a virtual reality environment administered by a consumer version Oculus Rift head mounted display (HMD). Participants recorded their responses using two wireless handheld controllers, a button on the right controller was used to indicate a “yes” response and a button on the left controller was used to indicate a “no” response. The Unity game engine software (Version 2017.1.1f1) was used to program, and deliver the environment along with the C# programming language to script events and data recordings. Two table mounted motion sensors tracked participant’s movement as well as sensors contained in the HMD. The data drawn from the HMD was the data used to record head movement and assess postural instability.

The virtual environment consisted of a room with textured walls and natural lighting. The visual stimulus was a sphere (approximately the size of a tennis ball) that was suspended on a wire at the specific shoulder height of each participant (see Figure 1). This allowed for comfortable judgments of reachability. Reachability was defined as the ability to grasp the object with both the thumb and forefinger without leaning or bending forward at the hip or ankle.

Experimental Design

This study employed a 3(stance: normal, heel-toe, tree pose) x 5 (π-ratio) repeated-measures design. The stimulus was placed at separate distances in front of participants. These distances were determined by dimensionless π-ratios (Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989) ranging from 0.9 to 1.3. It was originally proposed that the distances be set at a range of 0.8 to 1.2. After analyzing pilot data it was determined that a shift in distances was necessary to achieve greater variability in responses due to overestimation observed in recent research.

The equation for these ratios is as follows:

$$\pi = \frac{d}{a}$$

The equation takes into account both environmental and participant specific measurements. Here it is the case that *d* equals the physical distance to the target or visual stimulus and *a* equals the specific length of the individual's arm. Thus, a ratio of $\pi = 1.00$ represents the individual's maximum reaching distance. Therefore, ratios of $\pi \leq 1.00$ will be within the participant's reach and ratios of $\pi > 1.00$ will be out of reach. Participants were randomly exposed to all five distances (π-ratios of .9, 1.0, 1.1, 1.2, and

1.3) three times in each stance for a total of 45 trials. The repetitions were grouped into three blocks for each stance to minimize back-to-back trials being presented with the same distances.

Balance Conditions

Over the course of the study participants were required to maintain three separate balance positions to the best of their ability. The first was a normal stance (see Figure 2) where both feet were comfortably placed on the floor, the second was a toe-to-heel (tandem) stance (see Figure 3) where one foot was placed directly in front of the other so that the toes of one met the heel of the other. Lastly, there was a tree pose (commonly used in yoga practice, see Figure 4; Yu et al., 2012) where the sole of one foot was brought to rest on the alternate calf.

Procedure

After providing informed consent, physical measurements (e.g. shoulder height, eye height, arm length) were taken for each participant and entered into the VR software. Verbal instructions were given on how to operate the VR equipment as well as what to expect within the virtual environment. Demonstrations were given on how to perform the appropriate standing positions. After the participant had been fitted with the HMD and had each of the wireless controllers in hand they began a series of practice trials. There were 15 total practice trials. At each increment of five trials verbal instructions were given instructing a transition into the next balance condition. This allowed participants to become acquainted with the virtual environment as well as all three different standing conditions. At all points of verbal instruction throughout the experiment, participants were allowed the option to rest if needed.

Once the practice trials were complete, participants were assigned a beginning stance. This differed depending on the counterbalance order into which they were randomly placed. The first group experienced the following order of stances: Normal, Tandem, Tree; the second group: Tandem, Tree, Normal; whereas the third group: Tree, Normal, Tandem. Before beginning the experimental trials participants were given verbal instructions on which stance to maintain first. After each sequence of 15 trials participants were allowed the opportunity to rest as additional verbal instructions were provided indicating which stance they would transition to next. Once they were comfortable in that stance they pushed a button to proceed. After concluding all 45 experimental trials, the experiment was complete. Participants were then asked to answer a brief demographic questionnaire and were given the opportunity to ask any questions. They were then granted credit for participation and excused from the experimental space.

Response times were recorded in milliseconds for each trial. Response time recording began with a button press marking the start of the trial and continued until the participant again pressed a button giving a response. There was a 500ms inter-stimulus interval (ISI) between trials. Physical head and body movements were not restricted in any way. Participants were asked to not perform any type of reaching or leaning while making judgements. In the event that the participant had to step out of a pose and regain balance during a trial, the researcher recorded this by the press of a button. These recordings were documented in an excel file accompanied by a time stamp.

CHAPTER III - RESULTS

Data was screened for missing values and anomalies. A total of 38 individuals were tested. Five participants were excluded from the data because they were unable to follow experimental instructions (n = 33). Two individual trials of movement data were adjusted due to technical issues, and the mean, standard deviation, and sum were recalculated.

Our general predictions considered two main sources of influence on perceptual judgments: task demands and organismic factors. The three poses constituted the main task demand. The placement of the stimuli at different distances was a spatial variable that was combined with arm length to form the pi-ratio, an intrinsic measure of affordance capability. In this sense the pi-ratio was a combination of external spatial task demands and organismic constraints. Each pose was grouped into blocks of trials, defining a temporal task demand. Given the differential energetic requirements of maintaining some postures for an extended period of time, we expected that performance would change across blocks of trials. The second class of factors that were predicted to influence perceptual performance were organismic factors that described postural sway during trials: mean head movement, variability of head movement expressed as the coefficient of variation (CV), and the multifractality of movement (MFW), indicating the complexity of postural sway. We assumed that these variables would play a significant role in shaping perceptual judgments based on the differential sophistication with which they described body movement. Specifically, we assumed that the Mean would be the least useful predictor, given the nonstationary nature of postural sway, CV being significantly better, and MFW faring as the best predictor. This reasoning drove our model building, so we expected that spatiotemporal task demands (pi, Block) would differentially interact with organismic factors (Mean, CV and MFW) in the context of the three poses.

3 Pose (Normal, Tandem, Tree) × 5 Distance (π-ratios of 0.9, 1.0, 1.1, 1.2, and 1.3) repeated measures analyses of variance (ANOVAs) were performed for several dependent variables. For response time, there was a statistically significant main effect of both Pose, $F(2,64) = 3.23$, $p = .046$, and Distance, $F(2.44, 78.13) = 11.29$, $p <.01$ (Greenhouse-Geisser correction). Overall, participants took less amount of time to respond while maintaining the tree pose as compared to the tandem pose ($p<.014$, Bonferroni correction). See Figure 5 for details. Response times increased as distance increased. Accuracy of response was calculated by using the affordance judgment (e.g. yes = 1, no = 0) as a function of stimulus distance. There was a significant main effect of distance, $F(2.5, 80.21) = 87.32$, $p <.01$ (Greenhouse-Geisser correction). See Figure 6 for details. Participants overestimated their reaching abilities by approximately 22% of their actual arm length based on a logistic curve fit. This is in line with previous research (Doyon, 2018; Weast & Proffitt, 2018).

