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The Role of Action in Affordance Perception Using Virtual Reality

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The University of Southern Mississippi

The Role of Action in Affordance Perception Using Virtual Reality

by

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A Thesis
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The University of Southern Mississippi
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of Honors Requirements

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Abstract

Space perception in virtual reality (VR) is distorted. Does action in conjunction with an avatar's presence improve perception in VR? Participants judged whether a virtual ball was within reach. Condition 1 was perception-only, where the participant was not allowed to move nor could see their arms. Condition 2 was perception with nonvisible action, where the participant could move their real arm to reach but could not see an avatar representation of the arm. Condition 3 was perception with visible action, where the participant could move and see a virtual hand that corresponded to the actual arm movement. Participants overestimated their own reach by about 15% in the avatar condition and the proprioceptive condition. The perception-only condition was the most accurate (only 5% overestimation). Response times were comparable for distances within reach but got longer in Conditions 2 and 3 when the ball was out of reach. The affordance responses ('yes' or 'no') did not correlate with response time, postural instability, nor with the head leaning forward. Instead, affordance responses mapped onto the mean magnitude of head movements. Specifically, complexity measured by effort-to-compress (ETC), which was lowest at the action boundary in the avatar condition, may helped to differentiate between experimental conditions. Our results point to the lack of expected haptic feedback as a critical variable, and the utility of complex exploration that may have contributed to the difference between the avatar and the perception-only condition.

Keywords: virtual reality, affordance, reach, avatars, perception, complexity

Dedication

Dedicated to my family, Luc Lagarde, and the Perception, Action, Cognition Lab. I couldn't have done it without you guys. Love y'all.

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List of Abbreviations

VR	Virtual Reality
HMD	Head Mounted Displays
ETC	Effort to Compress
CV	Coefficient of Variation

Chapter 1: Introduction

With *Virtual Reality* (VR) more accessible and affordable than in the past, it is becoming a common component of perceptual research. VR studies use head-mounted displays (HMD) that completely surround the user's visual field by a virtual environment created by the researcher to provide immersive virtual experience. Oftentimes, a virtual representation of the person, called an *avatar* (Bailenson & Blascovich, 2004), is used to visualize the body of the agent. In most cases, these avatars are from the third person perspective, as creating an avatar from the first-person perspective is a more difficult task. As such, most experiments that require a participant to be in first-person often do not have an avatar, as it is difficult to accurately create a body that is similar to the participant and moves in the same way as the participant. It has been observed that in the VR environment, participants are less accurate judging distances in comparison to real life (Loomis & Knapp, 2003; Thompson et al., 2004). An avatar that moves with the user has been shown to provide an anchor for where the user is and a metric to scale dimensions in space.

Chapter 2: Literature Review

Virtual reality technology is suitable for studying perception and action due to the immediacy of the experience and the embodiment that goes with it. The term “*affordance*” is used to describe the connection between perception and action (e.g. if a ball can be grasped or caught; Gibson, 1977). In a typical situation, humans perceive future actions without the benefit of knowing in advance how accurate the ensuing action will be. How well does perception estimate the accuracy of future actions? Bootsma (1989) discovered that performing an action can increase the accuracy of a perceptual judgement that otherwise precedes it. Bootsma’s study had participants judge if a ball would pass at a certain location by either hitting the ball with their own arm, hitting the ball with an artificial arm, or pressing a button at the right moment to indicate when the ball will pass by. The study found that participants judged more accurately when they hit a ball with their own hand because they were actually performing the action. A similar study about catching fly balls found that running towards the ball (as opposed to standing and observing) improved perceptual judgments about the catchability of the ball (Oudejans et al., 1996). They argued that the awareness of one’s body during motion directly influences the ability to judge whether the ball can be caught and therefore improve the ability to catch.

Mohler et al. (2010) observed that distance perception in VR was improved by the presence of an avatar. The present study aims to investigate if the presence of a virtual hand in VR helps accuracy in reaching tasks. When the correspondence between one’s own proprioception and visual perception of where their body parts are located is not available (e.g. due to occlusion), or broken (e.g. due to mismatch between visible and felt position), the visual information often takes over to resolve the conflict. The rubber hand illusion has a similar mechanism: when a visible artificial hand is stroked while hiding the real one, we feel the strokes

on the real hand and behave accordingly (Botvinick & Cohen, 1998). There have been several successful attempts to recreate this illusion in VR (Slater et al., 2007; 2008). A similar study observing participants walking over a virtual fence found that participants would have more real world like (i.e. more accurate) results when the VR system had an avatar that performed similar actions to the participant (Lin et al., 2015). Distorted virtual hand size can affect perceived graspability of objects, again suggesting the dominance of vision over proprioception (Linkenauger et al., 2011).

The present study aimed to test if the action of moving the hand in addition to having an avatar of the hand visible (Avatar condition) would improve the accuracy of reaching judgements in VR compared to controls (Perception condition: no movement; Proprioception condition: hand movement without visible avatar representation of the hand). The primary prediction was that increasing involvement of action in affordance tasks should improve the accuracy of affordance perception (Hypothesis 1). Response time was expected to be longer in the conditions involving action (Hypothesis 2). In the Avatar condition, participants were predicted to move more (Hypothesis 3), lean forward more (Hypothesis 4), be more variable in their movements (Hypothesis 5), and exhibit more complex postural adjustments (Hypothesis 6) compared to the Perception and Proprioception conditions. In addition to that, we expected that body movements during the experimental task would modulate perceptual judgments. Specifically, we hypothesized that complex movements of the head should be the best predictors of affordance perception (Hypothesis 7) regardless of how task-specific the involvement of the action system is in the task at hand.

