

Perceiving affordances for receiving a serve in virtual volleyball

A Dissertation

SUBMITTED TO THE FACULTY OF THE

UNIVERSITY OF MINNESOTA

By

Danilo Gomes de Arruda

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

Adviser: Dr. Thomas A. Stoffregen

April, 2024

© Danilo Gomes de Arruda

Acknowledgment

I would like to express my deepest gratitude to my family for their unwavering support and encouragement throughout this journey. Their love, patience, and understanding have been my pillars of strength, enabling me to pursue my academic endeavors with confidence.

I am immensely grateful to my advisor Dr. Thomas Stoffregen for his invaluable guidance, mentorship, and scholarly insights. His dedication to my academic growth and endless belief in my capabilities have been instrumental in shaping this dissertation and my academic and professional development.

I extend my appreciation to the esteemed members of my committee, Dr. Evan Suma Rosenberg, Dr. Rachel Hawe, and Dr. Chih-Hui "Nicky" Chang, for graciously agreeing to join and contribute their expertise to this dissertation.

I am also grateful to all the volleyball players who generously contributed their time and effort to this study. Without their participation, this research would not have been possible.

I wanted to acknowledge all the growth I have had during this journey. Certainly, I am grateful for all the drawbacks and difficulties I had along the way as they were the conditions that “afforded” my success.

Dedication

This dissertation is dedicated to my parents.

Abstract

Affordances are opportunities for action that are available for a given person in a given environment. When receiving serves in volleyball, players commonly use one of two techniques; overhead (hands pronated above the head) or underhand (hands supinated near the waist). The relative utility of those techniques is influenced by characteristics of each serve, including its height. At the same time, the importance of serve height varies with the height of the player. This relationship suggests that it might be possible (and useful) to consider serve reception in volleyball in the context of affordances. Using a head-mounted virtual reality system, I varied the height of incoming serves, ranging from 1 m to 2.25 m. Participants responded to each serve by attempting to intercept it using either the overhead or underhand technique. I predicted that participants (skilled volleyball players) would use the overhead technique for higher serves and the underhand technique for lower serves, and that there would be discrete transition between the two techniques, consistent with the hypothesis that players perceive incoming serves in terms of whether they afford one or the other technique. I varied the height of participants by utilizing players from men's and women's volleyball teams. I separately analyzed the choice of serve reception techniques in terms of serve height expressed extrinsically (i.e., in meters) and expressed intrinsically (i.e., in relation to each participant's maximum vertical reach). These separate analyses made it possible for me to identify possible sex differences in serve reception that were related to sex differences in height, as well as differences in serve reception technique that were not related to sex differences in height. I also analyzed data about displacement of the VR headset and used those data as a measure of whole-body movement as participants prepared to receive each serve. As predicted, I found discrete transitions between techniques, in relation to

serve height. Separately, I found evidence for sex differences in serve reception that were related to sex differences in height, but also others that were not related to sex differences in height. Finally, I found systematic relationships between serve height, patterns of whole-body anticipatory movement, and use of the overhead and underhand techniques. I interpreted those relationships as evidence for the perception of higher order affordances for the use of anticipatory whole-body movement to optimize the utility of particular serve reception techniques. I concluded 1) that incoming serves in volleyball can be perceived in terms of their affordances, 2) that head-mounted virtual reality is a useful method for the study of affordance perception in time-constrained domains, such as volleyball, 3) that sex differences in volleyball arise from anthropometric sex differences but also from sex differences that are not related to anthropometrics, and 4) that skilled volleyball players can perceive incoming serves in terms of higher order affordances in which anticipatory movements are relative to techniques for serve reception.

Table of Contents

List of Figures	ix
Chapter 1: Introduction	1
Overview	1
Affordances	2
Higher Order Affordances	8
Affordances: Sex Differences	14
A new default	15
Sex differences in affordance perception	16
Sex differences in serve reception	19
Using action metrics to investigate affordance perception	22
Virtual Reality as a method to investigate affordance perception using action	24
Purpose of the Study	27
Chapter 2: Perception of affordances for receiving serves in virtual volleyball: Serve height and anticipatory whole-body movement in women and men	29
Introduction	29
Receiving serves in volleyball	30
Sex differences in serve reception	32
Higher order affordances: Moving to optimize a preferred technique?	33
Methods	36
Participants	36
Apparatus	37
Task	37
Procedure	39

Data Analysis.....	41
Results.....	43
Serve reception techniques	43
Anticipatory whole-body movement	44
Discussion.....	47
Serve reception techniques	48
Anticipatory whole-body movements.....	51
Limitations	54
Conclusion	54
Chapter 3: Perception of higher order affordances relating to serve reception with experimental control of anticipatory whole-body movement.....	56
Introduction.....	56
Limited movement in volleyball.....	56
Higher order affordances in Experiment 2.....	59
Methods	62
Participants.....	62
Apparatus	62
Task.....	62
Procedure	62
Data Analysis.....	63
Results.....	64
Proportion of underhand serve reception	64
Jump Proportion.....	65
Anticipatory whole-body movement	67

Discussion	70
Serve reception techniques	71
Proportion of jumps	72
Anticipatory whole-body movements.....	74
Chapter 4: General Discussion.....	77
Affordances.....	78
Overhead vs. underhand	78
Stepping versus jumping.....	80
Higher order affordances	81
Affordances: Sex differences	82
Overhead vs. Underhand.....	84
Limitations	89
Future Research	89
Conclusion	90
References.....	92

List of Figures

Figure 1 - The proportion of staircases that were reported to be climbable for short and tall participants.....	4
Figure 2 - Commonly used techniques to receive a serve in volleyball	7
Figure 3 - Hypothetical result for transitions between serve reception techniques as a function of serve height.	8
Figure 4 – The facing direction manipulation in Peker et al. (2023).....	11
Figure 5 – The perceived minimum kickable gap size by kick distance (Peker et al., 2023).....	12
Figure 6 – Results from Pepping et al. (2011)	13
Figure 7 - Hypothetical result for receiving serves of different heights in volleyball	22
Figure 8 - The conditions used by Correia et al. (2012)	26
Figure 9 - Commonly used techniques to receive a serve in volleyball	32
Figure 10 – Volleyball situation in which a serve can afford different reception techniques	35
Figure 11 - VR equipment used for the experiment.....	37
Figure 12 - Virtual Environment used in the experiments	39
Figure 13 - Demonstration of the position adopted to measure maximum reach.....	40
Figure 14 – Experiment 1. The proportion of underhand serve receives as a function of serve height and sex	44
Figure 15 – Experiment 1. Headset displacement on the backward-forward axis.....	45
Figure 16 – Experiment 1. Headset displacement on the vertical axis	46
Figure 17 – Experiment 1. Headset displacement on the lateral axis	47
Figure 18 – Volleyball situation in which players are not allowed to move forward or backward	58
Figure 19 – Variations in the underhand technique	59
Figure 20 – Experiment 2. The proportion of underhand serve receives as a function of serve height and sex	65
Figure 21 – Experiment 2. The proportion of jumps as a function of serve height and sex	66
Figure 22 – Experiment 2. Correlation between number of jumps and maximum reach.....	67

Figure 23 – Experiment 2. Headset displacement on the backward-forward under a movement constrained condition	68
Figure 24 – Experiment 2. Headset displacement on the vertical axis under a movement constrained condition	69
Figure 25 – Experiment 2. Headset displacement on the lateral axis under a movement- constrained condition	70

Chapter 1: Introduction

Overview

Affordances are opportunities for action that are available for a specific animal in a specific environment (Stoffregen, 2003). This is a powerful concept that has been studied for more than 40 decades and has implications in multiple domains such as psychology, sports, design, and philosophy (Osiurak et al., 2017).

In this dissertation I address several issues within the affordance literature, including affordance perception in volleyball, the perception of higher order affordances, sex differences in affordance perception, and the inference of affordance perception from action, rather than from conscious reports — each of which I will discuss in the following sections. To effectively investigate these topics in a single study, I designed two closely related experiments. In these experiments, I systematically varied the availability of particular affordances and the sex of participants. I did this in the context of a head-mounted virtual reality system that allowed me simultaneously to measure qualitative action choices (from which I inferred the perception of “target” affordances) and quantitative movements related to those choices (from which I inferred the perception of higher order affordances). Some of my predictions were confirmed, but in other cases, novel (unexpected) results led to new questions about the basis and perception of affordances in volleyball. Overall, the results allowed me to conclude 1) that participants perceived affordances for receiving serves in a virtual volleyball game, 2) that participants perceived higher order affordances for optimizing the utility of different techniques for receiving serves, and 3) that affordance perception differed between women and men in relation to actual

(i.e., non-laboratory) sex differences in game play that were not completely explained by anthropometric differences.

Affordances

The concept of affordances, as elucidated by Gibson (1986), highlights the dynamic relationship between the attributes of an animal and its environment, revealing how these factors jointly influence the activities available to that individual. Affordances emerge from interactions between the performer and the environment, also known as the animal-environment system (Stoffregen, 2003). For instance, a chair only affords sitting for the anatomical structure of adult humans. Conversely, the same chair may not afford the same action for a human infant, or for a giraffe due to their distinct anthropometrics, rendering sitting on a typical chair impractical or impossible. Since affordances are defined by characteristics of the environment and the animal, it is possible to calculate a metric that captures this relationship and gives information about that affordance. In the example of sitting, leg length divided by seat height is a metric that defines the affordance for sitting (Mark et al., 1990)

Affordances extend beyond mere static attributes such as leg length or seat height; they arise also from the interplay between the spatiotemporal characteristics of an organism and its surroundings. For instance, the opportunity to cross a busy street emerges from a relation between the time available (e.g., the gap between passing cars) and the time required to cross (Lee et al., 1984). Similarly, the time available before a ball drops at a specific location and the time needed to arrive at that location defines the affordance for catching a fly ball (Oudejans et al., 1996).

Affordances differ qualitatively from the underlying properties of the animal, and of the environment. Take, for instance, the act of running to catch a fly ball, where timing is critical to reach the ball before it drops to the ground. This differs significantly from simply running to a specific location, where no such time constraint exists. Similarly, walking on land vs. walking on a ship deck in high seas. Thus, it is argued that affordances are emergent properties of animal-environment systems (Stoffregen, 2003).

Perceiving affordances

On a daily basis, humans and other animals effortlessly navigate the world, engaging in actions that align with their current goals and their ability to interact with the environment. Therefore, it would be adaptive (in a Darwinian sense) if we had the capacity to perceive affordances as such. That is, it would be adaptive for us to perceive relations between properties of the animal and of the environment, rather than separately perceiving the animal and environmental properties and extracting affordance relations through some internal process. Indeed, it is hypothesized that the perception of affordances plays a significant role in natural selection, alongside other evolutionary concepts (Heras-Escribano, 2020). There is an abundance of experimental research demonstrating that humans and other animals have the capacity to accurately perceive affordances. A classic example is the study by Warren (1984), in which tall and short participants looked at stairways of different heights and reported whether each stairway was climbable or not. Obviously, we could predict that the likelihood of “no” responses would grow as stair height increased. But Warren predicted that this transition from “yes” to “no” reports would be discrete (i.e., sudden), rather than continuous (i.e., gradual). His prediction was confirmed (Figure 1). In addition, it seems self-evident that taller participants would response “yes” for higher stairs than

shorter participants (Figure 1 – A). However, Warren argued that this effect was an artifact of the common practice of measuring the world in extrinsic units (in this case, inches). Warren argued that, if affordances were perceived, then all participants should perceive stairs to be climbable as a constant proportion of their own height; 88% of leg length. Consistent with his prediction, when stair height was measured intrinsically (i.e., in units of leg length), both short and tall participants reported the maximum climbable height as being at 88% of the leg length (Figure 1 – B). Warren’s results demonstrated that the perception of action capabilities was linked to properties of the performer.

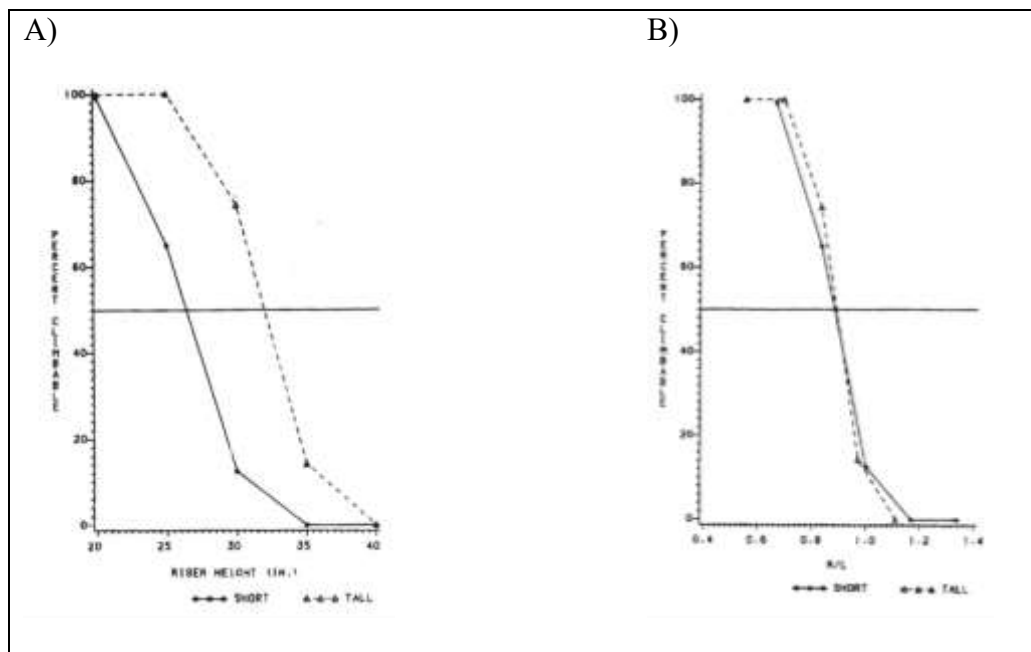


Figure 1 - The proportion of staircases that were reported to be climbable for short and tall participants. A. The X-axis is extrinsic, metric units (inches). B. The X-axis is intrinsic units (riser height/leg length). The horizontal solid line indicates chance, at which both responses (climbable or not) had 50% of occurrence. The location at the responses crossed the chance line was determined as the maximum climbable stair.