The mean of head movements (meters) were considered in order to observe magnitude of postural sway. There was a significant main effect for distance, $F(3.17, 101.5) = 2.83$, $p = .04$. In all three conditions the largest head movements occurred for the furthest distance. There was also a significant main effect of pose, $F(1.36, 43.58) = 59.76$, $p <.01$. The most head movement occurred in the tree pose, followed by the tandem pose, and the normal control pose (see Figure 7 for details). The coefficient of variation (CV) for head movements was also calculated and analyzed in order to observe variability.

Once again, we found a significant main effect for distance, F(3.25, 107.33) = 4.83, p = .003 as well as a significant interaction of distance and pose, F(8,264) = 2.19, p = .03. The coefficient of variation was most extreme for the shortest and longest distances in the normal stance.

We did not perform an ANOVA on MFW due to the limitations posed by the postural sway measurements. In order to compute a stable MFW value the multifractal algorithm requires that a minimum of 1500 data points be considered. Since the sampling rate was 30Hz, and typical responses did not last longer than 1-2 seconds, we did not have enough head position recordings to compute the MFW for each trial. In subsequent modeling we used the MFW computed over each block of trials which had a sufficient number of recordings.

Probability Data. Since affordance judgments are measured with a dichotomous variable (yes/no), we used a mixed-effects hierarchical logistic regression (Bates, Maechler, Bolker, & Walker, 2014) as it is a more appropriate analysis than ANOVA. Here is the model:

Response ~ Trial + Condition x π x Block x Mean + Condition x π x Block x CV + Condition x π x Block x MFW + (Trial|Participant),

Trial and participant were set as random effects, all other variables were fixed effects. Condition included the three separate standing conditions coded as: 1= normal (control), 2= tandem, 3= tree pose. The model was set up in order to test how affordance responses were affected by postural demands (Condition) along spatial aspects of the task (distance ratio π), and temporal aspects of the task (blocks of trials). In addition, the model tested the contributions of various measures of head movement: magnitude

(Mean), variability (CV), and complexity (multifractal spectrum width - MFW). The prediction was that more complex tasks will demand more postural adjustments, and that more complex movements will be governed by more complex head movements resulting in commensurate postural adjustments. Table 1 shows the output of the statistical analysis.

Table 1 *Best fitting mixed-effects logistic regression model of Affordance Judgments. Significant effects are in bold font.*

Predictor	*β*	*SE*	*p*	
Intercept	55.36	30.64	0.071	
Trial	-0.01	0.03	0.586	
Block	-9.59	12.83	0.455	
π	-44.56	25.21	0.077	
Tandem Pose (Condition 2)	-56.54	42.27	0.181	
Tree Pose (Condition 3)	**-104.52**	**40.16**	**0.009**	*****
Mean	-36849.5	25.21	0.354	
CV (Coefficient of variation)	23.25	32.5	0.475	
MFW	-18.19	20.61	0.378	
π × Mean	35897.34	31785.62	0.259	
π × Block	6.87	10.67	0.519	
π × CV	-14.99	26.12	0.566	
π × MFW	10.95	17.02	0.520	
Block × MFW	6.65	11.2	0.552	

Table 1 (cont.)

Block × CV	-6.54	14.4	0.65
Block × Mean	20017.43	18681.71	0.284
π × Mean × Block	-18103.4	14757.14	0.22
π × CV × Block	3.95	11.78	0.738
π × MFW × Block	-3.09	9.29	0.74
Interactions of Tandem Pose (Condition 2) with other terms			
Tandem Pose (Condition 2) × Mean	45657.98	44207.3	0.302
Tandem Pose (Condition 2) × π	39.54	34.98	0.26
Tandem Pose (Condition 2) × Block	9.93	19.81	0.616
Tandem Pose (Condition 2) × CV	-51.16	37.56	0.274
Tandem Pose (Condition 2) × MFW	37.92	35.79	0.29
Tandem Pose (Condition 2) × π × Mean	-38507.9	35811.98	0.282
Tandem Pose (Condition 2) × π × Block	-4.88	16028	0.764
Tandem Pose (Condition 2) × π × CV	36.45	30.8	0.237
Tandem Pose (Condition 2) × π × MFW	-23.29	29.41	0.429
Tandem Pose (Condition 2) × Block × Mean	-27784.9	20905.92	0.184
Tandem Pose (Condition 2) × Block × CV	25.63	19.9	0.198
Tandem Pose (Condition 2) × Block × MFW	1.29	20.11	0.949
Tandem Pose (Condition 2) × π × Mean × Block	22067.28	16755.23	0.188
Tandem Pose (Condition 2) × π × CV × Block	-18.53	16.37	0.258
Tandem Pose (Condition 2) × π × MFW × Block	-4.64	16.38	0.777

Table 1 (cont.)

Interactions of Tree Pose (Condition 3) with other terms				
Tree Pose (Condition 3) × Mean	21665.91	40327.91	0.591	
Tree Pose (Condition 3) × π	**83.64**	**33.14**	**0.012**	*****
Tree Pose (Condition 3) × Block	**45.73**	**17.26**	**0.008**	******
Tree Pose (Condition 3) × CV	-6.21	46.81	0.895	
Tree Pose (Condition 3) × MFW	**109.44**	**32.98**	**0.001**	******
Tree Pose (Condition 3) × π × Mean	-22032.8	32314	0.496	
Tree Pose (Condition 3) × π × Block	**-35.91**	**14.37**	**0.013**	******
Tree Pose (Condition 3) × π × CV	2.29	38.59	0.953	
Tree Pose (Condition 3) × π × MFW	**-83.98**	**26.89**	**0.002**	******
Tree Pose (Condition 3) × Block × Mean	-17446.5	18968.46	0.358	
Tree Pose (Condition 3) × Block × CV	-8.36	20.35	0.681	
Tree Pose (Condition 3) × Block × MFW	**-41.59**	**15.22**	**0.006**	******
Tree Pose (Condition 3) × π × Mean × Block	22067.28	16755.23	0.188	
Tree Pose (Condition 3) × π × CV × Block	7.55	16.9	0.655	
Tree Pose (Condition 3) × π × MFW × Block	**30.96**	**12.6**	**0.014**	*****

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

There was a significant negative main effect of Tree Pose (β =-104.52, *SE* = 40.16, *p* = 0.0093). Overall, there was no effect of Mean or Coefficient of Variation (CV) on affordance judgments. There were three significant positive two-way interactions for Tree Pose. Tree Pose × π (β =83.64, *SE* = 33.14, *p* = 0.012) was significant as well as

Tree Pose × Block (*β* =45.73, *SE* = 17.26, *p* = 0.008) and Tree Pose × MFW (*β* =109.44, *SE* = 32.98, *p* = 0.001). There were no significant two-way interactions for Tandem Pose.