Chapter 3: Methods

Participants

Using the experimental subject pool of the Psychology Department, 73 participants (53 females, 20 males) with an average age of 19.7 were recruited. In order to compensate them for their time, they were given 1.5 credits that could be used for extra credit or course credit. Students with vision and/or motor impairments as well as those with recent physical injury did not take part in the study.

Materials

The study utilized the Oculus Rift HMD and controllers in a virtual environment created in the Unity Game Engine. In the virtual environment, there was a red ball with a 6.8cm diameter suspended on a wire from a virtual ceiling structure. A virtual hand was created that was attached to the controller's motion and moved with the hand of the participant in real time. Head movements in three-dimensional coordinates were tracked and extracted from the Oculus Rift headset at a rate of 80 frames per second. Hand movements were also tracked by the Oculus Rift controllers. An Acer 15.6" Predator Helios 300 Gaming Laptop was used to create the virtual environment, run the program for the HMD, and record data.

Experimental Design

We employed a 3 (Condition) x 7 (π -ratio) mixed design. The π -ratios used in the experiment were 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, and 1.3. The π -ratio was a within-subjects variable and was defined as a dimensionless ratio of arm length and target distance. The experimental Condition (Perception, Proprioception, Avatar) was a between-subjects variable. Each trial was repeated three times for a total of 21 trials per participant. Trials were presented in random order. Participants were assigned to one of three conditions in order of appearance by the following

sequence: Perception, Proprioception, and Avatar. Several dependent variables were recorded. “Yes” and “No” responses were recorded with button presses using the handheld controllers. Response time was measured from the beginning of the trial presentation until a button press. Spatial coordinates of head motion were recorded from the VR headset (x, y and z coordinates in meters). From these coordinates we computed the Euclidean distances between each adjacent sample recording of the head position and generated a one-dimensional time series for each trial. These time series were analyzed in several ways. The overall mean was calculated to indicate the average magnitude of head movement. The coefficient of variation (CV) was computed by dividing each time series’ standard deviation with the mean magnitude. In order to check if participants leaned forward in spite of instructions to the contrary, we computed the range of head motion in the z-direction (forward and backward motion) by subtracting the minimal head excursion from the maximal head excursion.

A complexity measure called effort-to-compress (ETC) was calculated for each time series. ETC is a measure of the heterogeneity of the time series and the ease with which it can be converted into a homogeneous series (Nagaraj & Balasubramanian, 2017a; 2017b). ETC is especially well suited for the description of short time series (less than 500 samples) in a variety of disciplines, such as neuroscience (neural spikes, heart rate) and engineering (structural complexity of materials, Virmani & Nagaraj, 2019). ETC measures the heterogeneity by identifying “streaks” in the time series. These repeated occurrences (streaks or patterns) are labeled as a unit and effectively shorten the time series. This logic is also used in engineering technology and computer science to compress data files such as music files and digital images. The number of steps involved in compressing the time series into its smallest possible length is a measure of how complex the original series was. In the present experiment we used ETC as a

measure of complexity of head movements by analyzing the Euclidean distance series for each trial.

Procedure

Upon entering the laboratory measurements of the participant's height and arm length were taken. Then, the participant put on the Oculus Rift headset and was asked about the reachability of the virtual ball: "Would you be able to reach and grasp the object with your hand, without the aid of a tool or implement, and without leaning or bending forward?" Participants were asked to respond by pressing buttons on the hand-held VR controller to record their answer ("yes" or "no."). In Condition 1 (perception-only), the participant was not allowed to move their arms and could not see his or her virtual hand. In Condition 2 (proprioception), the participant was allowed to move their arm to reach but could not see a virtual hand to accompany the movement. This condition was meant to combine visual perception with nonvisual proprioception of the arm's position and movement. Finally, in Condition 3 (Avatar) the participant was allowed to move their arm and was able to see a virtual hand that corresponds to the movement. There were seven different ball distances tested: three beyond reach, three within reach, and one right at the action boundary. Reachability was determined by a dimensionless ratio (π), which was defined by the distance of the ball divided by arm length of the participant in meters. When π is greater than 1, the ball is out of reach. Each π -ratio was repeated three times for a total of 21 trials per participant. The experiment lasted approximately 15 minutes. No feedback about accuracy was given during the experiment.

The trial sequence started with 21 practice trials and was followed by 21 actual trials. There was a variable inter-stimulus interval between each trial. Participants could control when

they started the next trial by pressing the trigger button. During this interval, there was a black screen preventing them from seeing anything.