In addition to the perception of affordances for climbing stairs, affordances have been studied in a diverse range of common daily tasks, such as sitting (Mark, 1987), perception of

affordances for crossing the street in traffic (Lee et al., 1984), and perception of affordances for catching fly balls (Oudejans et al., 1996). Separately, other researchers have demonstrated that awareness of affordances (i.e., relations between animal and environmental properties) is more accurate than awareness of either animal properties or of environmental properties (e.g., Mark, 1987). As one commonsense example, few people know the metric length of their own legs, or the metric height of a stair or seat, but those same people report with great accuracy whether they can climb the stair or sit on the chair.

In sports, athletes must guide their actions based on the available affordances (Silva et al., 2013). Early studies (e.g., Oudejans et al., 1996) have inspired a large and growing literature on the perception of affordances relating to sports and sport performance. For example, Pepping and Li (2000a) investigated the perception of affordances for blocking in volleyball. Participants were asked to report whether or not a suspended volleyball was reachable with a jump under two different conditions (with vs. without added body weight). In the added body weight condition, participants gave lower maximum reach estimation than without added weight. Thus, participants perceived how the added weight altered their action capabilities. Relations between performers' action capabilities and their static (e.g., height) and dynamic (e. g., fatigue) properties has also been investigated in other sports, such as fatigue and climbing ability (Pijpers et al., 2007), dribbling ability and positioning cones to optimize ball touch in soccer (Duncan et al., 2022), power stroke speed and the selection of racquet string tension for badminton players (Zhu, 2013), and leg power and the use of rolling technique to jump off a wall of different heights in parkour (Croft & Bertram, 2017).

Affordances for receiving serves in volleyball

When the ball is served, the receiving team may touch the ball up to three times in returning it over the net. The first contact with the arriving serve is called the *serve receive*. In receiving serves, two methods are ubiquitously used: the underhand and overhead techniques (Figure 2). When employing the underhand technique, players bring their arms together in a supinated position, receiving the ball on their forearms (FIVB, 2011). In the overhead technique, players raise their hands above their head, spreading their fingers and receiving the ball on the fingertips (FIVB, 2011). Among skilled volleyball players, the overwhelming majority of serve receptions utilize either the underhand or overhead technique (Barsingerhorn et al., 2013).

Within the rules of volleyball, both the underhand and overhead techniques are afforded. In general, when the ball is served the receiving player must differentiate between them, that is, the player will determine which affordance is optimal. The utility of the underhand and overhead techniques may be influenced by many factors. One important factor is the height of the serve. If it is low (e.g., at the hip level), the underhand technique is likely, whereas if the serve is high (e.g., at the head level), the overhead technique is likely. (Cf. Barsingerhorn et al., 2013). At some intermediate height, the player should transition from overhead to underhand, or vice versa.

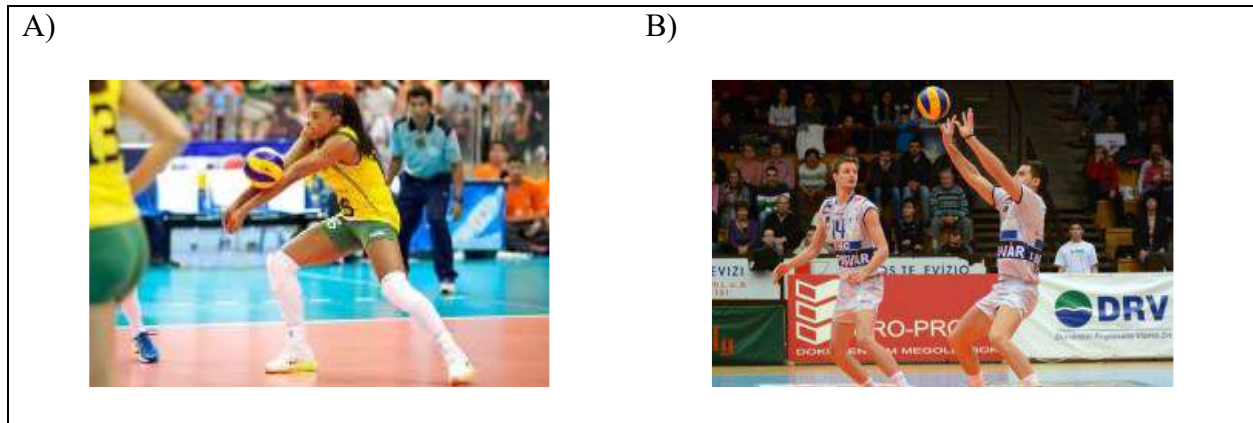


Figure 2 - Commonly used techniques to receive a serve in volleyball. A) Underhand technique. B) Overhead technique

In this dissertation, one of my primary goals was to evaluate the differential perception of affordances for the use of the overhead and underhand techniques as a function of controlled variation in the height of incoming serves. I predicted that, in general, skilled volleyball players would use the overhead technique in receiving higher serves, and the underhand technique in receiving lower serves, with a consistent transition between the two techniques as a function of controlled variations in serve height (Figure 3).

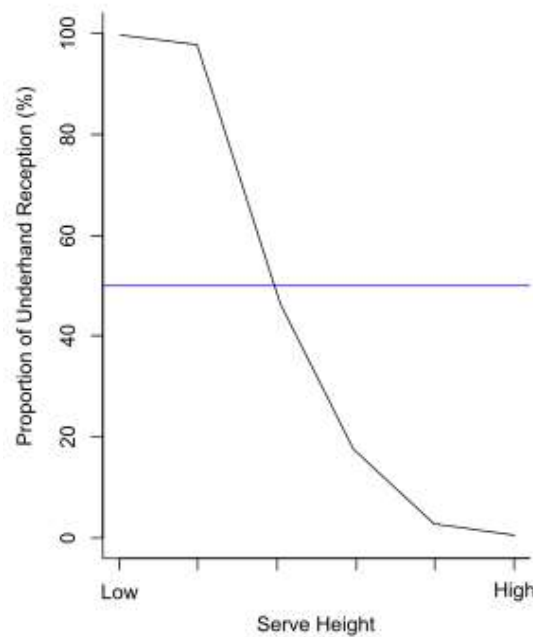


Figure 3 - Hypothetical result for transitions between serve reception techniques as a function of serve height.

Higher Order Affordances

Typically, both theoretical and empirical investigations have focused on individual affordances. That is, scholars have identified a particular affordance, and have attempted to define and formalize that affordance, or to assess the perception of that affordance. Examples include the affordance for aperture passing (Yasuda et al., 2014), for standing on a surface (Hajnal et al., 2018), for fitting hand through apertures (Ishak et al., 2008), and for walking (Walter et al., 2017). In each of those studies, participants were asked only to indicate their ability to perform an action designated by the experimenters. By contrast, other studies have been designed in such a way that participants were free to choose from among several available affordances. A notable example is the study of Gardner, Mark, Ward, and Edkins (2001), in

which seated participants were asked to reach for and grasp a target that was presented at some distance on a table. Participants could elect to use any of five different reaching actions: 1) Only using arm and/or torso (arm-torso), 2) sliding forward on the chair, 3) partially standing, 4) completely standing, or 5) locomoting. That is, the researchers identified five different affordances for reaching and grasping, and asked whether participants would choose among them on a systematic basis relating to the distance of targets. The results revealed that participants systematically selected action modes in relation to the distance of the target. For instance, when the target was within 90% of the individual's seated reaching distance all participants used the arm-torso mode, whereas when the target was beyond seated reaching distance participants used other reaching modes.

The study of Gardner et al. (2001) reminds us that, in general, in any given situation many actions are available, that is, there are many affordances. This fact, in turn, raises questions about how affordances relate to one another. Does each affordance exist as a separate and distinct entity? Or, are there relations among affordances that might be important for perception and action? These considerations have led to the development of the concept of higher order affordances (Wagman, Caputo, & Stoffregen, 2016). The concept is simple: Some affordances emerge from relations between other affordances. That is, some (higher order) affordances emerge from relations between other (lower order) affordances. Just as affordances can emerge from relations between properties of the animal and properties of the environment, Wagman et al., argued that (higher order) affordances can emerge from relations between (lower order) affordances.

Consider the situation where a person jumps and reaches to pick an apple from a tree. In this scenario, picking an apple could be considered a higher order affordance that has two lower order or subordinate affordances, an affordance for jumping (e.g., how high can one jump?) and an affordance for reaching (how far can one reach?). Several studies have been designed to permit evaluation of the hypothesis that higher order affordances might be perceived (Peker et al., 2023; Seifert et al., 2021a; Wagman et al., 2016; Wagman & Stoffregen, 2020). Wagman and Stoffregen (2020) explored how individuals perceive their ability to reach objects both with their bare hands and with the aid of a handheld tool that extends their reach. Using verbal instructions to an unseen experimenter, participants positioned a suspended object at the height they believed to be their maximum reachable point, separately for reaching with their arm alone and for reaching with a handheld gripping tool that extended their reach. Next, participants stood with their arms at their sides and positioned the suspended object (again, using verbal instructions) to the perceived height of their own shoulder, their own hand, and the distal end of the gripping tool. Following these verbal reports, the researchers measured the participants' actual reaching capabilities and anatomical properties. The results revealed that the reported affordances for vertical reaching with the tool did not align with a simple additive model based on the reported length of the arm or of the arm + tool. That is, the data were not compatible with the hypothesis that participants separately perceived the affordance for reaching with their arm alone, the affordance for reaching with the tool alone, and then combined those to yield their reports. Instead, they seemed to perceive the affordance for reaching as such. This result suggests that individuals perceive higher-order affordances directly, without the need to compute the lower-order characteristics of the task.

The notion of higher-order affordances has particular salience in many sports, where 1) there are many affordances (i.e., many actions that a player can take) and 2) the choice of actions is influenced by many situational factors. Consider soccer. It can be argued that, in game situations, there is no such thing as a generic “affordance for kicking the ball” but, rather, that there are separate affordances for “kicking the ball to different distances”, for “kicking the ball to teammates”, for “kicking the ball away from opponents”, and so on. This idea was explored by Peker et al. (2023), who conducted an investigation to analyze how soccer players perceived the affordance for kicking a soccer ball through a gap formed by two experimental confederates.

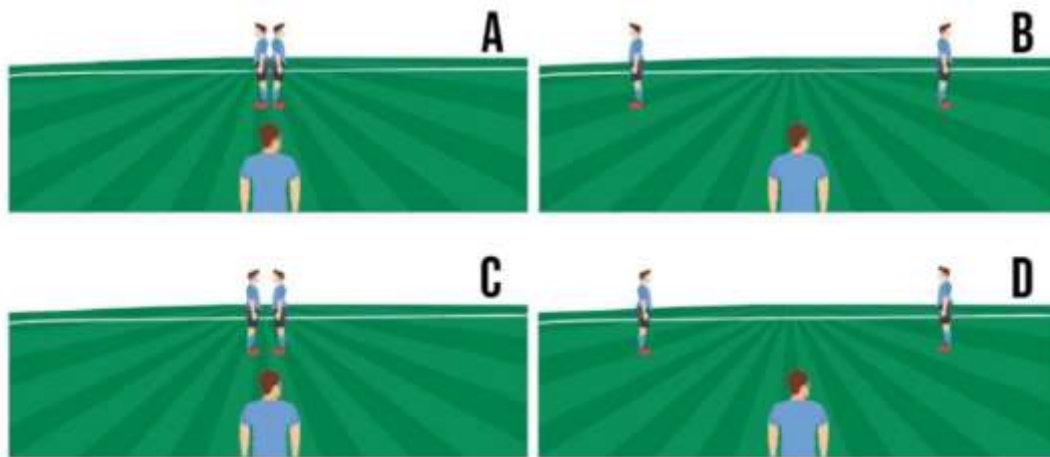


Figure 4 – The facing direction manipulation in Peker et al. (2023). A. Facing away condition, in which confederates were positioned back-to-back in the beginning of the trial. B. Facing away condition, confederates began the trial apart. C. Facing together condition with confederates beginning the trial face-to-face. D. Facing together condition in which the trial began with confederates apart.

The soccer players reported the minimum gap through which they could kick a soccer ball. Reports were obtained using the Method of Adjustment (Arruda et al., 2023; Mark et al., 1990; Stoffregen et al., 2009), wherein experimenters systematically manipulated the gap size, incrementally increasing or decreasing it until participants indicated that the minimum gap had been reached. The Independent Variables included the distance between the participant and the

gap; that is, the distance to which the ball would be kicked (10, 20, 30, 40 meters), the nominal role of the confederates who formed the gaps (Teammate vs. Opponent), and the positioning of the confederates (Facing Together, in which the two confederates stood facing each other, vs. Facing Apart, in which the two confederates stood facing away from each other). The latter two variables were independently manipulated to yield four gap configurations: (1) teammates facing each other, (2) teammates facing away from each other, (3) opponents facing each other, (4) opponents facing away (Figure 4). The results revealed a significant three-way interaction between kick distance, team, and facing direction (Figure 5).

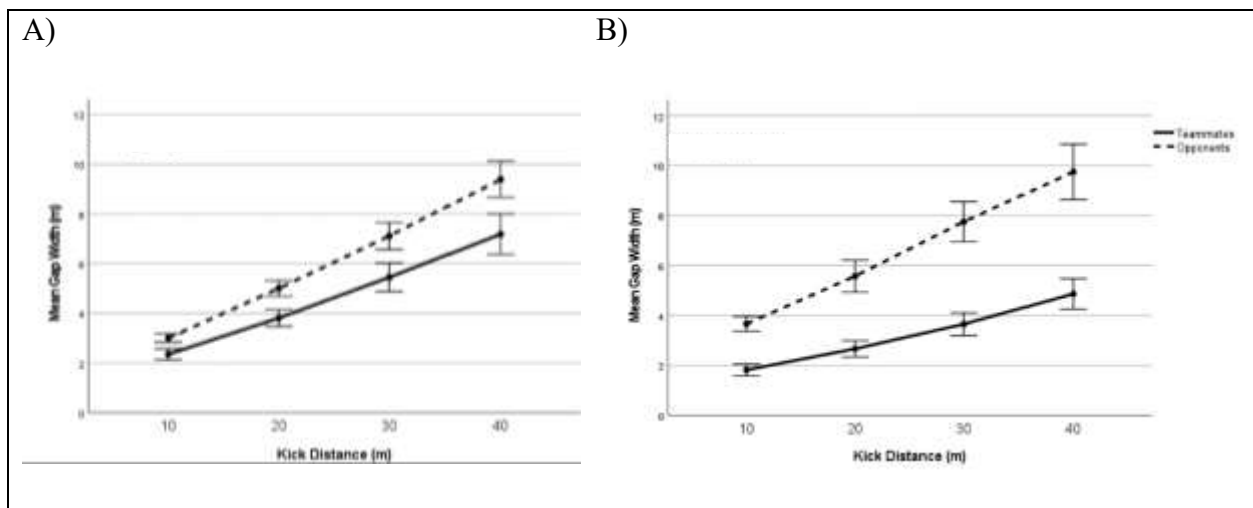


Figure 5 – The perceived minimum kickable gap size by kick distance (Peker et al., 2023). A) Facing away condition. B) Facing together condition. See text for details

This interaction indicated that the perceived minimum gap size was uniquely influenced by the combination of all of the factors, instead of additive models. In practice, what this means is that the gaps were not only perceived based on the physical distance of the players, but that the role of the player (teammate vs. opponent) and distance yielded a unique perceptual mechanism.