There were three negative three-way interactions for Tree Pose. Tree Pose × π × Block (*β* = -35.91, *SE* = 14.37, *p* = 0.013), Tree Pose × π × MFW (*β* = -83.98, *SE* = 26.89, *p* = 0.002), and Tree Pose × Block × MFW (*β* = -41.59, *SE* = 15.22, *p* = 0.006). There were no three-way interactions for Tandem Pose. There was one four-way positive interaction between Tree Pose, π, Block, and MFW (*β* = 30.96, *SE* = 12.6, *p* = 0.014). The four-way interaction is presented in Figure 8. In order to visualize the pattern of results, a schematic diagram of all significant main effects and interactions was presented in Figure 9.

A linear mixed-effects model was created to predict Response Time. The model is as follows:

Response Time ~ Condition × π × Block × Mean + Condition × π × Block × CV + Condition × π × Block × MFW

Table 2 shows the output of the statistical analysis.

Table 2 *Best fitting mixed-effects linear regression model of Response Time. Significant effects are in bold font.*

Predictor	*β*	*SE*	*p*
Intercept	-4.78	3.80	0.208
Block	2.18	1.72	0.207
π	5.63	3.38	0.096
Tandem Pose (Condition 2)	-2.61	6.49	0.687

Table 2 (cont.)

Tree Pose (Condition 3)	4.29	5.83	0.461	
Mean	-232.61	4747.40	0.961	
CV (Coefficient of variation)	-3.60	4.85	0.457	
MFW	4.21	2.55	0.099	
π × Mean	1373.05	4254.28	0.747	
π × Block	-2.35	1.54	0.127	
π × CV	3.56	4.19	0.396	
π × MFW	-3.79	2.29	0.097	
Block × MFW	-2.02	1.41	0.152	
Block × CV	0.88	2.31	0.704	
Block × Mean	173.83	1726.65	0.920	
π × Mean × Block	-467.49	1558.25	0.764	
π × CV × Block	-0.31	2.02	0.880	
π × MFW × Block	1.88	1.27	0.137	
Interactions of Tandem Pose (Condition 2) with other terms				
Tandem Pose (Condition 2) × Mean	10217.8	6547.59	0.119	
Tandem Pose (Condition 2) × π	1.42	5.84	0.808	
Tandem Pose (Condition 2) × Block	0.15	2.86	0.958	
Tandem Pose (Condition 2) × CV	**20.49**	**6.85**	**0.003**	*******
Tandem Pose (Condition 2) × MFW	-9.33	4.88	0.056	
Tandem Pose (Condition 2) × π × Mean	-9334.5	5874.94	0.112	

Table 2 (cont.)

Tandem Pose (Condition 2) × π × Block	0.2	2.56	0.938	
Tandem Pose (Condition 2) × π × CV	**-17.20**	**6.14**	**0.005**	*******
Tandem Pose (Condition 2) × π × MFW	**8.62**	**4.37**	**0.048**	*****
Tandem Pose (Condition 2) × Block × Mean	-2599.1	2461.24	0.291	
Tandem Pose (Condition 2) × Block × CV	**-8.03**	**3.33**	**0.016**	******
Tandem Pose (Condition 2) × Block × MFW	4.4	2.36	0.063	
Tandem Pose (Condition 2) × π × Mean × Block	2634.43	2220.44	0.236	
Tandem Pose (Condition 2) × π × CV × Block	**6.80**	**2.97**	**0.022**	*****
Tandem Pose (Condition 2) × π × MFW × Block	-4.11	2.12	0.053	
Interactions of Tree Pose (Condition 3) with other terms				
Tree Pose (Condition 3) × Mean	5756.93	5013.14	0.251	
Tree Pose (Condition 3) × π	-4.61	5.24	0.379	
Tree Pose (Condition 3) × Block	-0.8	2.57	0.757	
Tree Pose (Condition 3) × CV	13.01	7.65	0.089	
Tree Pose (Condition 3) × MFW	**-11.36**	**4.12**	**0.006**	*******
Tree Pose (Condition 3) × π × Mean	-6647.3	4512.34	0.141	
Tree Pose (Condition 3) × π × Block	0.89	2.31	0.699	
Tree Pose (Condition 3) × π × CV	-9.43	6.83	0.168	
Tree Pose (Condition 3) × π × MFW	**9.78**	**3.69**	**0.008**	*******
Tree Pose (Condition 3) × Block × Mean	-2632.5	1895.33	0.165	
Tree Pose (Condition 3) × Block × CV	-6.29	3.46	0.069	

Tree Pose (Condition 3) × Block × MFW	**4.55**	**2.07**	**0.028**	**
Tree Pose (Condition 3) × π × Mean × Block	2940.30	1709.99	0.085	
Tree Pose (Condition 3) × π × CV × Block	5.04	3.06	0.101	
Tree Pose (Condition 3) × π × MFW × Block	**-4.02**	**1.86**	**0.031**	*

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

There were no significant main effects. Importantly, there was no effect of Mean. CV interacted with Tandem pose but not Tree Pose. Specifically, Tandem Pose had a significant positive two-way interaction with CV (β = 20.49, *SE* = 6.85, *p* = 0.003), indicating that response times increased as the variability of head movement increased while in the Tandem pose compared to the control stance. There were two significant negative three-way interactions for Tandem pose. First, Tandem Pose × π × CV (β = -17.20, *SE* = 6.14, *p* = 0.005) and second, Tandem Pose × Block × CV (β = -8.03, *SE* = 3.33, *p* = 0.016). Additionally, there was a significant positive three-way interaction, Tandem Pose × π × MFW (β =8.62, *SE* = 4.37, *p* = 0.049). There was one significant positive four-way interaction containing Tandem pose × π × Block × CV (β =6.80, *SE* = 2.97, *p* = 0.022).

There was a significant negative two-way interaction of Tree Pose and MFW (β = -11.36, *SE* = 4.12, *p* = 0.006). There were also two significant positive three-way interactions including Tree Pose. These include the Tree pose × π × MFW interaction (β = 9.78, *SE* = 3.69, *p* = 0.008) as well as Tree Pose × Block × MFW (β = 4.55, *SE* = 2.07, *p* = 0.028). Lastly, there was a significant negative four-way interaction of Tree Pose × π × Block × MFW (β = -4.02, *SE* = 1.86, *p* = 0.03). In order to better understand the pattern of results, a schematic diagram of all significant main effects and interactions was presented in Figure 9.