Chapter 4: Results

Perceptual Responses

A 3 (Condition) \times 7 (π -ratio) mixed analysis of variance (ANOVA) was conducted on affordance responses. The dependent measure was expressed as a proportion of YES responses. The main effect of π was significant, $F(6,420)=123.94$, $p<0.001$, $\eta_p^2=0.64$, indicating that proportion of YES responses decreased with distance. The main effect of Condition was also significant, $F(2,70)=5.12$, $p<0.01$, $\eta_p^2=0.13$. Post-hoc tests (with a Bonferroni correction) showed that the Perception condition was significantly different from the Avatar condition ($p=0.004$) and from Proprioception ($p=0.015$). There was a significant $\pi \times$ Condition interaction, $F(12,420)=2.54$, $p<0.02$, $\eta_p^2=0.07$, indicating that the largest differences between the conditions occurred for distances near the action boundary ($\pi=1$). The results are shown in *Figure 1*.

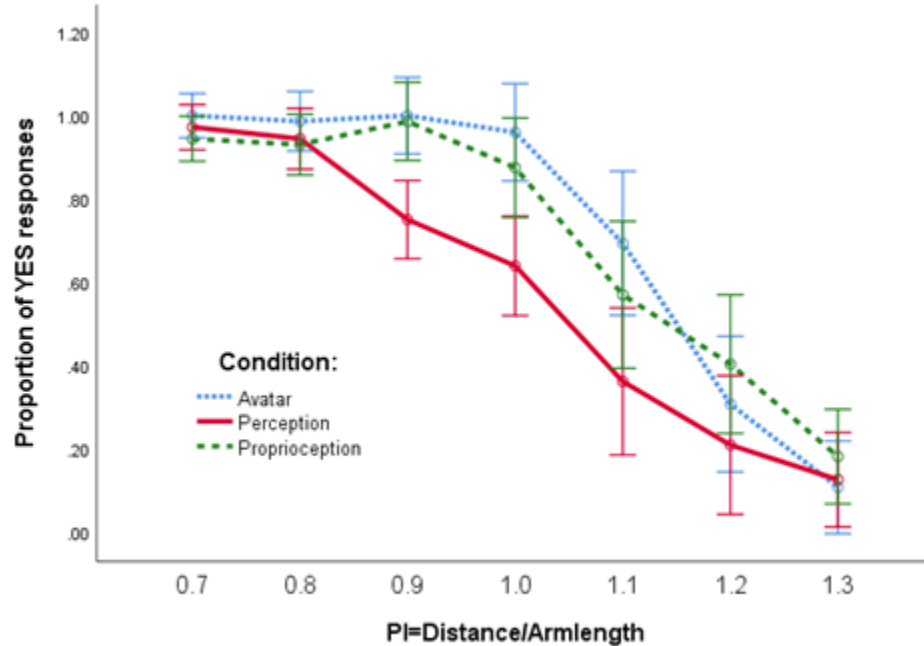


Figure 1. Proportion of YES responses as a function of experimental Condition and π -ratio. $\pi=1$ corresponds to the action boundary. Error bars correspond to 95% confidence intervals.

Response Time

A 3 (Condition) \times 7 (π -ratio) mixed analysis of variance (ANOVA) was conducted on response time. The main effect of π was significant, $F(6,420)=11.62$, $p<0.001$, $\eta_p^2=0.14$, suggesting that response time increased with distance. The main effect of Condition was also significant, $F(2,70)=3.35$, $p<0.04$, $\eta_p^2=0.09$. Post-hoc tests showed that the Perception condition was significantly different from the Avatar condition ($p=0.021$) and from the Proprioception condition ($p=0.037$), respectively. These main effects were qualified by a significant $\pi \times$ Condition interaction, $F(12,420)=2.37$, $p<0.03$, $\eta_p^2=0.06$. Response times diverged beyond reach (for $\pi>1$) such that response time increased in the Avatar and Proprioception Condition, whereas in the Perception condition the response time remained low. There was no difference between conditions in response times for reachable distances. It is also worth noting that the longest response time occurred at the action boundary ($\pi=1$). The results are shown in *Figure 2*.