Pepping, Heijmerikx, and Poel (2011) designed a study to investigate affordances for kicking. While their primary focus did not center on investigating higher-order affordances, nor

did their design deliberately incorporate that framework, I assert that the findings lend themselves to interpretation within the conceptual framework of higher-order affordances. I believe that the results effectively showcase higher-order affordances in a practical context through the utilization of action. The investigation examined how soccer players performed passes under two distinct conditions: passing the ball to a stationary target or to a teammate. The researchers analyzed the employed technique and ball kinematics. Notably, all analyzed variables were influenced by the specific conditions of the pass (teammate versus target and/or distances). A clear demonstration of higher-order affordances can be viewed when examining ball speed, the results exhibited divergent trends across varying distances (Figure 6). This indicated that players tended to increase ball speed only for longer distances when passing to another teammate, while the opposite trend was observed in the alternate condition. Such findings underscored the perception of affordances as a higher-order construct, wherein the physical act of kicking serves as a subordinate affordance that conforms to the overarching affordance of the given situation—whether it involves passing to a teammate or targeting a stationary object.

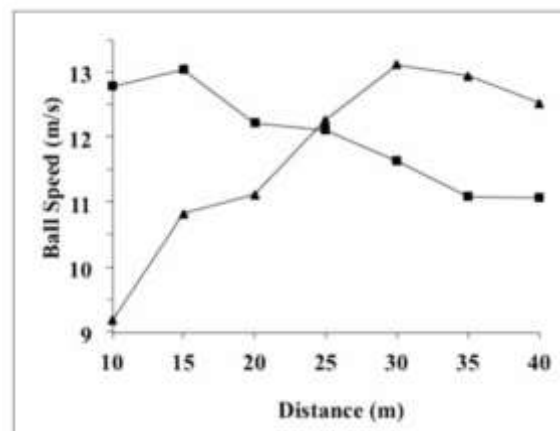


Figure 6 – Results from Pepping et al. (2011). Average ball speed in kicking for different distances. The triangles represent kicking to a teammate, whereas the squares represent kicking to a stationary small goal.

In conclusion, the notion of higher order affordances introduces the idea that multiple affordances can be perceived simultaneously. This represents a significant departure from conventional approaches in affordance research, which have typically focused on understanding singular affordances primarily linked to the physical attributes of the organism or its surroundings. Embracing this paradigm shift is crucial for advancing affordance research, as it enables a deeper exploration of the intricate interplay of nested affordances.

In this dissertation, I asked whether higher order affordances might emerge from relations between affordances for the overhead and underhand serve reception techniques, on the one hand, and on the other hand affordances for anticipatory adjustments (prior to serve reception) that could optimize a preferred serve reception technique. Specifically, I expected that skilled players' anticipatory whole-body movements would be systematically related both to controlled variations in serve height and to their own choice between the two serve reception techniques. My specific predictions will be explained separately for each experiment.

Affordances: Sex Differences

Amid the many diverse investigations on affordances, one variable has remained conspicuously overlooked within the field—sex. Many studies have compared male and female athletes (e.g., Bradley et al., 2014; Fuchs et al., 2019; Hilenio et al., 2023; Hughes et al., 2010; Kitsiou et al., 2020; Lima et al., 2019; Paulo et al., 2009; Salci et al., 2004; Sattler et al., 2015), but very few of those comparisons have included any consideration of affordance perception. Many studies have addressed affordances that are influenced by both static (e.g., stature) and dynamic (e.g., speed) properties of the body, but few have addressed the fact that affordances

might differ by sex. In my study, I included sex as an independent variable. I did this for two reasons: one relating to general principles of fairness and study design, and one related to particular characteristics of volleyball.

A new default

Few studies have included sex (i.e., male vs. female) in the analysis and definition of affordances (that is, in terms of the properties of the individual that enter into affordance relations) or in terms of the perception of affordances. In this regard, the study of affordances resembles many other fields of study, in which sex is not treated as an independent variable. In a recent analysis of male bias in the collection and interpretation of data in many areas of study, Perez (2019) noted that in many fields little is known about possible sex differences, and that this lack of knowledge often stems from characteristics of study design. Historically, women often were simply excluded from studies of human behavior, physiology, health, and from studies of affordances (e.g., Warren, 1984). More recently, changes in administrative constraints (e.g., NIH rules) mean that many studies now include both women and men. Yet this latter group often fails to yield information about possible sex differences. Perez points out that the inclusion of both males and females as research participants cannot provide information about possible differences between the sexes if the data are analyzed in terms of group means; that is, if means are computed across samples that include both males and females. This approach characterizes the majority of existing research on affordances (e.g., Bhargava et al., 2020; Ishak et al., 2008; Masoner et al., 2020; Zhu, 2013). Perez advocated the adoption of a new research standard, in which the default study design not only includes both males and females but also treats Sex as an independent variable in inferential analyses.

Sex differences in affordance perception

Much of the existing research on affordance perception has focused on affordances that are related to physical properties of the animal, such as anthropometrics: leg length (e.g., Mark, 1987; Warren, 1984), arm length (e.g., Mark et al., 1997; Yonas & Hartman, 1993), and dynamic properties that are related to size and strength, such as running speed (e.g., Oudejans et al., 1996). Women and men characteristically differ in all those properties. These anthropometric sex differences may explain the fact that most existing research has given scant attention to the possibility that individual differences in affordances might usefully be understood in relation to sex. In many cases, sex has been deliberately excluded as a variable. For example, Warren (1984) included only male participants, while Mark (1997) included only females. Neither author offered any discussion of possible sex differences in affordances or in the perception of affordances. When samples have included males and females, results have not been analyzed on the basis of sex (Barsingerhorn et al., 2013; S. M. Lopresti-Goodman et al., 2009, 2009; Mark et al., 1990; Postma et al., 2018). Fortunately, a few studies have incorporated sex in their analysis. Those will be discussed next.

The first investigation on affordances including sex as independent variable was conducted by Pepping and Li (2000b) who compared sexes on the perception of overhand reaching. The researchers asked participants to verbally report whether they could reach a suspended ball with both hands without jumping in two different conditions: wearing wooden blocks of 15 cm high underneath their shoes or without the wooden blocks. Subsequently, the investigators measured their actual maximum reach. The results revealed a significant main effect of sex and condition, suggesting that males perceived greater reaching heights, and all

participants perceived increased reach capability when wearing the wooden blocks. However, when transforming the perceived height to an intrinsic measure considering maximum actual reach (perceived height divided by actual maximum reach), the effects of condition and sex dissipated, indicating that the earlier observed effects were attributed to variances in anthropometrics. The authors discussed that affordances are specified independently of height and sex; instead, they are expressed in action-scaled terms, as demonstrated by the results. The study by Pepping and Li (2000b) illustrated that the effects attributed to sex differences might primarily arise from variances in anthropometric measurements. However, this assertion warrants careful interpretation, particularly considering that the study focused solely on one task with specific characteristics.

Lopresti-Goodman et al. (2010) examined how males and females perceive affordances for passing through apertures. Participants walked through apertures of varying widths while the researchers observed whether they rotated their hips. Separately, participants verbally estimated whether they could pass through the aperture with or without hip rotation. Half of each group wore form-fitting lycra clothes, and the other half wore loose-fitting jogging suits. The dependent variable was the gap width at which participants turned their hips, expressed as a ratio in intrinsic units – mean gap width divided by hip width. The performance results indicated that the sex effect was significant only in the loose-fitting clothing condition, in which males had a higher ratio than females. For the verbal reports, clothing condition had no significant effects. However, the main effect of sex was significant, with women having a smaller ratio than men. The authors reasoned that the perceptual main effect of sex aligns with the notion that women tend to possess greater body awareness compared to men. They suggested that this heightened body awareness

in women may stem from chronic societal influences, wherein the sexual objectification of women's bodies is prevalent, while societal pressures on men's bodies are comparatively weaker. The results from Lopresti-Goodman et al. are relevant to my study because they demonstrate that sex differences may arise independently of anthropometric variations.

Zheng et al. (2022) compared male and female soccer goalies. On a soccer pitch, goalies stood in the middle of the goal and attempted to stop (or “save”) penalty kicks. Kickers attempted to target kicks either to the left or right end of the goal, and either attempted or did not attempt to deceive the goalie about their kicking target. One of the factors analyzed was the number of times each goalie dove to the correct side. The results revealed a statistically significant interaction between kicker intent and goalie sex, with post-hoc analysis indicating that female goalies were less likely to dive to the correct side when the kicker had deceptive intent, while the males were less affected by deceptive intent. Zheng et al. attributed this sex difference to different movement strategies that players learned through their playing experience. They speculated that, potentially, in women’s soccer, the deceptive kicks might be less common than in men’s soccer. If that were true, then goalies in women’s soccer would have less experience (and, presumably, less skill) in saving deceptive penalty kicks. Their speculation remains untested.

In the case of sports, investigating sex differences is relevant. Many sports have the same rules for men and women, yet anecdotal observations (as well as occasional empirical studies, e.g., Zheng et al., 2022) suggest that aspects of game play often differ between the sexes. Thus, it is reasonable to ask whether the perception of sport-specific affordances may also differ between sexes. As shown in Figure 1, Warren (1984) compared tall versus short participants and found

that group differences existed when perceptual data were scaled extrinsically (riser height in meters) but were absent when data were scaled intrinsically (riser height as a proportion of leg length). On average, men are taller than women and for this reason, it might be argued that sex differences would appear when affordance data were scaled extrinsically (e.g., in meters, meters/second, and so on; cf. Figure 1 – A) but should disappear when data were scaled intrinsically (cf. Figure 1 – B). It is important to note that sex differences in height are correlated with many other sex-related differences in other factors, such as strength, and speed (Podstawski et al., 2020). Yet there may also be sex differences that do not correlate with height. Following the logic of Perez' (2019) argument, the only way to find out is to conduct the relevant research, that is, to include sex as an independent variable in experimental design and data analysis. Thus, in my study, separate analyses of data that are scaled extrinsically and intrinsically allowed me to ask whether there might be sex differences in volleyball serve reception that are independent of sex differences in anthropometrics.

Sex differences in serve reception

Men's and women's volleyball have distinct characteristics, evident across various quantitative and qualitative dimensions. Quantitative disparities include metrics such as amount of errors (Lima et al., 2019), rally length (Hileno et al., 2023), serve speed (Palao, 2014), and vertical jump height (Sattler et al., 2015). Additionally, the differences are also qualitative, such as serve type, in which most females use the float jump serve while most males use power jump serve (Kitsiou et al., 2020). While volleyball techniques are accessible to both men and women, their utilization may diverge. As will be described in detail in Chapter 2, one such difference exists in the choice of techniques used in receiving serves. When a serve arrives over the net, a

player on the receiving team must make a choice about how to receive that serve in passing it to a teammate. The most common techniques for receiving serves are shown in Figure 5.

Palao, Manzanares, and Ortega (2009) reported an observational study from a professional adult volleyball tournament. The results revealed that although both sexes used the underhand technique most of the times (90% for men and 93% for women), the use of overhead technique significantly differed, with male participants using it 6.5% and females 3%. In this study, the minimal sex differences may stem from the serve type prevalent in men's volleyball, namely the jump power serve, which renders the overhead technique difficult or nearly impossible. Otherwise, when receiving float serves, male players might have opted for the overhead technique more frequently. For instance, when receiving float serves, adult male professional athletes used the overhead technique 25.3% of the time (Paulo et al., 2016). In contrast, female players generally displayed a lower inclination towards the overhead technique, as evidenced by Echeverría et al.'s (2019) findings indicating a range of 3.3% to 5.4% usage. Those observational studies might indicate a sex disparity in the preference for overhead versus underhand technique when receiving float serves. While there are no direct studies comparing the technique use between males and females, there exists a prevalent belief within the volleyball community that women employ the overhead technique less frequently than men (VolleyTalk, 2007). This sentiment is echoed in my own coaching experience spanning 12 years and over 15 years of playing experience. This experience-based perception is one of the motivations for developing this study.

Also, no previous studies have systematically investigated the influence of serve height on the selection of serve receiving techniques for either men or women. In accordance with the

affordance literature, it is possible that sex differences would arise from anthropometric factors, such as maximum reach or strength. For example, executing the overhead technique in volleyball necessitates applying adequate stiffness to the fingers for ball control. Therefore, disparities in finger strength could contribute to different utilization rates of the overhead technique among females, given that females typically exhibit lower finger strength compared to males (Khanna & Koley, 2020). Yet it is also possible that the sex difference arises from factors that are not correlated with height. This possibility is demonstrated by the study of Zheng et al. (2022) who found that male and female soccer goalies differed in their ability to perceive deceptive intent in players making penalty kicks. Thus, in the present study, I did not make a prediction about the results when serve reception data for males and females were scaled to participants' body size.

The variation in techniques employed by women and men provides a compelling rationale for utilizing volleyball as a platform to explore the interplay between affordance perception and sex. I designed my experiments to investigate the possible existence of sex differences in the influence of serve height on the choice between the overhead and underhand technique in receiving serves. I expected that male and female players would differ in transition curves when serve height was defined extrinsically (Figure 7 - A). If sex differences in serve reception are related solely to player height (and factors correlated with player height, such as strength), then the results should resemble Figure 7 - B when serve height was expressed as a proportion of player height. On the other hand, if there are sex differences in serve reception that are not related to player height (or factors correlated with player height; cf. Perez, 2019), then we might expect a different result when serve height was expressed as a proportion of player height (Figure 7 - C).