CHAPTER IV – DISCUSSION

The purpose of this study was to investigate the effects of disrupted balance on affordance judgments of reachability. There is support in the literature that shows balance and cognition are intertwined (Teasdale & Simoneau, 2001; Horak, 2006). There is a relationship between one's ability to maintain balance and to simultaneously perform cognitive tasks. It is often true that maintaining postural equilibrium is prioritized over a simultaneous cognitive task. This is explained by the above mentioned "posture first" principle, which states that cognitive tasks suffer when physical balance must be actively maintained (Shumway-Cook, Woollacott, Kerm, & Baldwin, 1997; Lee, Pacheco, & Newell, 2018). Our aim was to demonstrate that postural adjustments can influence our perception. Specifically, more complex movement patterns are better predictors of perceptual responses than less complex movements. This should come as no surprise given the nonstationary nature of postural sway. This could also mean that complex movements carry important information that is picked up by our perceptual systems and used to determine if certain actions are possible or not (e.g. target is within reach or not).

As a reminder, this study included four separate hypotheses for the four variables that were used as dependent measures in ANOVA designs, listed in Table 3.

Table 3 *Overview of pose effect predictions for reachability, response time, and movement using ANOVA designs.*

	Normal (Control)	*Tandem*	*Tree*
Reachability Judgments	Most Accurate	Less Accurate	Least Accurate
Response Time	Least Time	More Time	Most Time
Head Movement (Mean)	Least Movement	More Movement	Most Movement
Head Movement (CV)	Least Variability	More Variability	Most Variability

The ANOVA analyses showed that increased demands on posture during perceptual tasks result in more overall postural sway and faster responses to stimuli. As such, the second hypothesis about response times was not supported. It is possible that the more demanding tree pose was so uncomfortable that participants sped up their responses to minimize energy expenditure. Movement variability (CV) exhibited a more complex pattern of dependency on postural demands. The significant $\pi \times$ pose interaction showed that the two difficult poses (tandem and tree) produced the same level of variability across distances, and that variability steadily increased over distances only in the control pose. This latter finding is consistent with past research on quiet stance where more distant targets caused more variability in postural sway (Stoffregen et al., 1999). It is still unclear why more difficult poses used in the present experiment did not follow the same effect of distance. Future research is needed to disentangle the interaction between distance and postural demands.

The ANOVA on yes/no responses revealed that as the stimulus distance increased participants more often responded “no”. Congruent with recent research, there was an overestimation of reachability in all conditions (Weast & Proffitt, 2018). This was found at approximately 120% of a participant’s actual arm length, as extrapolated by the value corresponding to the 50th percentile of the psychometric curve (see Figure 6). The overestimation we found in the VR is comparable to past research conducted in real 3D settings. The exact reasons for the inaccuracy is still unknown, and more research is needed to find its root cause.

Response time increased in all three conditions as stimulus distance increased, so that participants took the longest to respond for the furthest distance. Surprisingly, participants generally responded the fastest while in the tree pose. As mentioned above, this is not in line with the initial hypothesis. It was expected that the most difficult pose would cause participants to spend the most time making their decisions but in fact the reverse was true. Although this is counter to initial expectations it does seem to coincide with the “posture first” principle. In order to stay balanced participants were forced to respond quickly. It should be noted that this may have been encouraged by the fact that participants were given the option to recompose stability between trials.

Movements of the largest magnitude occurred while participants maintained the tree pose. This agrees with the original prediction. In all three conditions it was found that as stimulus distance increased head movement also increased. This was also found in other research that showed increased object distance is paired with increased postural sway (Bonnet, Temprado, & Berton, 2017; Stroffregen et al.,, 1999; 2000).

In order to get a more in depth picture of the data, regression models were constructed to predict responses. The models combine both spatial (π) and temporal (block) aspects in order to assess movement parameters.

Perceptual responses are a function of task demands and complexity of postural sway

Mixed effects hierarchical logistic regression modeling showed that affordance judgments were influenced by MFW when comparing the tree pose to the control condition but not by Mean or CV. Thus, the most difficult balance task was predicted by the most complex descriptor of movement.

The four way interaction of Tree Pose × π × Block × MFW is important to consider (see Figure 8). Participants who maintained the tree pose in block three and also showed high MFW, showed a dramatic shift in responses at approximately 110% of their actual arm length. In other words, for the closest two distances there was absolute certainty that the stimulus was within reach and for the furthest two distances there was absolute certainty that the object was out of reach. This suggests that the most accurate responses while maintaining a difficult pose occurred when there were less difficult poses held prior and when participants explored their environment through complex movements (i.e. high MFW). This finding is congruent with literature that states increases in movement complexity yield greater intake of environmental information and more accurate affordance judgments (Hajnal, Clark, Doyon, & Kelty-Stephen, 2018). Responses were not as accurate (i.e. showing overestimation) and not as sensitive (indicated by shallow slope of psychometric curve) when assessing tree pose in Blocks 1 and 2 for high MFW. The fact that affordance judgments changed over blocks means that performance was influenced by temporal factors. This may have been associated with fatigue, boredom, or both. However, the fact that performance generally increased in perceptual sensitivity over blocks of trials speaks against these effects. In fact, practice or experience with easier poses in earlier blocks may have benefited performance on the Block 3. Participants who maintained the tree pose in either Block 1 or Block 2 were more likely to be less accurate in judging the furthest distance stimulus ($\pi = 1.3$), whereas those who experienced the tree pose in Block 3 were more likely to be accurate when compared to control, but only when MFW was large. As mentioned before, this could be attributed to practice effects for either stimulus exposure or balance maintenance. This finding is interesting because response times for tree pose were overall shorter than the other pose conditions. This suggests that, when participants experienced the tree pose as last of all three poses, their responses were faster and more accurate compared to the control condition. This could suggest that perception of affordances is more accurate when judgments are made without taking too much time to dwell on the task at hand. One could argue that this is due to participant’s underestimation of abilities based on being in an unstable standing position, however in this circumstance it is still the case that an overestimation of reachability occurs for closer distances. In sum, participants who held the tree pose as the final portion of the experiment responded faster than those in the control condition and were more likely to be accurate, while still upholding the common overestimation of about 20 percent.

Response Times are affected by increased task demands and more complex movements.