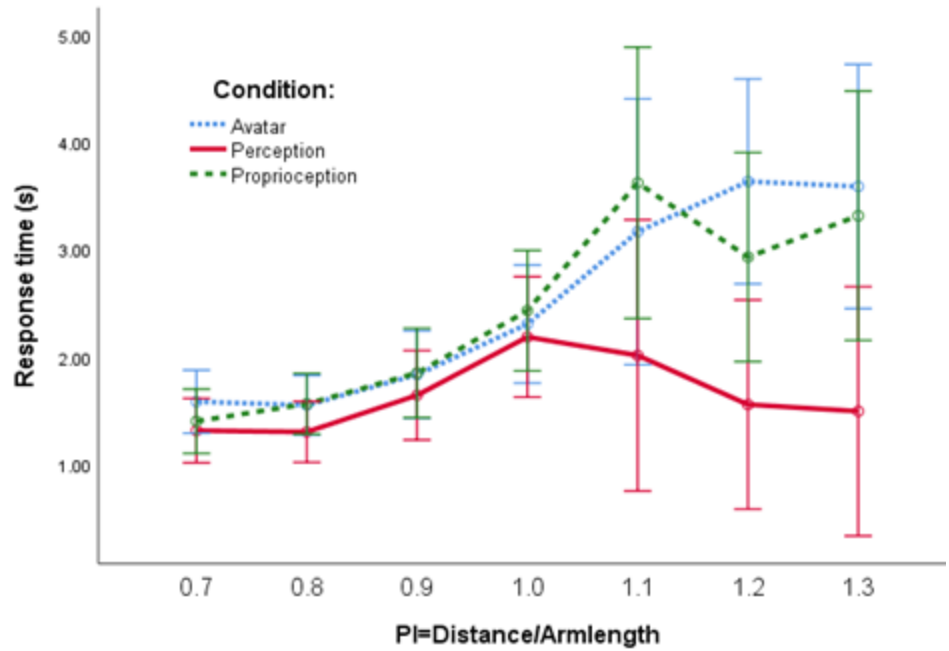


Figure 2. Response time in seconds as a function of experimental condition and π -ratio. Error bars correspond to 95% confidence intervals.

Mean Magnitude of Head Motion

A 3 (Condition) \times 7 (π -ratio) mixed analysis of variance (ANOVA) was conducted on the mean magnitude of head motion. The mean magnitude of head motion was based on the Euclidean distance time series of each trial. The main effect of Condition was significant, $F(2,70)=6.07$, $p<0.004$, $\eta_p^2=0.15$. Post-hoc tests (Bonferroni) showed that in the Perception condition head movement magnitude was significantly smaller than in the Avatar condition ($p=0.003$). The $\pi \times$ Condition interaction was also significant, $F(12,420)=2.77$, $p<0.02$, $\eta_p^2=0.07$, indicating that the differences between Perception and the Avatar condition increased with distance. The results are shown in Figure 3.

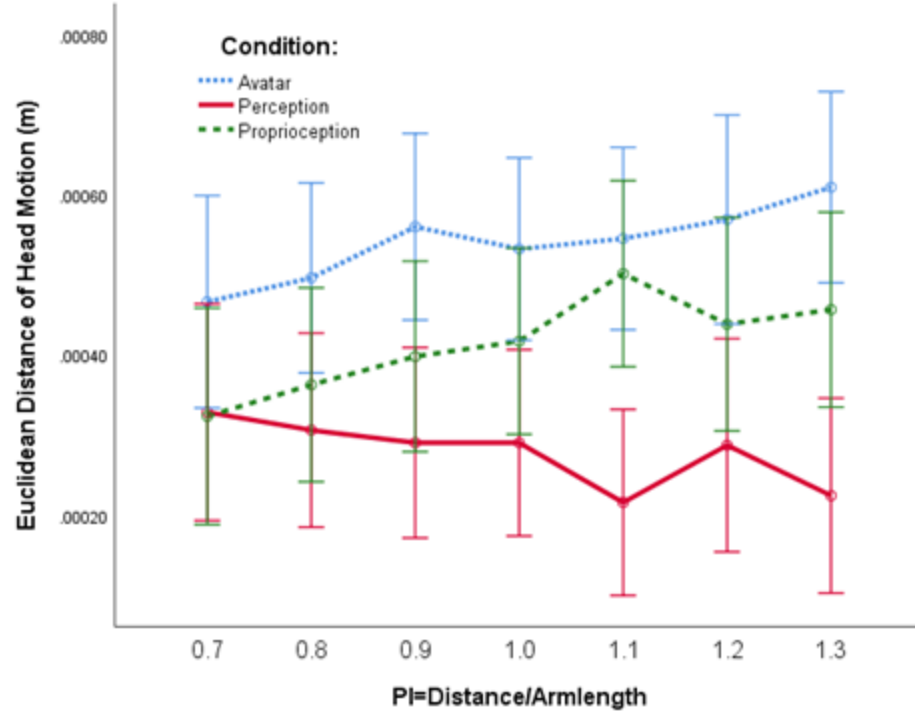


Figure 3. Mean magnitude of head motion in meters computed as a time series of Euclidean distances between adjacent samples as a function of experimental condition and π -ratio. Error bars correspond to 95% confidence intervals.

Range of Anterior-Posterior Head Motion

A 3 (Condition) \times 7 (π -ratio) mixed analysis of variance (ANOVA) was conducted on the range of forward-backward motion of the head. This measure was used to indicate the amount of lean the observer exhibited during each trial. The main effect of π was significant, $F(6,420)=5.54$, $p<0.001$, $\eta_p^2=0.07$. There was a significant $\pi \times$ Condition interaction, $F(12,420)=4.14$, $p<0.001$, $\eta_p^2=0.11$, revealing that the range of forward-backward motion increased for distances that were out of reach in the Avatar and Proprioception Condition, as opposed to the Perception condition in which the range remained small. The results are shown in Figure 4.