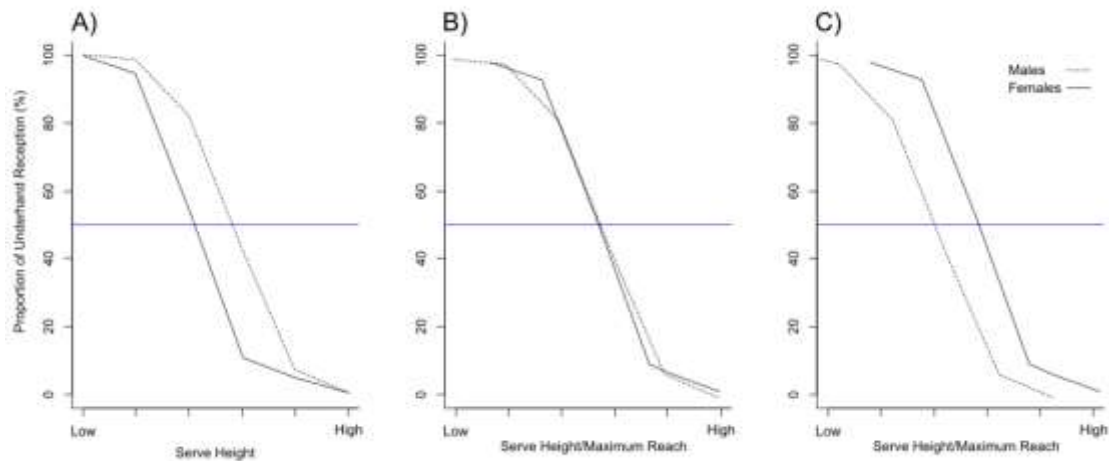


Figure 7 - Hypothetical result for receiving serves of different heights in volleyball. A) Serve height as an extrinsic metric (meters). B) Results with serve height expressed as a proportion of players' maximum vertical reaching ability, if sex differences arise solely from factors correlated with player height. C) As B, but hypothetical data if sex differences arise, in part, from factors not correlated with player height.

Using action metrics to investigate affordance perception

Research on the perception of affordances has predominantly relied on verbal reports. Typically, participants have been asked to state whether a given action was possible (e.g., Warren, 1984) or to use verbal instructions to adjust a parameter to fit with a perceived affordance (e.g., Peker et al., 2023). While this method is suitable for relatively static situations, it presents inherent challenges when applied to dynamic tasks. In scenarios where affordances dynamically emerge or dissipate due to rapidly changing environmental conditions and performer interactions, the limitations of relying solely on verbal reports become evident. In such cases, a better approach is to infer the perception of affordances from action rather than from verbal reports. Action-based methods embrace the foundational idea that perception is embodied rather than a separate entity (Stefanucci et al., 2021).

One example is the study by Seifert et al. (2018), who investigated the perception of affordances in rock climbing. They asked how affordance perception changed for intermediate

climbers after four sessions of practice using three different climbing walls. The data were not verbal reports. Rather, affordance perception was inferred from motion analysis. By asking the participants to use motion sensors, the authors identified five movement patterns: (1) the stationary state, with no movement at all; (2) posture regulation, in which the center of mass changed but the limbs remained on the same holds; (3) hold exploratory movements, where the hip was stationary but the limbs changed position or orientation on the hold; (4) the hold change, when the performer changed the hold followed by body motion; (5) the performatory state, in which the climber moved their hips while moving at least one limb. After training, as expected, subjects increased performance measures as indicated by the reduced number of falls and ascent duration. In addition, in the transfer test, the participants reduced the duration of exploratory movements, suggesting that they increased their perception of hold graspability as they could perceive it much faster. The authors also noted that participants' immobility decreased over the sessions, suggesting that participants were attuned to a landscape of nested affordances; instead of identifying each affordance step by step, the entire route was perceived as such.

Inferring affordance perception from action allows the researcher to study the perception of affordances in rapidly changing, naturalistic situations in which there is reason to believe that the use of perception in the guidance of action is not mediated by deliberative conscious awareness of the type required for verbal reports. In addition, the study of affordance perception during actual performance may give researchers insight into relationships between perception and action that are excluded from deliberative conscious reports. Rather than reactively choosing between two or more affordances, people may use affordance perception actively to adjust situations so as to optimize the availability of a preferred affordance. For example, in a rapidly

changing game situation, a player who wishes to use a particular action or technique might rapidly adjust their own position or motion in ways that increase the availability or reliability of that action or technique. To accommodate this possibility in my study, I included measures of players' movements above and beyond the simple, "black versus white" selection of the overhead versus underhand techniques. This approach allowed me to ask whether players might engage in whole body movements that might be systematically related to their choice of the overhead versus underhand techniques.

Virtual Reality as a method to investigate affordance perception using action

Given the challenges in using action and realistic situations to investigate perception (e.g., controlling of independent variables), virtual reality may offer a useful strategy. Virtual reality (VR) is an evolving technology that has been used in many contexts, such as engineering, education, healthcare, real estate, retail, military, video games, live events, and video entertainment (Zhao et al., 2019). One type of virtual reality system is the head-mounted display (HMD). This is a headset with motion sensors and one or multiple displays that fill most of the user's visual field. Data on head movements (obtained from the embedded motion sensors) is used to update the visual displays in real time, yielding a naturalistic sensation of "presence". For instance, it is possible to stand on a virtual street where the user can look, walk around, and even interact with virtual objects. Walking, head movements, and even body sway function as real-time inputs to the display system, thereby allowing uniquely compelling VR experiences. This aspect of the technology makes HMD systems extremely valuable for research in the field of perception-action (Craig, 2013), which emphasizes the fact that skilled movement is routinely

used to generate and obtain perceptual information and, in particular, to perceive affordances (Gibson, 1986).

Since HMDs allow users to move more naturally within the virtual environment, using this tool could be an effective way to investigate affordance perception in sports. Some researchers have successfully replicated classical affordance experiments in HMD systems, such as perception of “reachability” and “passability” (Bhargava et al., 2020; Masoner et al., 2020). These studies were of limited value as researchers inferred affordance perception from verbal reports.

Other researchers have made better use of the dynamism that HMDs offer by designing experiments in which affordance perception was inferred from action within the virtual environment. Correia et al. (2012) created an HMD setup for studying affordance perception in rugby. The HMD presented virtual 3 vs. 3 rugby scenarios in which the participant (rugby players and non-players) was with two other teammates, in a line formation facing three approaching opponents also in a line formation. Participants did not make verbal reports. Rather, the participant was required to either pass the ball to teammates or to keep the ball and run. In different conditions, the experimenters manipulated the gaps between opponents in a way that those gaps would potentially present different affordances for passing or running. Thus, as the opponents were running towards the participant, the opponents could run in a straight line (not changing gaps), or one of the three opponents would run at a different angle and dynamically change the gap between opponents, that, in turn, would afford different optimal solutions (Figure 8).

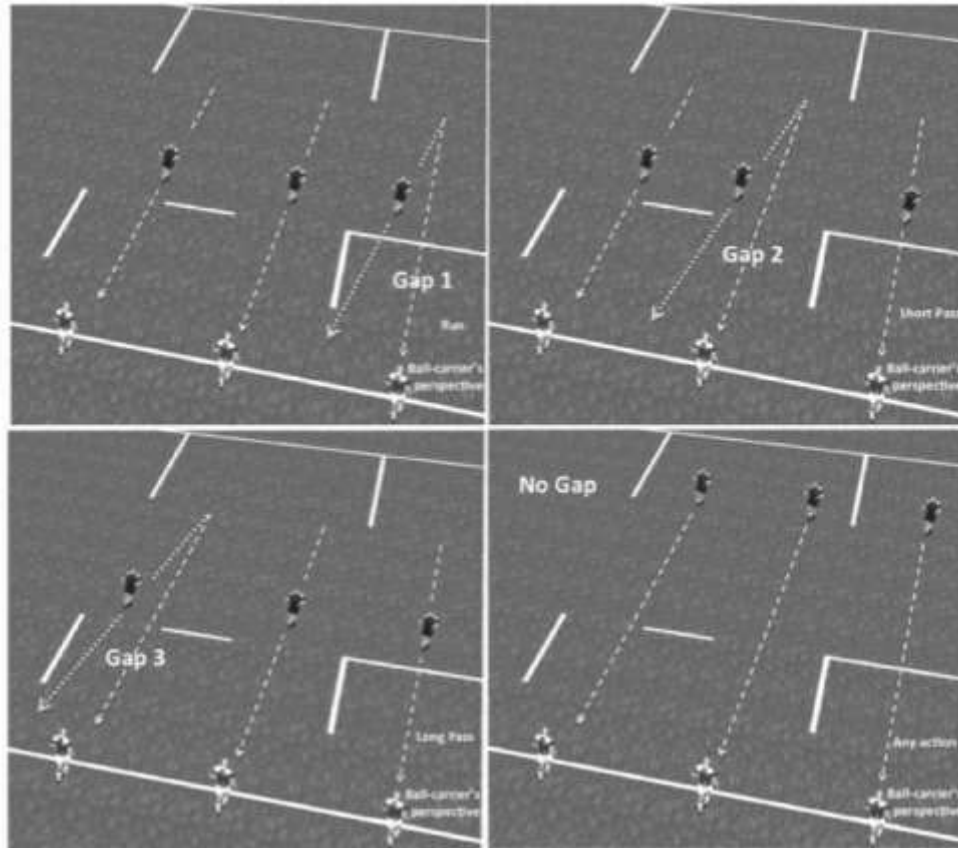


Figure 8 - The conditions used by Correia et al. (2012). The participant's perspective is represented by the right player on the bottom. For gap 1, the best option would be run; for 2, executing a short pass; for 3, executing a long pass, and for the no gap condition, there was no considered best solution.

The results revealed that players and non-players responded differently. When virtual gaps were far away, rugby players opted to pass, while non-players did not. This study, which remains unique, demonstrated 1) that HMDs can be used to study affordance perception in sports, and 2) that HMDs permit assessment of affordance perception from action decisions, without the need for verbal reports. The study of Correia et al. (2012) demonstrated that head-mounted VR can be used to evaluate affordance perception through measures of action, rather than verbal reports. In the present study, I inferred affordance perception from action metrics in head-mounted VR relating to volleyball.

Anticipatory movement in affordance perception

As demonstrated by Correia et al. (2012), head-mounted virtual reality systems make it possible to use data on body movement to infer the perception of affordances. While this technique is valuable, it does not exhaust the potential utility of data on body movement that are available when using head-mounted virtual reality systems. In my research, I used data on hand movements to infer the perception of affordances for the overhead and underhand serve reception techniques. In addition, I went beyond Correia et al. (2012) by acquiring and analyzing quantitative data from the sensors in the HMD headset. Those data served as a measure of participants' whole-body movements. In these analyses, my focus was on body movement before serve reception; that is, anticipatory whole-body movement before the contact between the ball and the hands. Analysis of those data permitted me to evaluate the hypothesis that players perceived higher order affordances for the optimization of particular serve reception techniques. Such analyses were made possible by my use of a head-mounted virtual reality system.

Purpose of the Study

I designed my research to simultaneously investigate several interrelated factors. First, I sought to understand affordance perception in naturalistic, rapidly changing game settings in volleyball. I did this by creating a virtual volleyball game that could be presented through a head-mounted display, such that I could infer the perception of affordances from participants' actions within the game (i.e., their use of either the overhead or underhand technique in receiving serves), rather than from verbal reports. Second, I asked whether participants might perceive higher order affordances for moving in ways that could optimize the availability of 'preferred' affordances for game play. I did this by recording and analyzing kinematics of body movement

that were logically distinct from the overhead and underhand techniques. Third, I asked whether known sex differences in volleyball playing technique (i.e., males more likely than females to use the overhead technique) might be reflected in affordance perception in virtual volleyball and might be independent of known sex differences in static anthropometrics.

I evaluated the following hypotheses:

- H1: In a head-mounted virtual environment, experienced volleyball players would replicate classical transition curves (e.g., Warren, 1984) for the differential perception of affordances for two types of actions used in receiving serves in relation to controlled variation on the height of serves (Figure 3).
- H2: Participants in men's and women's volleyball would exhibit different transition curves when serve height was expressed extrinsically (in meters), consistent with the existing literature on sex differences in receiving serves in volleyball. When serve height was expressed as a proportion of players' maximum vertical reach height, the result will reveal whether sex differences either solely or only partly arise from factors that are correlated with players' height (Figure 7).
- H3: Prior to ball-hand contact, participants would engage in body movements that were systematically related to serve height, suggesting perception (and actualization) of higher order affordances for "moving to optimize serve reception".

Chapter 2: Perception of affordances for receiving serves in virtual volleyball:

Serve height and anticipatory whole-body movement in women and men

Introduction

To thrive in sports, athletes must accurately perceive affordances within the sport context. Numerous studies have delved into this domain as a pivotal avenue for advancing our comprehension of affordance perception. Examples include research on the perception of affordances for catching a fly ball in baseball (Fink et al., 2009; Oudejans et al., 1996), perception of affordances for jumping in gymnastics (Peker, Erkmén, et al., 2020) and in basketball (Weast et al., 2011), for shooting the puck in ice hockey (Hove et al., 2006), for kicking in soccer (Peker, Böge, et al., 2020), and hitting in badminton (Zhu, 2013). In general, existing research has demonstrated that players of a particular sport exhibit perceptual sensitivity to affordances that are specific to that sport. While several sports have been investigated, many remain to be investigated. One of these is volleyball.

To date, only one study has experimentally investigated the perception of affordances in volleyball. Arruda et al. (2023) asked participants (skilled volleyball players) to report the smallest space into which they could serve the ball. On a physical volleyball court, participants stood in normal serving position (i.e., behind the back line). On the other side of the net the experimenters placed “traffic cones” to designate areas of the court. The position of the cones could be adjusted to change the size of the designated areas. In different conditions, participants were asked to report the smallest area into which they could serve the ball in relation to the side boundary, or in relation to the net. The data were participants’ verbal reports. The use of verbal reports was reasonable, given that in volleyball games players make conscious choices about

serving technique before they execute a serve—they “decide what to do” before they do it. By contrast, in this dissertation I chose to focus on the perception of affordances in situations that have greater time pressure, such that verbal reports cannot be representative of perception in game situations. Rather than asking players what they could do, I presented them with situations in which they were required to take action, and I inferred the perception of affordances from those actions.