In a linear mixed effects model of response time there was no effect of Mean, the simplest descriptor of postural sway. There were influences of CV and MFW on response times during the tandem pose when compared to the control pose. As variability in movement increased response times became longer for participants in the tandem pose, as indicated by the positive three way interactions containing CV and MFW, respectively. Increasing complexity of movement resulted in more deliberation of affordances (see Figure 10 for details). For the tree pose the pattern of results was such that only MFW modulated affordance judgments, but not CV. In general, this means that more complex postural demands go hand in hand with more complex movement parameters, and that these complex parameters (i.e. MFW) are more informative and predictive of perceptual judgments than less complex parameters. The highest order interaction had a negative effect on response time, which was consistent with the ANOVA findings of faster responses in the tree pose condition (see Figure 10 for details about the direction of interaction effects). In sum, as MFW increased and movements became more complex responses became faster. This again suggests that more movement and especially more complex movements lead to faster responding. It can be gathered from this that faster responses are most likely advocating informed and confident affordance judgments. This is not congruent with the original hypothesis because it was originally predicted that greater instability would result in longer latency of response decisions. However, it was suggested that increased variability may result in more information intake of the optic flow generated by head movements which will lead to more informed responses.

Conclusion

Overall, the tree pose was most influenced by movement parameters. This is not surprising because it is the less stable of the two active balance poses and requires these patterns of movements to maintain postural equilibrium. In order to get an accurate picture of this data it was necessary to use a complex descriptor of movement such as MFW. MFW allows for a clearer understanding of the processes of movement which occur during these complex tasks.

This research originated from the question “how do changes in balance influence affordance judgments?” This was based on the consideration that a very large portion of people face balance issues every day. It was the aim of this study to gain some knowledge on how the processes of judging affordances for these individuals might vary from those that do not face balance issues. One limitation to this is that all participants were healthy at the time of the study and were partaking in mock balance tasks rather than actually having some sort of balance issue. Nevertheless, it seems in this study, the adjustments which occur based on complex movements during such tasks actually aid in making affordance judgments. This is due to the increased movement setting the stage for more informed judgments. This is interesting because usually in dual-task situations, the harder the balance task becomes the more likely the cognitive task will suffer. This opens doors for further research involving such tasks that are affordance specific. Perhaps, the evolutionary nature of affordance perception, proposed by Gibson, leads to better affordance perception in difficult situations. Scientists may also have to rethink whether all cognitive tasks function the same way when performed during varying postural demands. Perception may not be susceptible to the same impediments as higher cognitive tasks in a dual-task situation, and may in fact benefit from increased demands brought onto the action system.

APPENDIX A - Figures

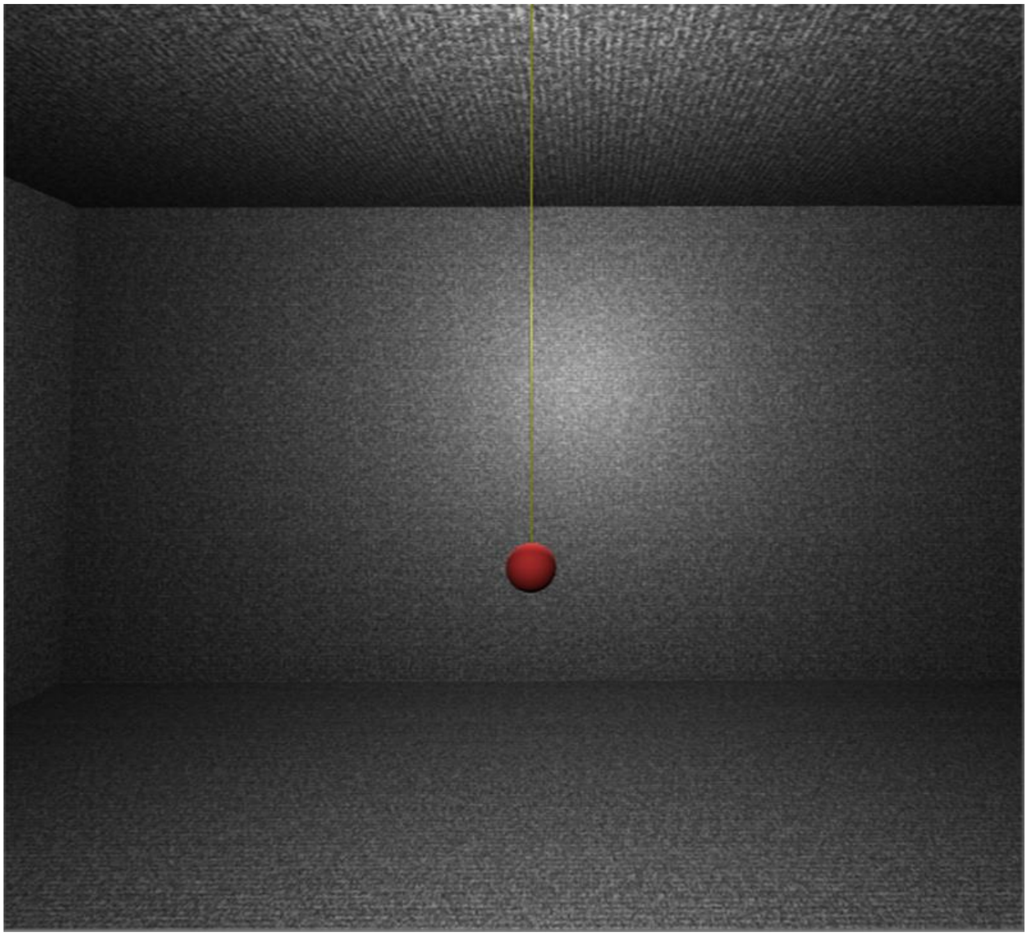

Figure A1.

Virtual reality environment: ball hanging from ceiling at shoulder height

Figure A2.

Normal (quiet) stance

Figure A3.