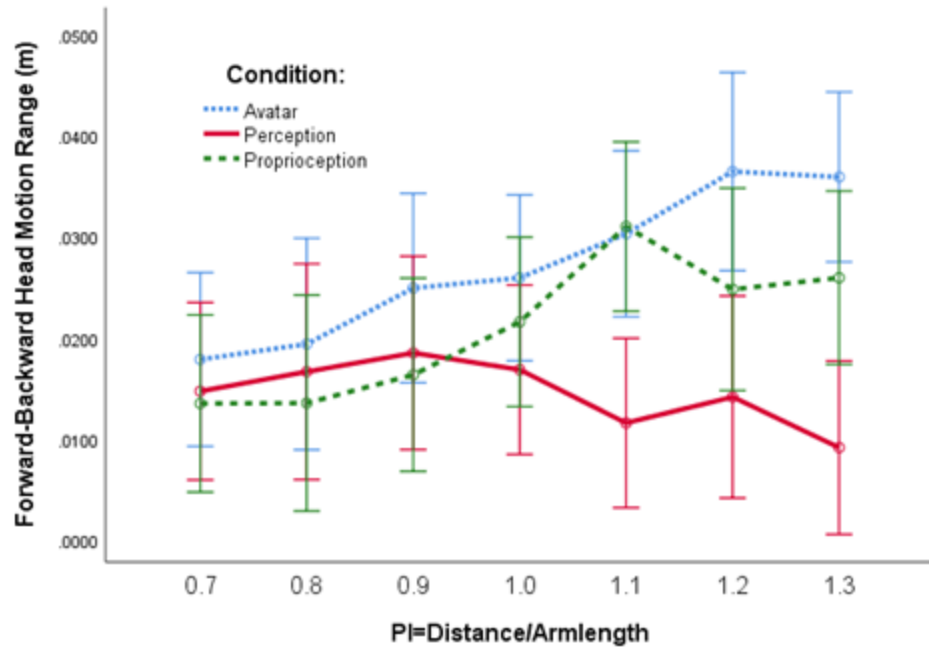


Figure 4. Range of forward to backward motion of the head in meters as a function of experimental condition and π -ratio. Error bars correspond to 95% confidence intervals.

Coefficient of Variation (CV) of Head Motion

A 3 (Condition) \times 7 (π -ratio) mixed analysis of variance (ANOVA) was conducted on the coefficient of variation (CV) of head motion. Apart from a main effect of π ($F(6,420)=3.03$, $p<0.007$, $\eta^2=0.04$), no other effects were significant. The results are shown in *Figure 5*.

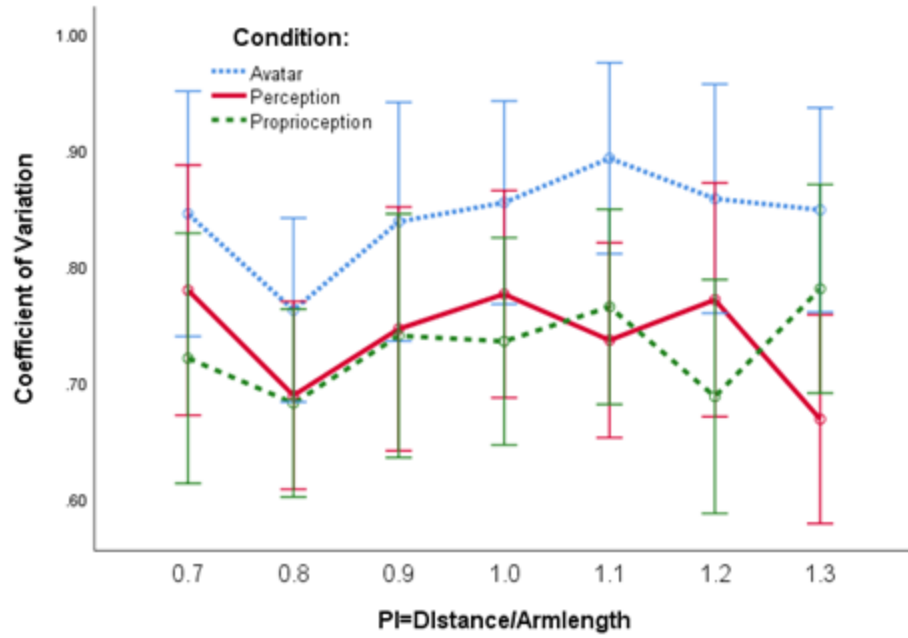


Figure 5. Coefficient of variation as a function of experimental condition and π -ratio. Error bars correspond to 95% confidence intervals.

Effort to Compress

A 3 (Condition) \times 7 (π -ratio) mixed analysis of variance (ANOVA) was conducted on effort to compress (ETC), a dimensionless parameter that measures heterogeneity in a time series. The main effect of π was significant, $F(6,420)=20.9$, $p<0.001$, $\eta^2=0.23$, as was the main effect of Condition, $F(2,70)=9.15$, $p<0.001$, $\eta^2=0.21$. Post-hoc tests showed that ETC was lower in the Avatar Condition compared to Perception ($p<0.001$), and compared to Proprioception ($p=0.028$). These main effects were qualified by a significant $\pi \times$ Condition, $F(12,420)=3.39$, $p<0.001$, $\eta^2=0.09$. ETC was at minimum at the action boundary ($\pi=1$) in the Perception condition and exhibited a U-shaped pattern. ETC showed a steady decrease as π increased in the Avatar and Proprioception condition. The results are presented in Figure 6.