As discussed in Chapter 1, few studies have considered the possibility that there may be sex differences in affordance perception. This fact is surprising as most sports are separated by sex and have significant differences in the actions displayed in the game. Sex differences have been identified in multiple sports, comparing the employed techniques during the game (Palao et al., 2009), emotional regulation (Millán-Sánchez et al., 2023), and physiological characteristics (Bradley et al., 2014).

Therefore, sports not only offer an optimal venue for affordance research in general, but it also opens new possibilities to deepen our understanding of sex differences regarding affordances.

Receiving serves in volleyball

When the ball is served, the receiving team may touch the ball up to three times in returning it over the net. The first contact with the arriving serve is called the *serve receive* or *serve reception*. It is vanishingly rare for the receiving player to attempt to return the ball directly over the net. Generally, serve reception leads to a pass; that is, the player who receives the serve attempts to pass the ball to another member of their own team (FIVB, 2011). Thus, the player receiving the serve must not only intercept the ball but, in the same movement, pass the ball to a

teammate. In receiving serves, two methods are ubiquitously used: the underhand and overhead techniques (Figure 9). When employing the underhand technique, players bring their arms together in a supinated position, receiving the ball on the forearms (FIVB, 2011). In the overhead technique, players raise their hands above their head, spreading their fingers and receiving the ball on the fingertips.

Within the rules of volleyball, players could elect to receive arriving serves with a wide variety of techniques. That is, many types of reception are afforded. However, as noted above, in practice skilled players use only the overhead and underhand techniques. Thus, we can say that both the underhand and overhead techniques are afforded and that, in general, when the ball is served the receiving player must decide which affordance is optimal. The choice between the underhand and overhead techniques should be influenced by many factors, such as the position and motion of the player's own body, and the time available to prepare to receive the ball.

Another important factor is the height of the incoming serve, relative to the player's position on the court. If the trajectory of the serve causes the ball to arrive at a low height (e.g., at the hip level), the underhand technique is likely to be used, whereas if the ball arrives at a higher height (e.g., at the head level), the overhead technique is likely. Serve height is closely related to serve distance, that is, the point at which the ball would hit the court if not received by a player.

Barsingerhorn et al. (2013) evaluated the choice between the overhead and underhand techniques as a function of whether the serve would fall in front of or behind the receiving player, and they found that players were more likely to use the underhand technique for serves that would land in front.

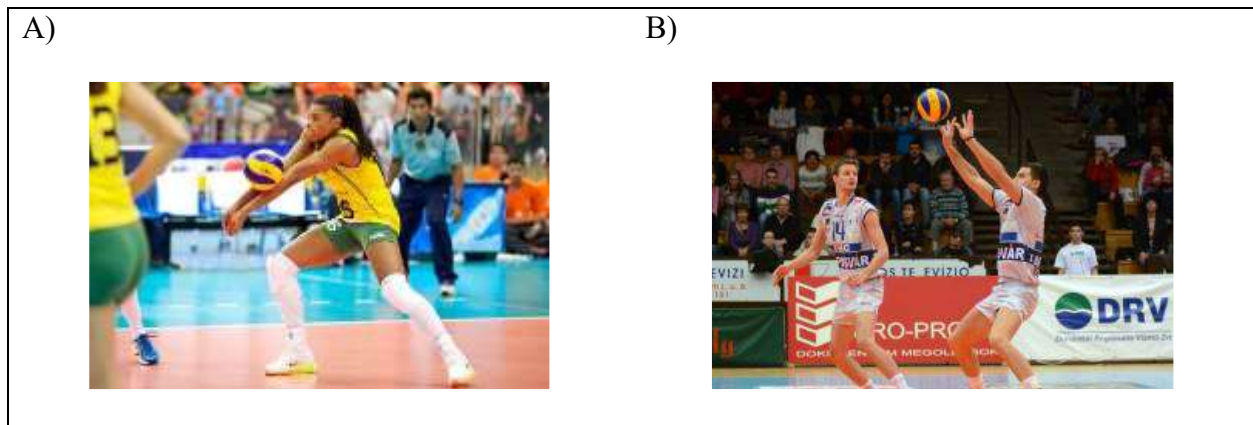


Figure 9 - Commonly used techniques to receive a serve in volleyball. A) Underhand technique. B) Overhead technique

Some observational studies have systematically assessed the utilization of underhand and overhead techniques in volleyball. Palao and colleagues (2009) conducted an analysis including 28 international volleyball matches, encompassing both women's and men's national teams. The predominant trend identified was the prevalence of the underhand technique, which emerged as the most used technique for both male and female players. Specifically, men utilized the underhand technique in 90.6% of serve receptions, while women exhibited a slightly higher rate at 93.4%. In contrast, the employment of the overhead technique was comparatively limited, accounting for 6.5% and 3% of serve receptions among males and females, respectively.

Sex differences in serve reception

In general, existing studies have not compared male and female players in terms of serve reception techniques. Most studies have included only one sex in their samples. González Silva et al. (2021) and Benerink et al., 2015 evaluated only male players, while Echeverría et al. (2019) evaluated only female players. While these studies are suggestive, they do not provide direct evidence of sex differences in the reception of volleyball serves. Studies that have included

both male and female participants (e.g., Barsingerhorn et al., 2013) have not analyzed for possible sex differences. An important aim of my study was directly to compare serve reception in skilled male and female volleyball players.

When responding to controlled variations in serve height, sex differences in the use of the overhead and underhand techniques might emerge from sex differences in height. Men are taller than women, which would imply that the theoretical transition point (action boundary) between utilizing underhand and overhead techniques should be higher for men (cf. Cole et al., 2013). This would naturally lead to differences in technique use between the sexes. Similarly, sex differences in height may be related to anticipatory movements that are used in receiving serves (cf. Zheng et al., 2022). Individual serves often do not arrive precisely at a player's position. Rather, in many cases, perhaps most cases, the player must move (forward, backward, or sideways) to position themselves to receive the serve. Taller players (e.g., men) would tend to make different anticipatory movements (e.g., smaller or slower) than shorter people (e.g., women). There are likely to be many such potential sex differences that are related to height. However, there may also be sex differences in receiving serves that are not related to the simple size difference between the sexes. As per Perez's (2019) argument, the most effective means to evaluate possible sex differences is to incorporate sex as an independent variable in experimental design and, in data analysis; that is, to compare the sexes.

Higher order affordances: Moving to optimize a preferred technique?

Volleyball, as most team sports, is highly dynamic, with spatial and temporal constraints, that significantly affects players' actions (Alfonso et al., 2010; González-Silva et al., 2020). To receive serves in volleyball, players have about a second to position themselves to properly

contact the ball (Paulo, Davids, et al., 2018). During that second, the way the players move, or change their position in relation to the ball significantly affects the affordance landscape. For instance, if the ball arrives a bit above the head, a player can use the overhead technique to pass (Figure 10 – Position A). However, the same trajectory also affords the underhand technique if the player moves backwards (Figure 10 – Position B). This was demonstrated by Barsingerhorn et al. (2013). In their research, volleyball players engaged in a serve-reception task on a volleyball court without a volleyball net. The experiment involved a person tossing the ball towards the participant at varying distances: three in front of the participant, one directly at the participant, and three behind the participant. The participant's goal was to pass the ball to a teammate in front of them. In the “choice condition”, participants had the freedom to choose between the overhead and underhand techniques. Performance was assessed by calculating the percentage of trials in which the teammate successfully caught the passed ball within a fixed area. At the beginning of each trial, the participant stood in a designated place on the court, but they were free to move before receiving the ball. The findings from the choice condition revealed that participants predominantly employed the underhand technique for serves that were in front of the starting position, and the overhead technique for serves that were behind the starting position. Because players were free to move before receiving the ball, it is likely that they did so, for example, adjusting their location or orientation in response to the trajectory of individual serves. Such anticipatory movements were recorded but were not analyzed by the authors. The authors focused on serve reception and on the success of consequent passes but did not consider the possibility that participants might have perceived higher order affordances for “anticipatory whole-body movement that would optimize a particular reception technique”. In addition, since

that study the study lacked rigorous control over key variables such as serve trajectory, distance, velocity, and height, it is likely that the researchers did not attempt to identify an affordance boundary or transition between the overhead and underhand techniques.

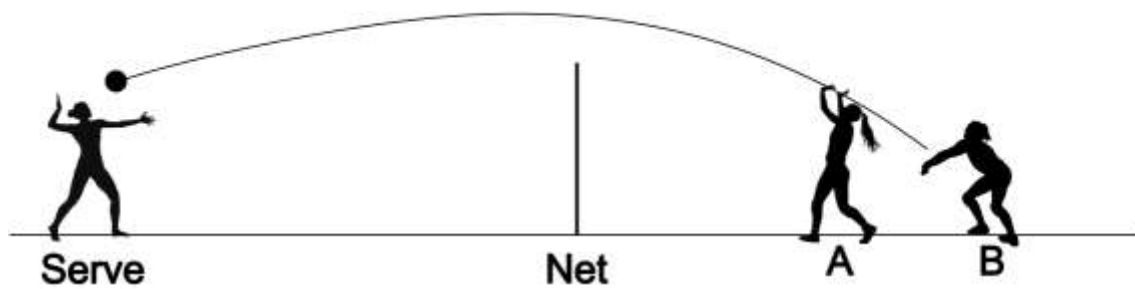


Figure 10 – Volleyball situation in which a serve can afford different reception techniques. Players can move to position A, if they want to use overhead, or position B if they want to use underhand.

The anticipatory movements that players perform might make a certain affordance available or unavailable. For example, a player can increase the likelihood of using overhead by always moving forward, while other can move backward to increase the likelihood of using underhand. These anticipatory movements are afforded. That is, for players on the court, moving forward, backward, and side-to-side are available actions. Movements forward and backward will influence the height (relative to the player's body) at which a serve arrives and, therefore, the serve reception technique that is optimal. Thus, it may be that forward and backward movements reflect the prior perception of a higher order affordance for “moving to optimize a preferred reception technique”.

The primary objective of this experiment was to assess whether a virtual environment can effectively induce distinct affordances that are dependent on serve height and sex, akin to those observed in real-world volleyball. My central hypothesis was that there would be a systematic

transition between the underhand and overhead serve reception techniques as a function of controlled variations in serve height (Figure 3), as suggested by previous research (Paulo, Zaal, et al., 2018). My second hypothesis was the transition curves would differ between male and female participants, when the data were extrinsically scaled (Figure 7 - A). I did not make a specific prediction about effects of sex when the data were intrinsically scaled in terms of maximum vertical reaching height (Figure 7 - B, C). Lastly, I hypothesized that when analyzing anticipatory whole-body movements, the main effect of serve height and sex would be significant.

Methods

Participants

Forty-two individuals participated. Of those, five females were excluded because of corrupted data. Also, three females and one male were excluded because they never used the overhead technique. After those exclusions, the final dataset included sixteen members of a women's volleyball community (age: 20.4, height: 1.72 ± 0.06 m, weight: 66.8 ± 7.21 kg) and seventeen members of men's volleyball community (age: 20.6, height: 1.86 ± 0.09 m weight: 79 ± 10.3 kg). I included only participants with at least three years of experience who had played at least two hours per week consistently in the past year. The average playing experience was 7.12 and 9.19 years for participants from women's and men's communities, respectively. Weekly practice sessions averaged 3.81 and 4.62 hours for participants from women's and the men's communities, respectively.

Apparatus

A head-mounted display (HTC Vive Pro Eye, with a horizontal field of view of 110 degrees) was used to display the virtual environment (Figure 11 - A). To allow mobility, the headset was tethered to a gaming computer using suspended cables. To track the movement of the hands one HTC tracker was strapped to each of the participant's wrists (Figure 11 - B). The wrist trackers were used to render virtual hands and forearms, and also to collect data on participants' choice of serve reception techniques.

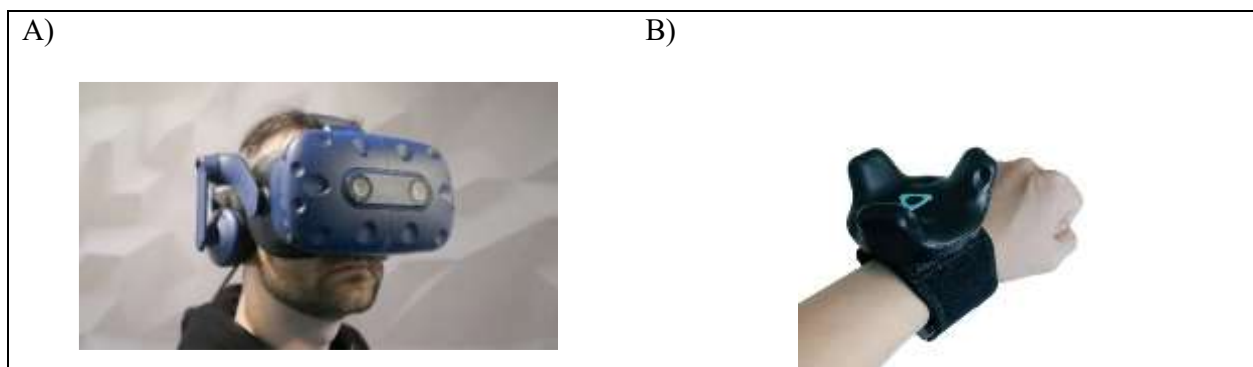


Figure 11 - VR equipment used for the experiment. A) Head-mounted display HTC Vive Pro Eye. B) HTC Vive Tracker

Task

As participants arrived for the experiment, the researcher explained the procedures and obtained informed consent. The study was conducted within a virtual environment developed using the Unity Engine, designed to simulate a standard volleyball court with a net height of 2.35 m. This net height was chosen to align with the common standard used in coed volleyball. In addition to the volleyball net, a distinct target was strategically positioned adjacent to the net. This target took the form of a 1 m x 1 m square, situated 2m above the floor at its center and tilted at a 45-degree angle. The primary purpose of this target was to provide participants with a tangible reference point for passing the volleyball during the course of the experiment. The

experiment was conducted in a dedicated room with an open space with dimensions of 4m x 4m, providing enough area for naturalistic volleyball movements. For all the trials, the participant was instructed to begin at the center of this area.

In the VR application, participants were alone on a volleyball court. Positioned at the opposing end line, a "pitching machine" was placed 9m away from the net and 4.5m from the sidelines. This apparatus was designed to emulate serves by propelling volleyballs toward the participant with precision. The ball release point was 2.75m high. I selected this height because it is the height between women's and men's volleyball float serves (Moras et al., 2008). The participant's goal was to simulate a serve-receive as if they wanted to pass the ball to the target in front of them. The whole experiment setting can be viewed in Figure 12.