Heel-toe (tandem balance) stance

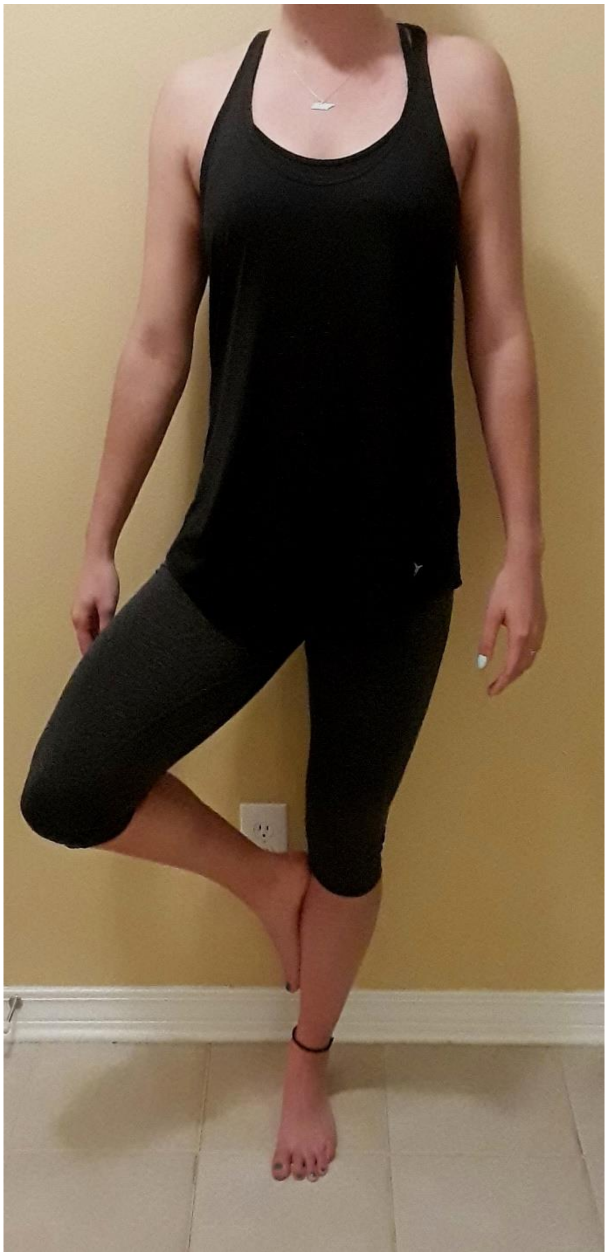

Figure A4.

Tree pose stance

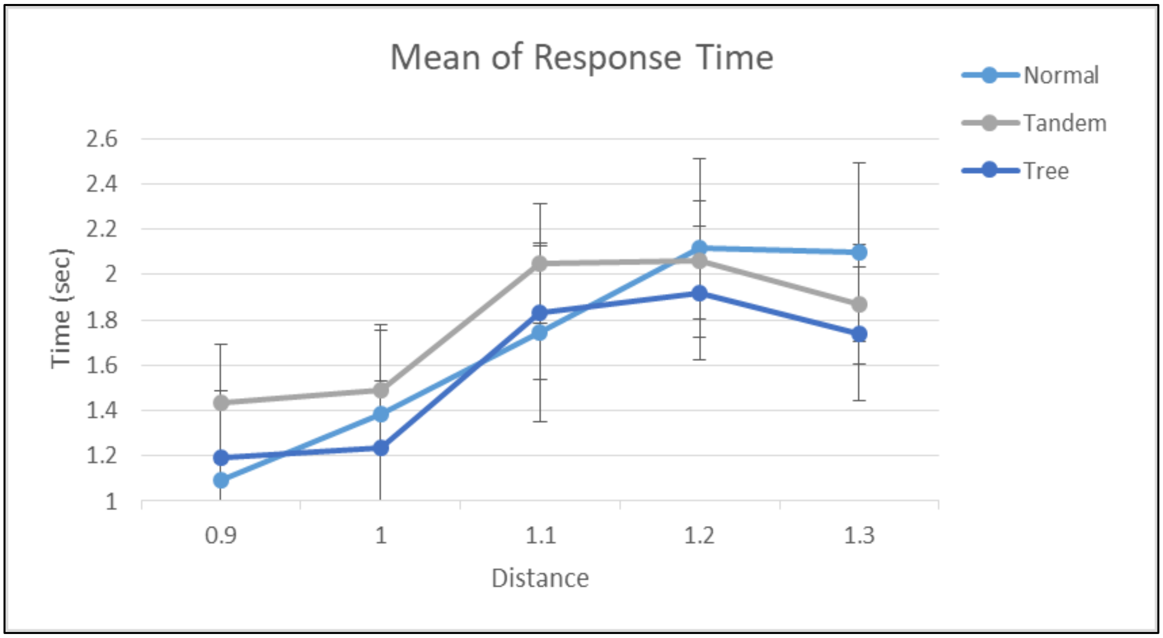

Figure A5.

Mean of Response Time across π (Distance) for each pose. Distance was expressed as ratio of arm length to actual distance of target object. Response times increase with distance and are smallest for the most difficult tree pose.

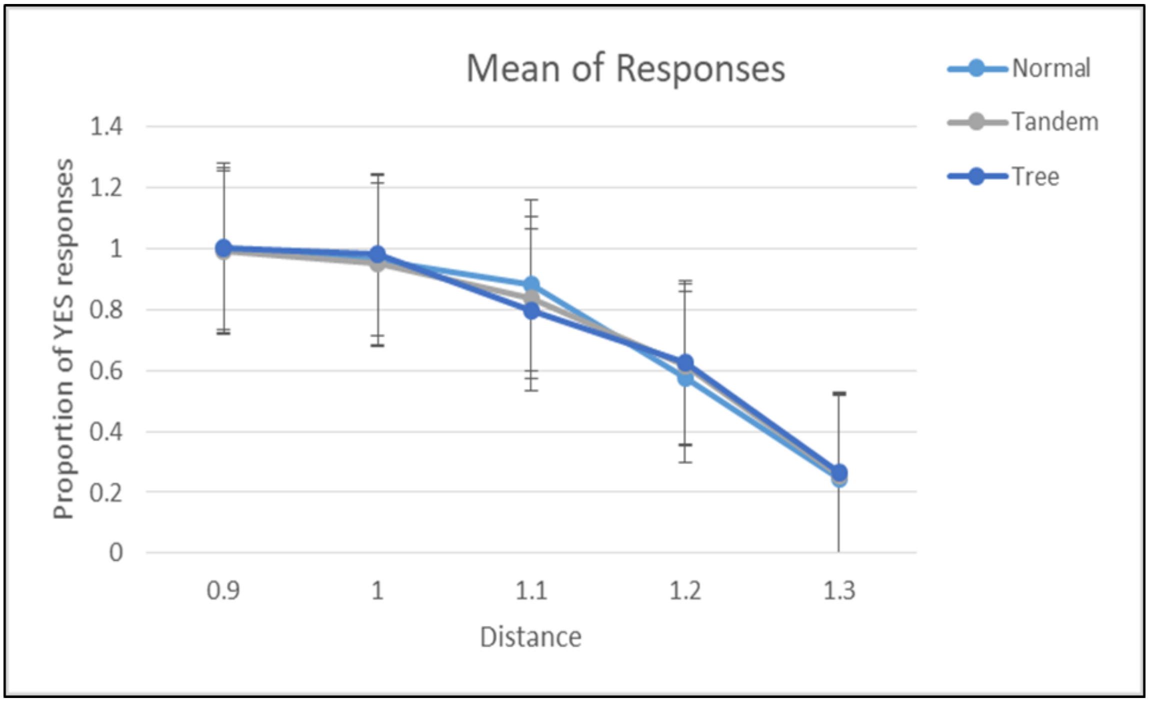

Figure A6.