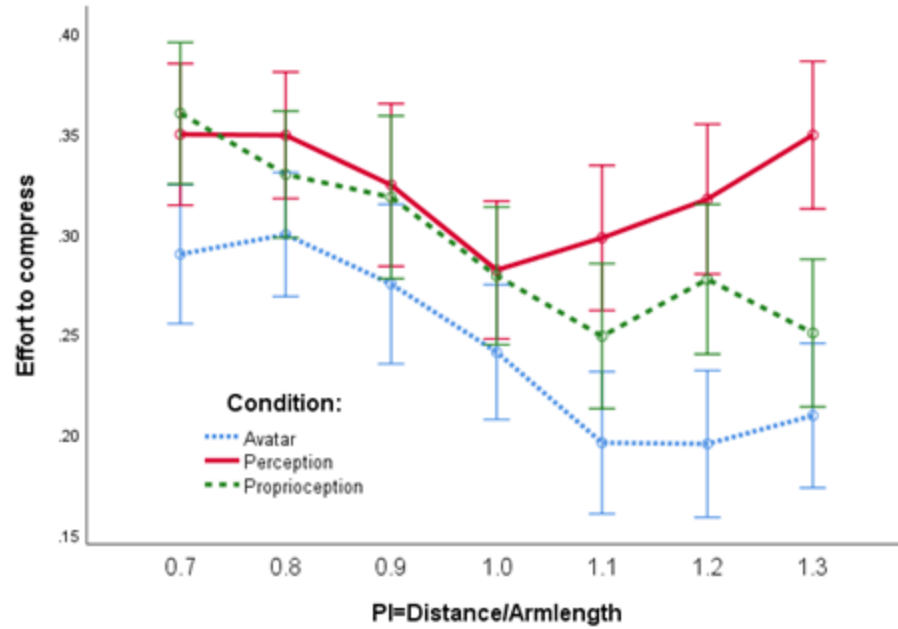


Figure 6. Effort to compress (ETC) as a function of experimental condition and π -ratio. Error bars correspond to 95% confidence intervals.

Do Movement Parameters Predict Affordance Judgments?

Hypothesis 7 tested which movement parameters (Mean head motion magnitude, Range of head movements, CV of head movement, ETC) contributed significantly to explaining the variance in affordance judgments. Since affordance judgments were measured with a dichotomous variable (yes/no), we used a mixed-effects hierarchical logistic regression (Bates, et al., 2014) as it is a more appropriate analysis than ANOVA for this type of data. The following model was used:

$$\text{Affordance Response} \sim \text{Trial} + \text{Condition} \times \pi + \text{Condition} \times \text{Range} + \text{Condition} \times \text{Mean} + \text{Condition} \times \text{CV} + \text{Condition} \times \text{ETC} + (\text{Trial}|\text{Participant}).$$

Trial and Participant were set as random effects; all other variables were fixed effects. Condition was coded as a categorical variable with three levels: Perception, Proprioception and

Avatar Condition. The model was built to test how affordance responses were affected by Condition along with spatial aspects of the task (distance ratio π). In addition, the model tested the contributions of various measures of head movement: Range, magnitude (Mean), variability (CV), and complexity (ETC). Due to the constraints of the *lmer* statistical package in R, the main effects of Condition, and interactions involving the Condition variable were always based on the comparison with the Perception condition.

Some of the measures reported so far suggested that participants responded in a qualitatively different manner for distances that were within reach as compared to distances that were out of reach. To further investigate the nature of this effect two separate mixed logistic models were run, one for distances that were within reach ($\pi \leq 1$) and another one for distances out of reach ($\pi > 1$). *Tables 1* and *2* show the outputs of the statistical analyses, respectively.

Predictor	β	<i>SE</i>	<i>p</i>
Intercept	18.68728	3.29342	1.39E-08
Trial	-0.01418	0.04789	0.767209
Proprioception	-11.95188	3.89609	0.002157
Avatar	-3.03964	7.15981	0.671171
π	-17.33655	3.29713	1.46E-07
Range	-1.06239	0.63505	0.094342
Mean	1.38193	0.847	0.102774
CV	-0.02569	0.33517	0.938906
ETC	-0.25547	0.37349	0.493966
Proprioception $\times \pi$	14.50805	4.19176	0.000538
Avatar $\times \pi$	6.70533	7.60895	0.378187
Proprioception \times Range	0.49616	1.00033	0.619893
Avatar \times Range	0.82909	1.57334	0.598221
Proprioception \times Mean	-0.86936	1.08419	0.422638
Avatar \times Mean	-0.27509	1.81045	0.879229
Proprioception \times CV	-0.02153	0.50807	0.966193
Avatar \times CV	-0.30805	0.56061	0.582676
Proprioception \times ETC	0.24811	0.54583	0.649428
Avatar \times ETC	0.4887	1.07306	0.648803

Table 1. Best fitting mixed-effects logistic regression model of Affordance Judgments for distances within reach ($\pi \leq 1$). Significant effects ($p < 0.05$) are in bold font.

Hypothesis 7 was not supported for distances within reach, as none of the movement parameters interacted significantly with the experimental Condition in predicting affordance judgments. There was a significant effect of Proprioception as compared to Perception ($\beta = -11.95$, $SE = 3.90$, $p = 0.002$) that was further qualified by a significant Proprioception \times π interaction ($\beta = 14.51$, $SE = 4.19$, $p = 0.001$). The patterning of the results illustrated that Perception increasingly diverged from the other conditions as distances approached the action boundary ($\pi = 1$). Specifically, participants tended to be more conservative in their affordance judgments near the action boundary in the Perception condition compared to Proprioception and the Avatar conditions (see *Figure 1* for details).