A)



B)



C)



Figure 12 - Virtual Environment used in the experiments. A. General view of the court. The blue circle represents the starting position of the participant. B. General perspective of the participant. The ball launcher can be seen beyond the net. C. The served ball passing over the net toward the participant.

Procedure

As the participants immersed in the virtual environment, I adjusted their virtual arms, usually making them larger or smaller, until the participant felt that the arms were a good representation of their real arms. Subsequently, participants were asked to move to a 1m diameter

blue circle on the floor positioned 4.5m away from the sideline, and 6.5m away from the net (Figure 10). This location was used throughout the experiment as their initial position to pass. I selected this distance because it was found that 6.5m is a location on the court that affords both underhand and overhead techniques in real volleyball (Paulo, Zaal, et al., 2018). Next, the participant was asked to raise their arms with elbows extended above their head, This position was used to measure the participant's maximum reach (Figure 13).



Figure 13 - Demonstration of the position adopted to measure maximum reach

Subsequently, within the virtual environment, there was a panel with instructions about the experiment, indicating the number of trials, informing the participants that they could use the technique they saw fit and move as they wish as long as they started on the circle. Also, I verbally instructed participants that they should perform as they would do in real volleyball. If the participant did not have any questions, the experimenter would give a warning signal and toss the ball by pressing a key on a computer. To diminish the potential adaptation and learning effects

from the virtual environment, as soon as the ball came into contact with the participant, the ball disappeared. This was an adequate strategy to prevent adaptation or learning effects from the VR environment.

The experiment comprised of one warm-up block with six trials (not used in the analysis), and five regular blocks with six trials each. In each block, the ball arrived at the participant's position at 6 different randomized heights, 1m, 1.25m, 1.50m, 1.75m, 2m, and 2.25m. Participants were allowed to rest as long as they needed between trials and blocks. The total participation time per participant was around 10 to 15 minutes.

In order to ensure that the ball arrived at the determined location, I kept a constant release angle and manipulated the release velocity of the serve using the kinematic equations for projectile motion (Lithio & Webb, 2006). The ball was served with a 20 degrees release angle at approximately 15m/s. This angle was selected because it yields serves with a flight time of 1.05s on average, which is a flight time that both sexes face in real games when receiving float serves (Palao, 2014). In addition, I set a drag component in unity of 0.1, which is commonly found in conventional volleyballs (Asai et al., 2010). To accommodate the influence of drag in the projection equations, the target's height was adjusted in the calculations. This adjustment ensured that the virtual ball accurately reached the intended experimental locations despite the drag effect.

Data Analysis

For demographic data, I used *t*-tests to compare weight, and maximum reach between women's and men's participants. To analyze the use of overhead and underhand techniques, for each height, I computed the proportion of underhand use, where zero indicated no use of that

technique and one indicated that the underhand was used for all the trials. Also, to investigate the role of sex while accounting for differences in maximum reach, the analyses were performed using serve height in meters and a relative serve height, which was calculated as the serve height divided by the participant's maximum reach.

To analyze the underhand use proportions a generalized linear model was implemented, with a logit link and a quasibinomial family using the function “*glmmPQL*” from the *Mass* package in R. This approach is commonly used to investigate proportions when investigating affordance perception (Gagnon et al., 2021; Postma et al., 2018). To account for the repeated measures effect, I included a random intercept for the participant effect.

The anticipatory movements were obtained through the coordinate system from the built-in headset system. The movements were analyzed considering the lateral displacement, vertical displacement, and backward-forward displacement prior to touching the ball. The displacement was calculated as the positional difference between the moment the ball was served and the moment the participant contacted the ball. This variable indicated how much the participant moved before making contact with the ball for all the three axes of movement. Similarly to the technique analysis, I also considered one analysis using the serve height in meters and another one using the relative serve height. When considering serve height in meters, a 2x6 ANOVA was used in R using the package *ezANOVA*. Sex was included as a between-subject variable and serve-height was a within-subject variable. When analyzing the relative serve-height, a linear mixed-effect model was employed using the package *lme4* in R, predicting the kinematic variable by sex and relative serve height with a random intercept for the repeated measure effect.

Results

Weight and maximum reach significantly differed between groups, $t(31) = 3.92$, $p < .001$, $d = 1.37$ and $t(31) = 4.68$, $p < .001$, $d = 1.63$, respectively. Specifically, the mean weight and standard deviation (SD) for women were 66.8 kg (SD = 7.21) and for men 79 kg (SD = 10.3). Additionally, women had a maximum reach (measured by the wrist sensors) of 1.92m (SD = 0.089) while men had a maximum reach of 2.09m (SD = 0.116).

Serve reception techniques

The results are summarized in Figure 14. For serve height in meters (Figure 14 - A), the effect of serve height was significant ($B = -1.37$, $SE = 0.12$, $t(163) = -11.46$, $p < 0.001$), indicating that as serve height increased, the underhand technique proportion decreased. The main effect of sex and the serve height $\times$ sex interaction were not significant.

For serve height as a proportion of maximum reaching height (Figure 14-B), the main effect of serve height was significant ($B = -10.68$, $SE = 0.95$, $t(163) = -11.29$, $p < 0.001$). In addition, the main effect of sex was significant ($B = -2.28$, $SE = 1.10$, $t(31) = -2.06$, $p = 0.048$), indicating that females had a higher proportion of underhand use. The serve height $\times$ sex interaction was not significant.

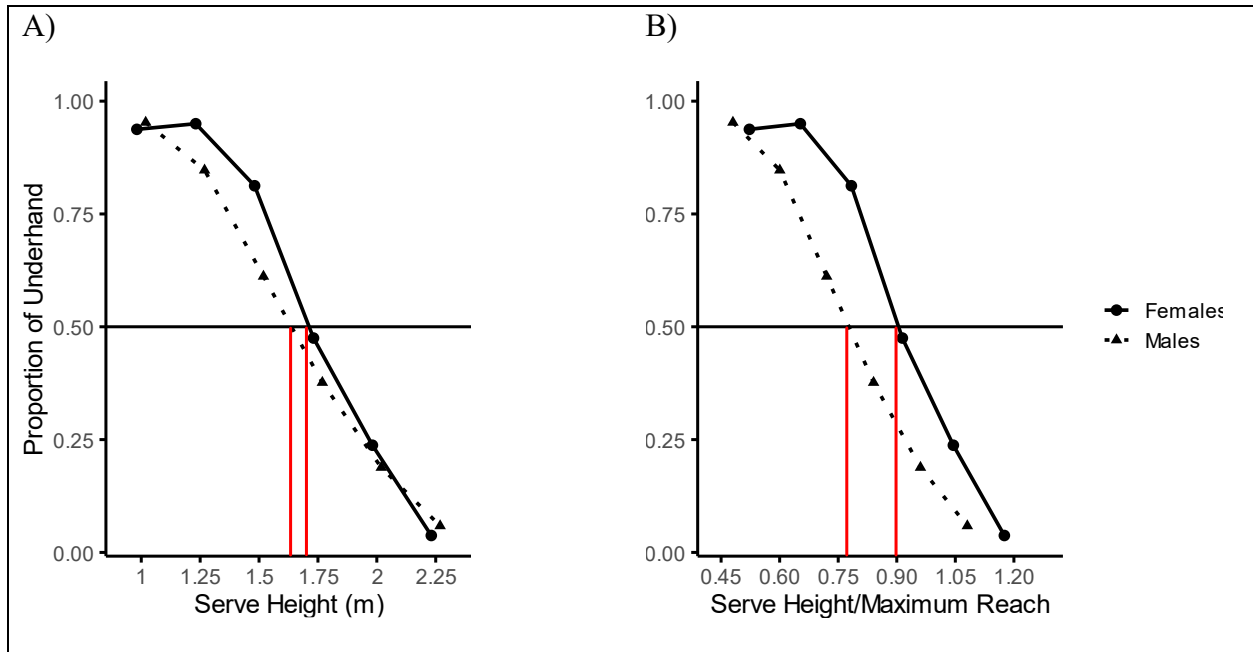


Figure 14 – Experiment 1. The proportion of underhand serve receives as a function of serve height and sex. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. The red lines represent the 50% action boundary. For A, the 50% boundary did not differ significantly between women and men. For B, the 50% boundary differed significantly between women and men.

Anticipatory whole-body movement

For movement in the forward-backward axis, the results are summarized in Figure 15. Most displacement occurred in the backward direction. When expressed in meters (Figure 15 - A), the effect of serve height was significant ($F(1.99, 61.59) = 51.11, p < .001$, partial eta-squared = .62). Higher serves were associated with greater movement. The effect of sex was significant ($F(1, 31) = 4.93, p = .034$, partial eta-squared = .14), revealing that females exhibited more movement compared to males. However, the sex $\times$ serve height interaction was not significant.

When expressed as a proportion of maximum reaching height (Figure 15-B), the effect of serve height was significant (Estimate = -0.527, Std. Error = 0.048, $t(163.85) = -10.915$, $p < 0.000$). The effect of sex and the sex $\times$ serve height interaction were not significant.

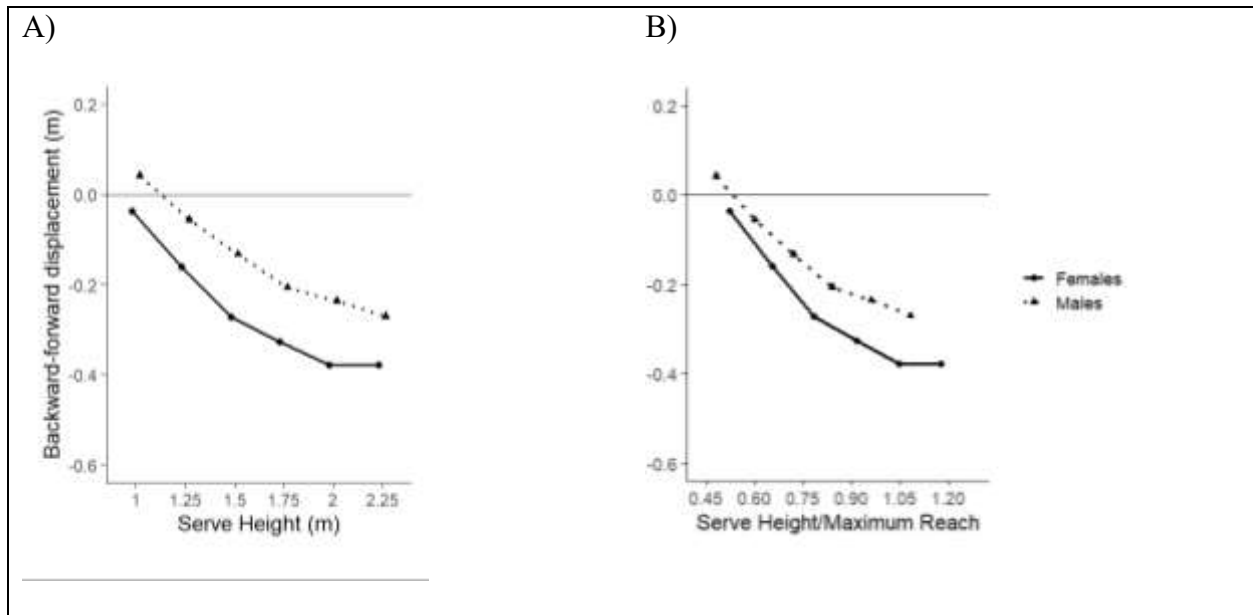


Figure 15 – Experiment 1. Headset displacement on the backward-forward axis. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. Negative numbers indicate backward displacement whereas positive indicates forward displacement.

The results for headset vertical displacement are summarized in Figure 16. For serve height in meters (Figure 16 - A), the effect of serve height was significant, $F(3.38, 104.83) = 237.28$, $p < 0.001$, partial eta-squared = 0.88. Higher serves were associated with greater vertical displacement. The main effect of sex was not significant. However, The sex $\times$ serve height interaction was significant, $F(3.38, 104.83) = 3.96$, $p = 0.008$, partial eta-squared = 0.11.

For serve height as a proportion of maximum vertical reach (Figure 16 - B), the effect of serve height on vertical displacement was significant, Estimate = 0.483, Std. Error = 0.024, $t(163.86) = 19.63$, $p < 0.000$. Similarly, the effect of sex was significant (Estimate = -0.110, Std.

Error = 0.038, $t(122.90) = -2.84$, $p = 0.005$), as was the sex $\times$ serve height interaction (Estimate = 0.169, Std. Error = 0.035, $t(164.05) = 4.75$, $p < 0.000$).

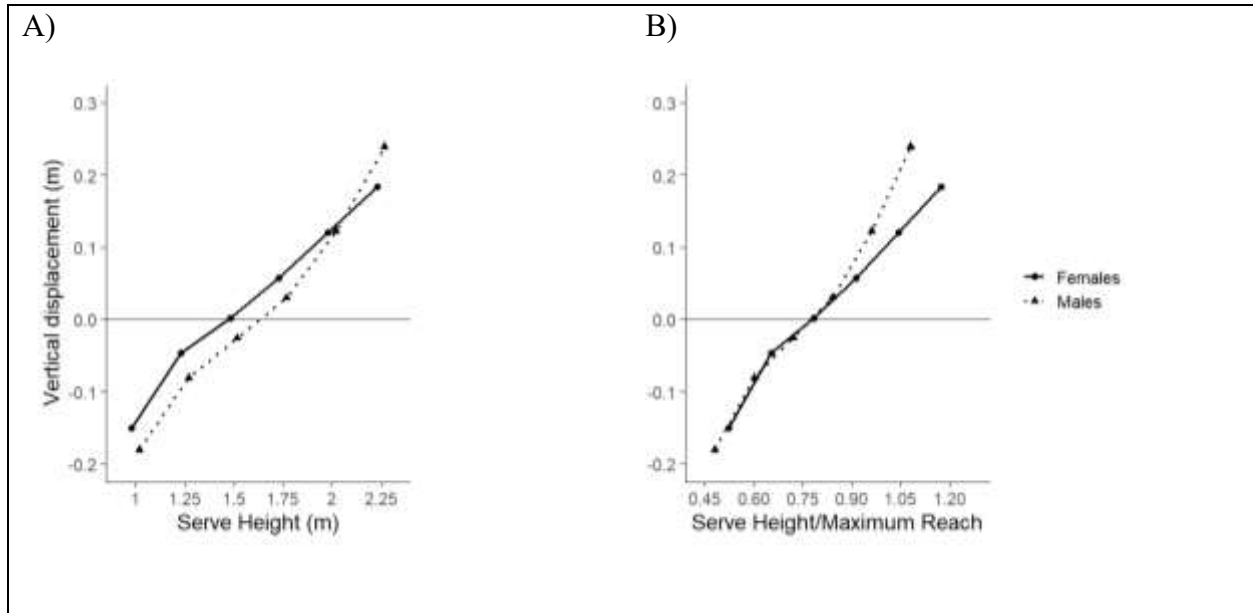


Figure 16 – Experiment 1. Headset displacement on the vertical axis. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. Negative numbers indicate downward displacements whereas positive indicates upward displacement.