Mean of Affordance Judgments (proportion of YES responses) across π (Distance) as a function of Pose. Distance was expressed as ratio of arm length to actual distance of target object. Answers were coded as 1= yes, 0= no. Overestimation of ~20% was observed corresponding to the 50% YES response level.

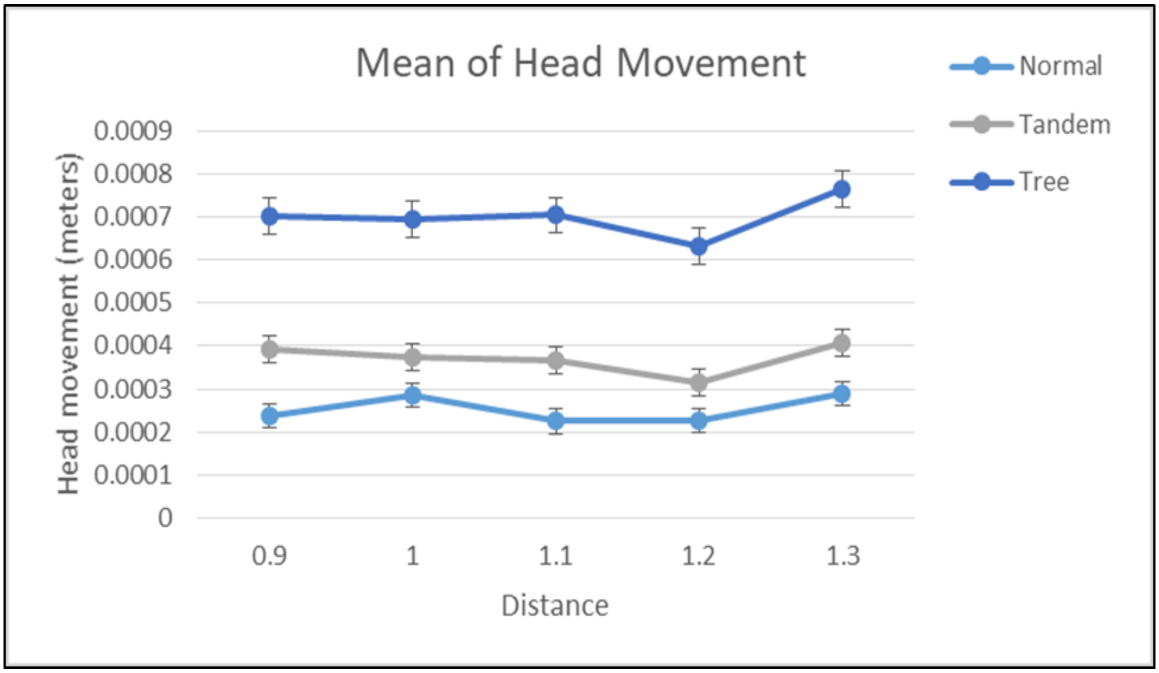

Figure A7.

Mean of head movements across π (Distance) for each pose. Head movement increased with pose difficulty.

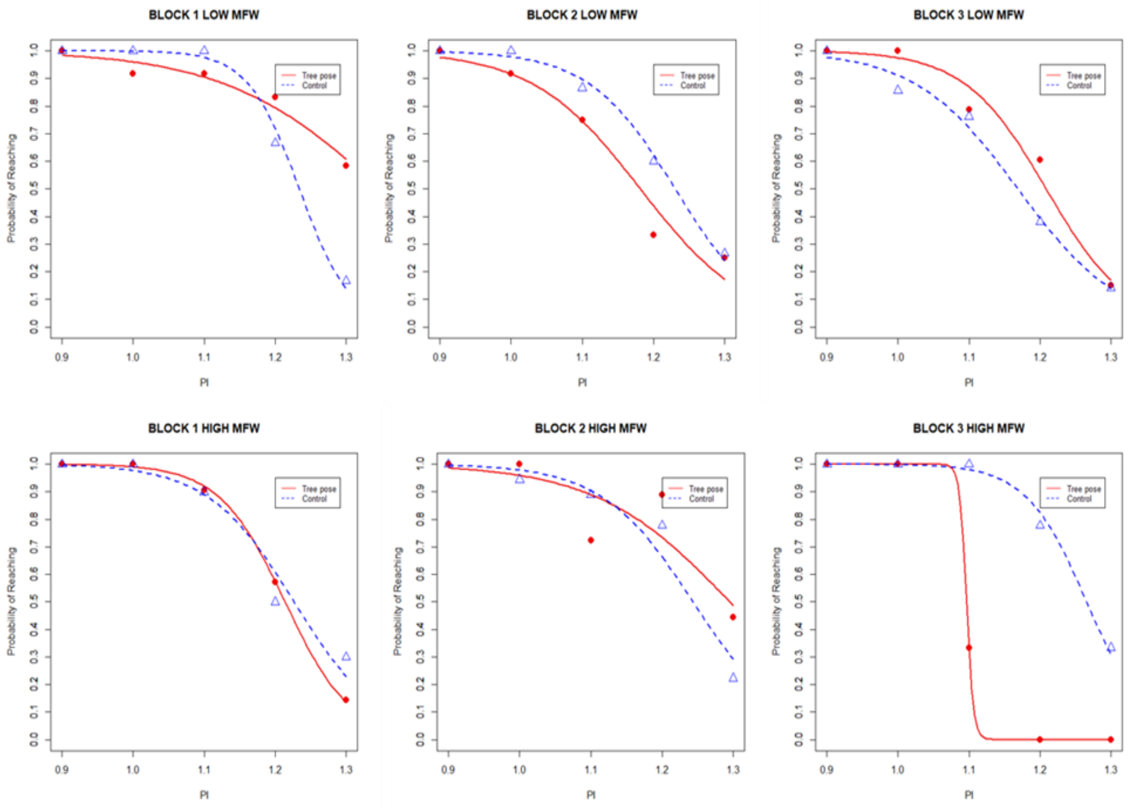

Figure A8.

The four-way C3 × Block × π × MFW interaction on perceptual responses in the hierarchical logistic regression. C3: represents the comparison between Tree pose (continuous lines) and Control pose (dashed lines). The points represent average probability of reaching (based on yes/no perceptual responses) at each value of π. For the sake of better visualization the continuous variable MFW was dichotomized by a median split (LOW and HIGH MFW).