The same analysis was repeated for the range of distances that were out of reach ($\pi > 1$). The results are presented in *Table 2*.

Predictor	β	SE	p
Intercept	20.32767	6.01655	0.000728
Trial	0.03444	0.03753	0.358761
Proprioception	2.93824	7.25721	0.685572
Avatar	21.16714	8.40696	0.011809
π	-20.4913	5.22295	8.73E-05
Range	0.83636	1.62488	0.606746
Mean	-1.62638	1.55599	0.295915
CV	-0.45143	0.54054	0.403634
ETC	-1.20786	0.65169	0.063821
Proprioception $\times \pi$	-0.44883	6.13244	0.941655
Avatar $\times \pi$	-15.51807	7.0344	0.027382
Proprioception \times Range	-0.60971	1.68688	0.717766
Avatar \times Range	0.56267	1.70401	0.741246
Proprioception \times Mean	2.29163	1.63333	0.160606
Avatar \times Mean	0.51898	1.70858	0.761318
Proprioception \times CV	0.28142	0.75946	0.710975
Avatar \times CV	0.74664	0.74678	0.3174
Proprioception \times ETC	1.45846	0.81973	0.075209
Avatar \times ETC	2.63388	0.943	0.005221

Table 2. Best fitting mixed-effects logistic regression model of Affordance Judgments for distances out of reach ($\pi > 1$). Significant effects ($p < 0.05$) are in bold font.

Hypothesis 7 was supported for distances beyond reach ($\pi > 1$). Specifically, ETC was a significant predictor of affordance judgments. There was a significant effect of Avatar as compared to Perception ($\beta = 21.17$, $SE = 8.41$, $p = 0.012$) that was further qualified by a significant Avatar $\times \pi$ interaction ($\beta = -15.52$, $SE = 7.03$, $p = 0.027$). The Avatar and Perception conditions increasingly diverged from the one another around the action boundary ($\pi = 1$). Specifically, participants tended to be more conservative in their affordance judgments near the action boundary in the Perception condition compared to the Avatar condition (see *Figure 1* for details). This pattern was similar to the one obtained for within-reach distances in the previous analysis. There was a significant Avatar \times ETC interaction ($\beta = 2.63$, $SE = 0.94$, $p = 0.005$). This result suggested that ETC modulated the differential effects of Avatar and Perception conditions on affordance judgments, whereas other parameters of exploratory activity did not. The range

and mean magnitude of head movements did not matter for affordance judgments, nor did variability as measured by CV.

Chapter 5: Discussion and Conclusion

Observers moved more, leaned forward more, and took longer to respond in a reaching affordance task when a virtual avatar visually represented their hand movements in VR. The movements were subtler and more complex in the Perception condition compared to the other conditions that required more motor activity. The emphasis of the present study was not on accuracy of judgments, rather on demonstrating that different exploratory opportunities lead to different patterns of body movement, and that these patterns differentially affect how we perceive affordances. This expectation is consistent with the ecological approach to perception and action (Gibson, 1979), an exemplary embodied approach to cognition. The current investigation showed that the factors that explain the difference in exploratory activity also modulate affordance perception. The exact reasons for this are unknown. The next section offers some theoretical background for some explanations.

Exploratory Motor Activity Links Perception and Action

Gibson (1979) proposed that perceptual systems actively seek out information to guide actions. Exploratory activity is necessary for detecting information that specifies affordances. It is an open question whether movements that are specific versus nonspecific to a given task matter more or less. In a reaching task, an outstretched arm is an action that is directly relevant to achieving the affordance goal. During the same task having the arms swinging as a person walks toward a target object to reach it might not be considered directly relevant, thus described as nonspecific. The same applies to many other movements of other body parts such as the head, legs, and torso. However, the theoretical approach of biotensegrity (Ingber, 2006; Turvey & Fonseca, 2014), and a growing body of empirical evidence suggests otherwise (e.g. Jones &

Widlus, 2020). Tensegrity describes the body as a collection of rigid and elastic components connected into a system that exhibits dynamical stability. Specifically, the body can be conceived as a tensegrity system comprising bones (rigid parts) and connective tissues (muscles, tendons, ligaments, etc.). The connections between parts maintain a stable pressure and distribute forces across the whole body in complex ways. This dynamic organization permits humans to assume different body postures and perform a variety of locomotory actions. In principle, a perturbation (change in impact forces) at one site is dealt with by redistributing the stresses and tensional properties across the whole system. To the extent that tensegrity is a viable theory about the organization of the musculoskeletal system, the distinction between specific and nonspecific movements does not apply. All movements contribute to perception, whether performed by the focal body part locally, or by a more distal, non-focal one at a remote location of the body. The reconfiguration of the body due to changing task demands and perturbations is complex, fast and efficient. The tensegrity structure allows researchers to hypothesize that complex movement patterns govern this rapid reconfiguration of internal forces in the system. The fact that traditional measures of central tendency did not predict perception in the current study, but ETC did, shows the subtlety of this reorganization. In addition, the manner in which this reorganization happens is probably non-voluntary, occurs without explicit awareness, and yet still affects behavior and perceptual performance. The current study successfully demonstrated that head movements that are ostensibly not supposed to be directly relevant to a reaching affordance task nevertheless contributed significantly to explaining perceptual

responses. Recent empirical investigations provide further evidence for the importance of local and nonlocal body parts in affordance tasks (Mangalam, et al., 2020; Mangalam & Kelty-Stephen, 2020). In addition to gathering more empirical data from behavioral studies, future investigations should focus on the neural underpinning of tensegrity systems that are needed to explain the exact nature of the link between exploratory motor activity and perception.