The results for headset lateral displacement are summarized in Figure 16. For serve height in meters (Figure 17 - A), the effect of serve height was significant, $F(3.87, 120.08) = 4.28$, $p = 0.003$, partial eta-squared = 0.12). The main effect of sex and the serve height $\times$ sex interaction were not significant.

For serve height expressed as a proportion of maximum reaching height (Figure 16 - B), the effect of serve height was significant (Estimate = 0.057, Std. Error = 0.027, $t(164.92) = 2.046$, $p = 0.042$), but sex and the serve height $\times$ sex interaction were not significant.

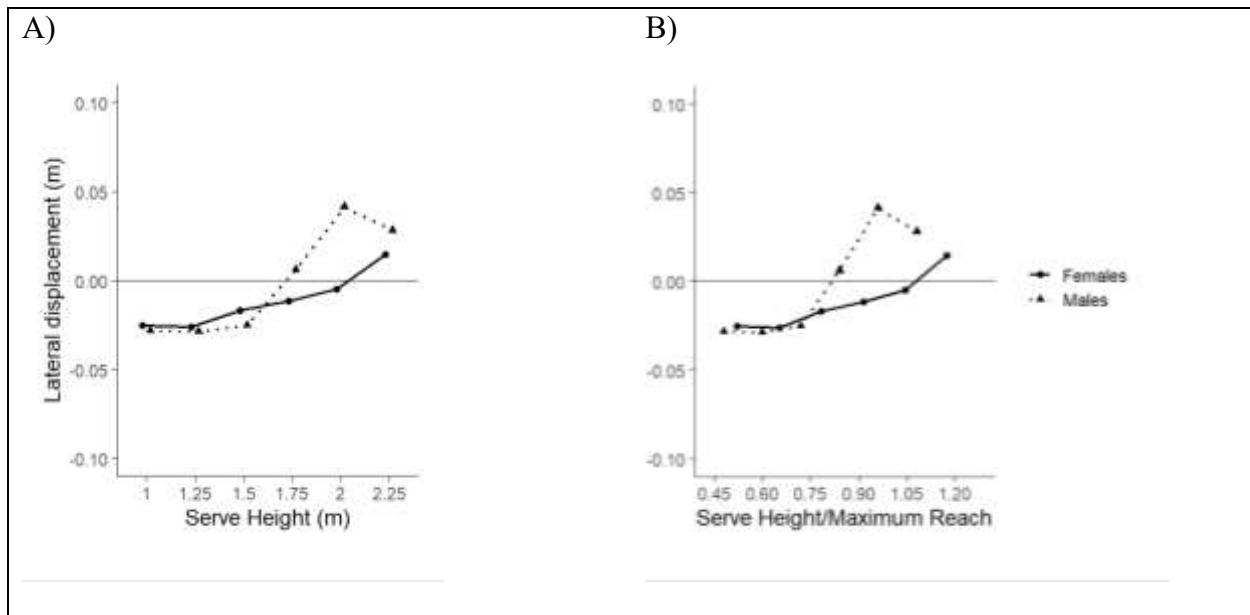


Figure 17 – Experiment 1. Headset displacement on the lateral axis. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height

Discussion

In this study, I hypothesized that the use of overhead versus underhand techniques in serve reception would vary systematically with serve height, exhibiting a clear transition between techniques consistent with the general literature on affordance perception. Additionally, I anticipated that those transitions would differ between women and men as a function of extrinsic serve height (i.e., serve height in meters). Finally, I expected that anticipatory whole-body movements also would vary systematically with extrinsic serve height. In separate analyses, I evaluated reception techniques and anticipatory movements when serve height was expressed intrinsically (i.e., as a proportion of participants' maximum vertical reaching height). In this chapter, I separately discuss 1) general effects of serve height on participants' choice of serve reception techniques, 2) sex differences in serve reception techniques and 3) anticipatory whole-body movements in relation to serve reception techniques.

Serve reception techniques

When analyzing the underhand proportion, serve height was a significant factor in determining the use of the passing technique as hypothesized. The shape of the curves neatly matched the results reported by Warren (1984); for example, compare Figure 1 - A with Figure 13 - A. Volleyball players, even in VR, systematically perceive different affordances given different serve heights, similarly to volleyball in the real world as demonstrated in previous research. For instance, Paulo et al. (2018) analyzed how ball kinematics, among other variables, affected the used technique to receive serves in volleyball. The results indicated that higher serves decreased the likelihood of using the underhand technique. A similar result was also found by Barsingerhorn and colleagues (2013), with males and females decreasing the use of underhand technique as the ball was higher in relation to their position on the court. The observed transition from underhand receptions for lower serves to overhead for higher serves may be attributed to the regulation of movement economy (Sparrow & Newell, 1998). For instance, when the serve is high (e.g., 2.25 m), the energy needed to step backward using legs and receive the serve using underhand is significantly greater than simply raising the arms to execute an overhead technique. Previous research has demonstrated that arm movements typically entail lower energy expenditure compared to leg movements (Chiu et al., 2009). While moving backward or forward may naturally arise, as will be explored later, these strategies could be energetically demanding or impractical due to time constraints in many instances.

Sex differences in serve reception

In Experiment 1, sex differences relating to serve reception were not significant when the data were expressed extrinsically (i.e., serve height in meters; Figure 14 - A). However, effects

relating to sex were significant when the data were expressed intrinsically (i.e., as a proportion of maximum vertical reach; Figure 14 - B). This result is different from studies including groups with varying anthropometric characteristics. A well-established result in affordance research indicates that groups with varying anthropometric characteristics exhibit differences when results are articulated in extrinsic units (e.g., meters) – taller people can reach higher, smaller people can fit into smaller apertures, etc. However, when data are expressed in intrinsic units (e.g., body-scaled), these group disparities disappear (Konczak et al., 1992; Warren, 1984; Warren & Whang, 1987). For instance, in investigating perception of affordances for stair climbing, Warren 1984 transformed staircase height into a relative measure, in which stair height was expressed as a proportion of the participant's leg length. This adjustment eliminated the group differences between short and tall individuals. However, these studies did not investigate sex differences. For instance, Warren (1984) only included male participants and Konczak (1992) did not disclose the sex distribution in the selected sample. Pepping and Li (2000b) compared men and women, and found that they did not differ when scaling affordances intrinsically, indicating that perception of affordances for maximum overhead reach were similar for women and men. Such results are interpreted as indicating that the perception of affordances is qualitatively similar across variations in body scale; that is, that individuals perceive affordances in relation to their own body.

The differences between my results in Experiment 1 and previous affordance research may stem from the fact that the serve-receive task has additional complexities. Such as, multiple affordances were available (overhead and underhand), participants were free to move, and the task had a timing constraint – participants had about one-second window between the ball's

release and the moment of contact to select a serve reception technique. It might be the case that for more complex tasks, other factors beyond anthropometrics might also play a role. The observed sex differences in Experiment 1 could be attributed to variances in anticipatory movements, particularly because individuals can intentionally favor one technique over another by moving backward or forward, as illustrated in Figure 10. For instance, Zheng et. al., (2022) investigated how male and female goalkeepers performed (physically blocking the kick) against deceptive and non-deceptive penalty kicks in a real scenario in which players kicked penalty shots on goal. The authors found that male and female goalies used different movement strategies that were not solely related to the physical differences between the sex (kicking velocity and movement time). In particular, female goalies were more susceptible to kickers' deceptive actions. Zheng et al. (2022) proposed that females exhibit greater susceptibility to deceptive kicks due to their movement strategy of initiating dives earlier than males, thereby relying on potentially misleading information, particularly as motion of the kicker before ball contact often contains deceptive cues. The authors speculated that women might choose this behavioral pattern because of its efficacy in responding to non-deceptive kicks, which are potentially more prevalent in women's soccer. As demonstrated by the sex differences in saving non-deceptive kicks, in which females were better than males.

Therefore, following from the findings of Zheng et al. (2022), male and female volleyball players might adopt sex-specific anticipatory movements, each honed through their individual experiences and perceptual attunement (Harrison et al., 2016). It is possible that those distinct anticipatory movements (movements that occur before contacting the ball) arise from factors that are not solely (or primarily) related to anthropometrics. Since movement abilities were not

manipulated in this experiment, I cannot determine that the result on technique differences was caused by movement. This was the main motivation for Experiment 2 (described in Chapter 3). As for why the sexes would systematically adopt different anticipatory movements will be discussed in detail in Chapter 4.

Anticipatory whole-body movements

Men and women have different anthropometric characteristics (Podstawski et al., 2020). One consequence of the physical differences between the sexes is well-documented sex differences in ubiquitous behaviors, such as the control of standing body sway (e.g., Era et al., 2006) and movements in sports, like the spike in volleyball (Fuchs et al., 2019), or dunks in basketball. For this reason, I anticipated that the anticipatory whole-body movements would differ when comparing the groups.

The analysis on anticipatory headset movement (that is, movement prior to hand-ball contact) was performed in three axes: backward-forward, side-to-side (lateral), and vertical. For each axis, I separately analyzed the data as a function of serve height expressed in meters and expressed as a proportion of maximum vertical reach. In each of those six analyses, the effect of serve height was statistically significant. The uniformity of these results demonstrates that participants chose to engage in anticipatory whole-body movement, and that those movements were tightly constrained by the controlled variations in serve height. Although most studies investigating affordances have not included movement analysis, there is a plethora of research in the sports field indicating that players of many sports systematically adjust their kinematics given different task constraints. For example, different release angle when throwing a basketball from different distances (Cabarkapa et al., 2022), changing maximum hip angle when performing

kicks on taekwondo from different distances (Kim et al., 2010), and changing the movement initiation time for hitting a ball with different trajectories in cricket (Sarpeshkar et al., 2017). Therefore, the consistent impact of serve height on movement patterns suggests that participants were not only responsive to the distinct techniques (overhead and underhand) but also adapted corresponding body movements, mirroring real-life scenarios. This outcome effectively demonstrates that my manipulation in VR successfully elicits realistic behaviors.

In addition to serve height, sex and the serve height $\times$ sex interaction were found to be statistically significant for specific axes of movement. I will examine each axis individually and discuss the corresponding effects below.

The largest displacement was noted along the forward-backward axis. Based on Experimenters' observations during data collection, this movement primarily consisted of steps, with players alternating between stepping forward and backward. Given that the ball was served toward the participant's initial position, I anticipated that most of the movement would be along this longitudinal axis. Movement in this direction alters the ball's height relative to the participant, allowing them to take an optimal position for using their selected technique. The magnitude of backward movement differed between the sexes when the data were expressed in meters (Figure 14 – A), but not when results were expressed as a proportion of maximum vertical reach height (Figure 14 – B). The observed sex effects in the extrinsic units might be a result of differences in anthropometrics. Given that females are shorter, they may have needed to move a greater distance to position themselves optimally for receptions. However, no previous affordance investigations have analyzed the relation of sex and movement variables when performing tasks. However, research examining affordances for road crossing has revealed

disparate results between children and adults concerning movement variables when confronted with varying temporal gap sizes between cars (Chung et al., 2020; O’Neal et al., 2018). The significant effects observed could potentially be linked to anthropometric distinctions between children and adults. Also, the absence of a significant sex effect in Figure 14 – B suggests that all participants stepped further back as serve height increased—that is, as serve height approached their own maximum vertical reach. Stepping backward ensures that the ball arrives at a lower height, placing players in a comfortable position to utilize their preferred technique.

Regarding vertical headset displacement, Experimenter observations during data collection suggested that vertical displacements were related to changes in the stance. In general, while awaiting a serve, participants adopted a posture characterized by feet placed apart, knees slightly bent, and a forward-leaning trunk. That posture aligns with coaching manuals (FIVB, 2011) and other investigations (Lenoir et al., 2005). Participants combined this stance with stepping, and they typically lowered their head to reach lower serves (often utilizing underhand techniques) or stood up to reach higher serves (often employing overhead methods). These adaptive movements naturally resulted in fluctuations in vertical headset displacement. The results for headset vertical displacement revealed a significant interaction for sex and serve height for extrinsic (Figure 16 – A) and intrinsic measures (Figure 16 – B), demonstrating that the sexes used different strategies when employing the techniques over the varying serve heights. The differences for the intrinsic measures might reflect distinct movement strategies as discussed in the technique differences. By employing certain anticipatory movements, players could position themselves more optimally to perform their preferred technique. For instance, it is conceivable that females might transition to an overhead technique for higher serves by

minimizing vertical displacement and increasing backward movement. It is noteworthy that in Experiment 1, players rarely jumped when receiving serves. This observation will be important in motivating Experiment 2.

Regarding lateral displacement, the only significant effect was serve height for both meters (Figure 17 – A) and relative (Figure 17 – B). Although this axis had the least magnitude in displacement, it seems to be systematically controlled in relation to serve height, as demonstrated by the significant effect. The limited magnitude observed along this axis could be attributed to the receivers' proficiency in making contact with the ball while positioning their body behind it, as suggested by Street (2018). In the context of the present experiment, participants would have no incentive to move laterally as the ball was served directly at them.

Limitations

The principal limitation of Experiment 1 was the absence of any controlled variation in participants' anticipatory whole-body movements. In effect, my data on body movement in three axes were observational and bear only a correlational relation to my data on the choice of serve reception techniques.

Conclusion

In Experiment 1, skilled volleyball players responded to the virtual volleyball task as they would do in real volleyball. In particular, I found that players' choice of serve reception techniques (overhead vs. underhand) was systematically related to controlled variations in the height of serves, as would be expected in volleyball games. This result also supports my prediction that participants would perceive that affordances for serve reception (i.e., the relative utility of the overhead and underhand techniques) would vary with serve height, consistent with

general findings in the literature on affordance perception (e.g., Warren, 1984). In addition, the results demonstrated that investigating sex differences might be relevant for affordance research. Men and women differ in anthropometrics (e.g., height), but they also differ in many other factors. My results suggest that there may exist sex differences in affordances, and/or in the perception of affordances that do not arise solely from sex-related differences in anthropometrics.