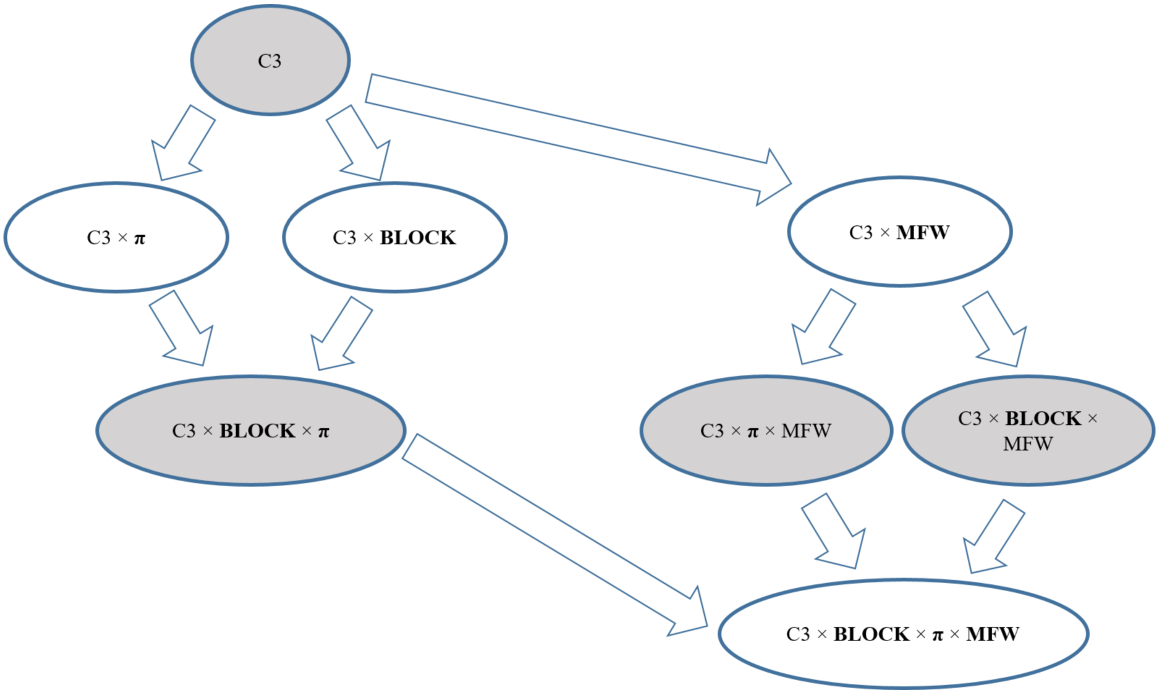

Figure A9.

Schematic diagram presenting significant effects of the logistic regression on perceptual responses. The shaded ovals are negative effects, the unfilled ovals are positive effects. C3: represents the comparison between Tree pose and Control pose. The arrows indicate how the variance explained is apportioned from lower- to higher-order interactions. Each new row represents the addition of a new dimension to the significant interactions. The boldface font indicates which new term was added at each, more complex level of interactions.

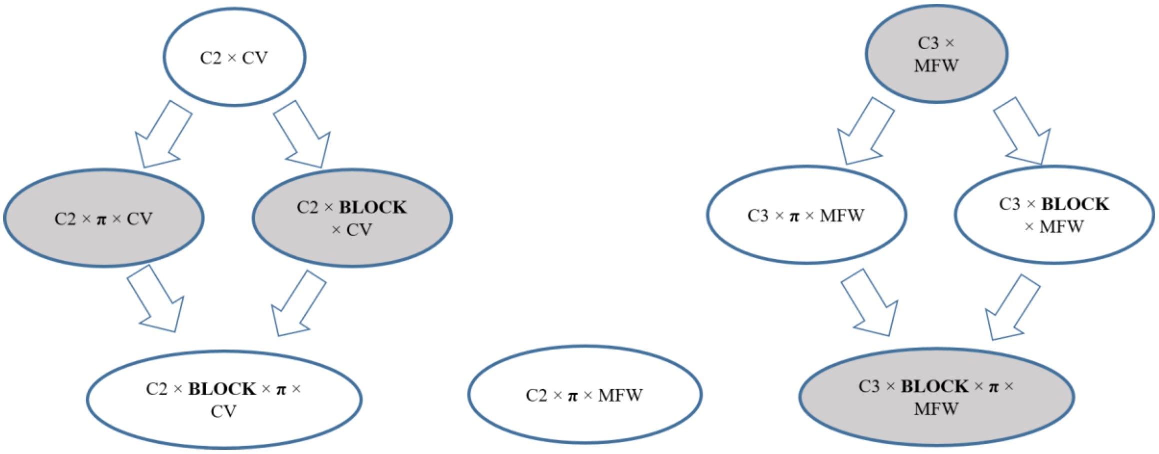

Figure A10.

Schematic diagram presenting significant effects of the mixed effects model on response time. The shaded ovals are negative effects, the unfilled ovals are positive effects. C2: represents the comparison between Tandem pose and Control pose. C3: represents the comparison between Tree pose and Control pose. The arrows indicate how the variance explained is apportioned from lower- to higher-order interactions. Each new row represents the addition of a new dimension to the significant interactions. The boldface font indicates which new term was added at each, more complex level of interactions.

APPENDIX B – IRB Approval Letter

THE UNIVERSITY OF
SOUTHERN MISSISSIPPI

INSTITUTIONAL REVIEW BOARD
118 College Drive #5147 | Hattiesburg, MS 39406-0001
Phone: 601.266.5997 | **Fax:** 601.266.4377 | www.usm.edu/research/institutional.review.board

NOTICE OF COMMITTEE ACTION

The project has been reviewed by The University of Southern Mississippi Institutional Review Board in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services (45 CFR Part 46), and university guidelines to ensure adherence to the following criteria:

- The risks to subjects are minimized.
- The risks to subjects are reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered regarding risks to subjects must be reported immediately, but not later than 10 days following the event. This should be reported to the IRB Office via the "Adverse Effect Report Form".
- If approved, the maximum period of approval is limited to twelve months.
  Projects that exceed this period must submit an application for renewal or continuation.

PROTOCOL NUMBER: 18071902
PROJECT TITLE: Through the Eyes of the Offset: Affordance Judgements Based on Balance Using Virtual Reality
PROJECT TYPE: Master's Thesis
RESEARCHER(S): Hannah Masoner
COLLEGE/DIVISION: College of Education and Human Sciences
SCHOOL: Psychology
FUNDING AGENCY/SPONSOR: N/A
IRB COMMITTEE ACTION: Expedited Review Approval
PERIOD OF APPROVAL: 9/25/2018 to 9/25/2019

Edward L. Goshorn, Ph.D.
Institutional Review Board

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