Complexity of Exploratory Activity Affects Perceptual Performance Beyond the Action Boundary

The results of the current study revealed that affordance judgments are affected by exploratory activity for distances beyond reach. The exact reasons for this finding are unclear. One possibility might be the lack of feedback about accuracy. Without feedback (or knowledge of results) perceptual performance remains uncertain: the observer may still attribute some probability to the possibility that the object could be within reach. It is not clear whether the effects of complexity for distances beyond reach can be attributed to increased focus of attention or effort for the purpose of finding the true maximum limit of one's action capabilities. The maximum limit of action capability remains uncertain until the next attempt, when the observer may try harder to beat the previous "record". Regardless of the reasons, the fact remains that complexity (as measured by ETC) is the best predictor of perceptual responses in the absence of feedback for the range where the possibility to expand the range of the affordance still exists. Uniquely, low complexity appears to characterize embodied responses (where the avatar is visible as the reaching action is performed) as compared to less embodied and integrated conditions (Proprioception and Perception). Why is complexity of exploratory activity lower in more embodied conditions? It may be the case that the Avatar condition requires more

stereotypical gestures and movement patterns performed with the focal body part (the hand), whereas in the Perception condition subtle head movements might carry more influence. If true, this result demonstrates the importance of subtle, nonspecific patterns of exploration that may nevertheless provide a rich informational pattern in the ambient global array.

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Appendix A

Consent form
THE UNIVERSITY OF SOUTHERN MISSISSIPPI
AUTHORIZATION TO PARTICIPATE IN RESEARCH PROJECT

Consent is hereby given to participate in the study: Perceiving what is reachable in virtual reality

PURPOSE: This present study is designed to examine and understand how individuals perceive the three-dimensional space of virtual environments, and how they react to spatial properties of objects at various locations and elevation.

DESCRIPTION OF STUDY: Participation will consist of the participants estimating one or several of the many spatial characteristics of objects and locations in front of them, such as distance, elevation, size, orientation, slant, etc. in different virtual environments.

BENEFITS: Participants are not expected to directly benefit from participation. However, it is hoped that this study will be interesting to the participant and that it will contribute to our understanding of cognitive, perceptual and motor functioning with regards to virtual three-dimensional spaces. Participants will receive 1.5 credit for every half hour of their participation.

RISKS: No foreseeable risks beyond those present in routine daily life are anticipated in this study. If participants find that they are distressed from participating in this research, they should notify the researcher immediately.

CONFIDENTIALITY: Other than the consent forms, participants will not place their name on any other information provided for this study. Participants' responses will be matched using a participant identification number that has been assigned to each individual for the duration of this study. At the conclusion of data collection for this study, the list linking participant names with participant identification numbers will be destroyed. Data gathered from the present study will be stored in a secure location for six years, at which time it will be destroyed. Findings will be presented in aggregate form with no identifying information to ensure confidentiality.

PARTICIPANT ASSURANCE: Whereas no assurance can be made concerning results that may be obtained (since results from investigational studies cannot be predicted) the researcher will take every precaution consistent with the best scientific practice. Participation in this project is completely voluntary, and participants may withdraw from this study at any time without penalty, prejudice, or loss of benefits. Questions concerning the research should be directed to Ashley Funkhouser at (228) 209 3797 (or e-mail at ashley.funkhouser@usm.edu) or to Dr. Alen Hajnal at (601) 266-4617 (or e-mail at alen.hajnal@usm.edu). This project and this consent form have been reviewed by the Institutional Review Board, which ensures that research projects involving human participants follow federal regulations. Any questions or concerns about rights as a research participant should be directed to the Chair of the Institutional Review Board, The University of Southern Mississippi, Box 5147, Hattiesburg, MS 39406, (601) 266-6820. A copy of this form will be given to the participant upon request.

Printed Name of the Research Participant

Signature of the Research Participant

Date

Signature of the Person Explaining the Study

Date

Appendix B

IRB Approval



**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: 19011401

PROJECT TITLE: The Role of Action in Affordance Judgements Using Virtual Reality

PROJECT TYPE: Undergraduate Project

RESEARCHER(S): Ashley Funkhouser

COLLEGE/DIVISION: College of Education and Human Sciences

SCHOOL: Psychology

FUNDING AGENCY/SPONSOR: N/A

IRB COMMITTEE ACTION: Expedited Review Approval

PERIOD OF APPROVAL: 03/07/2019 to 03/06/2020

**Donald Sacco,
Ph.D. Institutional
Review Board**