In addition, the findings also demonstrated differences in anticipatory whole-body movements. Prior to ball-hand contact, patterns of headset displacement (which I used as a proxy for whole-body movement) varied systematically with serve height, even when serve height was expressed intrinsically. The fact that both serve reception and anticipatory whole-body movement varied systematically with serve height means that they also varied systematically with each other, and on that basis, I argued that participants might have perceived higher order affordances for “moving to optimize a preferred serve reception technique”.

In Experiment 1, data on anticipatory whole-body movements were observational, in the sense that my experimental design did not impose any controlled variation in anticipatory whole-body movement. To determine whether participants (both men and women) perceived higher order affordances relating to the selection of the overhead and underhand techniques, body movement must be systematically controlled independent of variations in serve height. That was my primary purpose in designing Experiment 2.

Chapter 3: Perception of higher order affordances relating to serve reception with experimental control of anticipatory whole-body movement

Introduction

The results in Experiment 1 indicated that the serve reception type varied by serve height and sex independent of anthropometric differences. The results also yielded differences in anticipatory whole-body movements, which I hypothesized as being directly related to the technique selection. That is, I interpreted the results of Experiment 1 as revealing that participants perceived higher order affordances that emerged from relations between serve height, anticipatory whole-body movements, and serve reception techniques. To test this hypothesis, in Experiment 2, I constrained participants' ability to move, prohibiting stepping in any direction. I asked whether this manipulation might systematically influence relations between technique selection and anticipatory whole-body movement.

The ability to move within the environment directly affects the affordance landscape. Consider a goalkeeper who is lying down, perhaps after making a diving save or being knocked down. While recumbent, they cannot move quickly or easily. While they might still be able to do something to block kicks, the available affordances are different from the standing situation. In this chapter, I focus on situations in which the ability to move is constrained but actions are still afforded.

Limited movement in volleyball

In receiving serves in volleyball, free movement gives the players the ability to extend their reaching capabilities (e.g., can reach further balls) or to position themselves in a more

comfortable posture or location to receive serves. Thus, when mobility is limited, the available affordances are different than in the regular situation. Suppose a volleyball player is passing a ball served directly at them that arrives at 2.25m. While a tall player can easily pass the ball using the overhead technique (Figure 18 – Panel A), for a short player, the only way to pass that ball would be by moving backwards so the ball drops and becomes reachable. However, if the players are not allowed to move on the longitudinal axis, the short player still might reach that ball by jumping (Figure 18 – Panel B); a situation that would be less likely to occur in a normal unconstrained situation. The potential emergence of the affordance for jumping to receive serves is similar to the emergence of distinct action modes observed in studies such as Gardner et al. (2001). In their research, participants were initially seated and asked to reach for objects placed at varying distances in front of them. As the distance to the objects increased, participants systematically transitioned from utilizing solely their arm and torso, to incorporating partial standing, and finally to full locomotion to complete the reach. Reaching served as the final action goal; however, to execute the reach effectively, participants needed to position themselves appropriately. In the context of volleyball, when the serve is high, the ultimate action required is overhead, when moving backward is not an option, shorter players may opt to position themselves for this action by employing jumping. Thus, constraining movement shapes the affordance landscapes accordingly. One of the purposes of this experiment is to investigate how constraining movement affects the perception of affordances between males and females. As well as to observe how the affordance landscape changes, such as the implementation of jumps to perform the receptions.

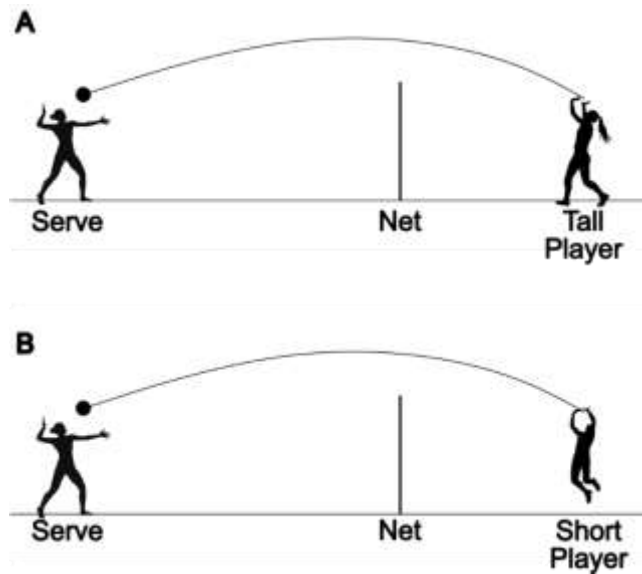


Figure 18 – Volleyball situation in which players are not allowed to move forward or backward. While a tall player can perform the overhead technique normally (Panel - A), a short player can only reach the ball if they jump (Panel – B)

In addition to overt displacements, such as stepping, players frequently make subtle adjustments. For instance, imagine a scenario where a player receiving a serve is prohibited from stepping in any direction. When the ball arrives at hip height, executing the underhand technique to pass becomes a straightforward task (see Figure 19 – A). However, when faced with a ball arriving at chest height, employing the underhand technique requires the player to lean laterally to create adequate space for the hands and arms to move (see Figure 19 – B). This modified maneuver, often referred to as the underhand-lateral pass (Paulo, Zaal, et al., 2018), underscores the adaptive nature of player movements in response to varying game situations.

In Experiment 1, the main effect of sex, independent of maximum reach differences, was a significant factor in choosing between the overhead and underhand serve reception techniques. Many studies have documented sex differences for landing, blocking, and spiking in volleyball (Fuchs et al., 2019; Giatsis et al., 2022; Hughes et al., 2010; Salci et al., 2004), but to my knowledge no studies have analyzed how men and women move in the context of serve

reception. A controlled manipulation of their anticipatory movement strategies could help to illuminate the sex differences identified in Experiment 1.

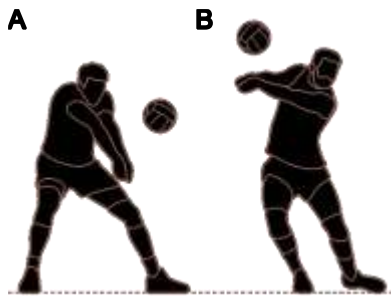


Figure 19 – Variations in the underhand technique. A. A comfortable passing situation in which the underhand technique is naturally implemented. B. A situation when the ball arrives at a higher location in which the underhand technique is optimized by leaning the torso laterally.

Higher order affordances in Experiment 2

The results of Experiment 1 suggested that players might not perceive simple affordances for serve reception (i.e., overhead vs. underhand). Rather, the results raised the possibility that players might instead perceive higher order affordances for stepping to optimize either the overhead or underhand technique. It is argued in the higher order affordance literature that higher order affordances are perceived as such, in other words, that perceived lower order affordances are not internally “added up” to yield knowledge about higher order affordances (Peker, Böge, et al., 2020; Seifert et al., 2021a; Wagman & Stoffregen, 2020). In practical terms, this implies that when adjusting the lower order affordances within a particular task, the result between the tasks with different lower order affordances would be different and not additive. For instance, Peker et al. (2023) demonstrated that the perception for kicking through gaps in soccer was affected not only by the width of gaps formed by two confederates but also (and simultaneously) by their role (teammate vs. opponent), and their facing direction (facing toward vs. away from each other). Critically, a significant 3-way interaction between gap size, confederate role and confederate

facing direction provided evidence that participants perceived a non-additive higher order affordance that emerged from relations among those three factors.

In Experiment 1, affordances for anticipatory movement (e.g., stepping backward vs. not) and affordances for serve reception (underhand vs. overhead) can be interpreted as lower order constituents of higher order affordances for “stepping back (or not) to optimize a preferred serve reception technique”. The results revealed that players from men’s and women’s volleyball employed different anticipatory movements before receiving serves and that those anticipatory movements were systematically related to my controlled variations in serve height. The fact that both anticipatory movements and the choice of serve reception techniques were systematically related to serve height means that anticipatory movements and the choice of serve reception techniques were systematically related to each other. That relationship is consistent with the idea that participants may have perceived a higher order affordance for “stepping back (or not) to optimize a preferred serve reception technique”.

In Experiment 2, my main aim was to test the above interpretation by manipulating anticipatory whole-body movements. In most respects, the design of Experiment 2 was identical to Experiment 1. There were two differences. 1) In Experiment 2, I prohibited stepping. I did this by instructing participants not to move their feet horizontally (i.e., forward, backward, or laterally). Therefore, in Experiment 2, “stepping back (or not) to optimize a preferred reception technique” was not afforded. 2) As noted in Chapter 2, in Experiment 1 participants rarely jumped in receiving serves; that is, data on vertical headset displacement did not include actual jumping. In Experiment 2, participants were explicitly instructed that they were permitted to jump in receiving serves.

For experiment 2, I hypothesized that a main effect of serve height would occur when the data were scaled in meters, and when the data were scaled in units of maximum vertical reach. Since anticipatory whole-body movements were not entirely constrained, participants would still be able to engage and employ systematic movement strategies to perform the serve-receives, akin to those observed in Experiment 1. Also, I hypothesized that the main effect of sex would be significant only when considering extrinsic metrics (serve height in meters). Since men and women have different anthropometric properties and stepping was not allowed, participants would have limited options in coordinating anticipatory whole-body movement with the choice of serve reception techniques, such as stepping backward to employ the underhand. I also expected that the jumping would be systematically related to sex, with women demonstrating a higher proportion of jump use than men. This would be the case because jumping would be the only way women (i.e., shorter players) would be able to reach the ball in the absence of stepping. Finally, my last hypothesis suggested that sex differences in anticipatory whole-body movements would be observed primarily in the vertical axis.

To summarize, in Experiment 2, I predicted that the choice of serve reception techniques would again be systematically related to serve height. I predicted that the main effect of sex on reception techniques with extrinsic metrics would be significant. In addition, I predicted that my manipulation of serve height would exert systematic influence on the likelihood that participants would jump in receiving serves, leading to a correlation between proportion of jumps and maximum reach regardless of sex.

Methods

Participants

Fourteen players of women's volleyball (age: 22.3, height: 1.70 ± 0.07 m, weight: 68.9 ± 10.51 kg) participated in Experiment 2. After the exclusion of one male participant who used only the overhead technique, fifteen players of men's volleyball (age: 22.2, height: 1.83 ± 0.08 m, weight: 80.2 ± 12.5 kg) participated in the experiment. I included only participants with at least three years of experience who had played consistently (at least two hours per week) in the past year. The average experience was 9.19 and 7.12 years for women's and men's participants respectively. The average weekly practice was 3.81 and 4.62 hours for women's and men's participants respectively.

Apparatus

I used the same apparatus as described in Experiment 1.

Task

The task was the same as in Experiment 1, except that 1) participants were not allowed to step in any direction and 2) participants were instructed that they could bend down or jump in receiving serves.

Procedure

The procedure closely resembled that of Experiment 1, with the key difference being the restriction on participant movement. Participants were explicitly instructed not to step in any direction and remain within a designated circle throughout the experiment, with the flexibility to bend down, rotate and lean their torso, or jump as necessary while maintaining their position. In contrast to Experiment 1, I explicitly outlined these instructions to clarify to participants that

while stepping was restricted, they still could perform certain movements. Also, although participants could not step, the circle was important to ensure that they began every trial on the same location, especially after jumping. Throughout the trials, participants were regularly reminded of the prohibition against stepping in any direction. Furthermore, a notice within the virtual environment reiterated this restriction on movement. Overall, participants demonstrated little difficulty adhering to these instructions. The number of trials was the same as in Experiment 1.

Data Analysis

My analyses of serve reception techniques, and of headset movement in three axes were the same as in Experiment 1. The only difference in data analysis from Experiment 1 was that for Experiment 2, I included an analysis of the proportion of trials on which participants jumped. Jumping was coded manually during data collection. Any trial during which participants lifted both feet off the ground to make contact with the ball was classified as a jump. Most participants jumped for some serve heights but not for all serve heights. For this reason, I used a zero one inflated beta model to analyze the proportion of trials on which participants jumped. I utilized a Bayesian framework to examine the relationship between jump proportion, sex, and serve height, fitting a model using the 'brm' function from the 'brms' package in R (Bürkner, 2017). The model formula $jump_proportion \sim sex * serve_height + (1|id)$ specified jump proportion as the response variable, with predictors including sex and serve height, as well as their interaction. I also incorporated a random intercept to account for the within-participants effects. I ran the model for 4000 iterations and set the 'adapt_delta' parameter to 0.9 to ensure adequate exploration of the parameter space and reliable estimation. After fitting the model, I conducted diagnostic checks to

assess the model's performance and ensure its reliability. Specifically, I evaluated convergence, parameter estimates, and goodness-of-fit statistics. The diagnostic checks indicated satisfactory convergence, with all relevant diagnostics within acceptable ranges (Bürkner, 2017).

Also, to examine the potential correlation between maximum reach and the proportion of jumps, separate Pearson correlations were conducted for males and females. Finally, I performed a chi-square to compare the number of participants who performed jumps between the groups.

Results

Women and men differed in weight and maximum reach, with $t(27) = 2.64$, $p = .014$, $d = 0.98$ for weight and $t(27) = 4.59$, $p < .001$, $d = 1.70$ for maximum reach, respectively. The mean weight for women was $68.9 \text{ kg} \pm 10.5$, with a maximum reach of $1.9 \text{ m} \pm 0.08$, while for men mean weight was $80.2 \text{ kg} \pm 12.5$, with a maximum reach of $2.05 \text{ m} \pm 0.09$.

Proportion of underhand serve reception

When analyzing the proportion of underhand receptions as a function of serve height in meters (Figure 20 – A), it was found that the main effect of serve height was significant, $B = -8.36$, $SE = 0.62$, $t(143) = -13.48$, $p < 0.000$), implying that as serve height increased, the underhand serving proportion decreased. The main effect of sex and the serve height $\times$ sex interaction were not significant.

When analyzing the proportion of underhand receptions as a function of serve height in units of maximum vertical reach (Figure 20 – B), the main effect of serve height was significant, $B = -15.70$, $SE = 1.18$, $t(143) = -13.25$, $p < 0.000$). The main effect of sex and the serve height $\times$ sex interaction were not significant.

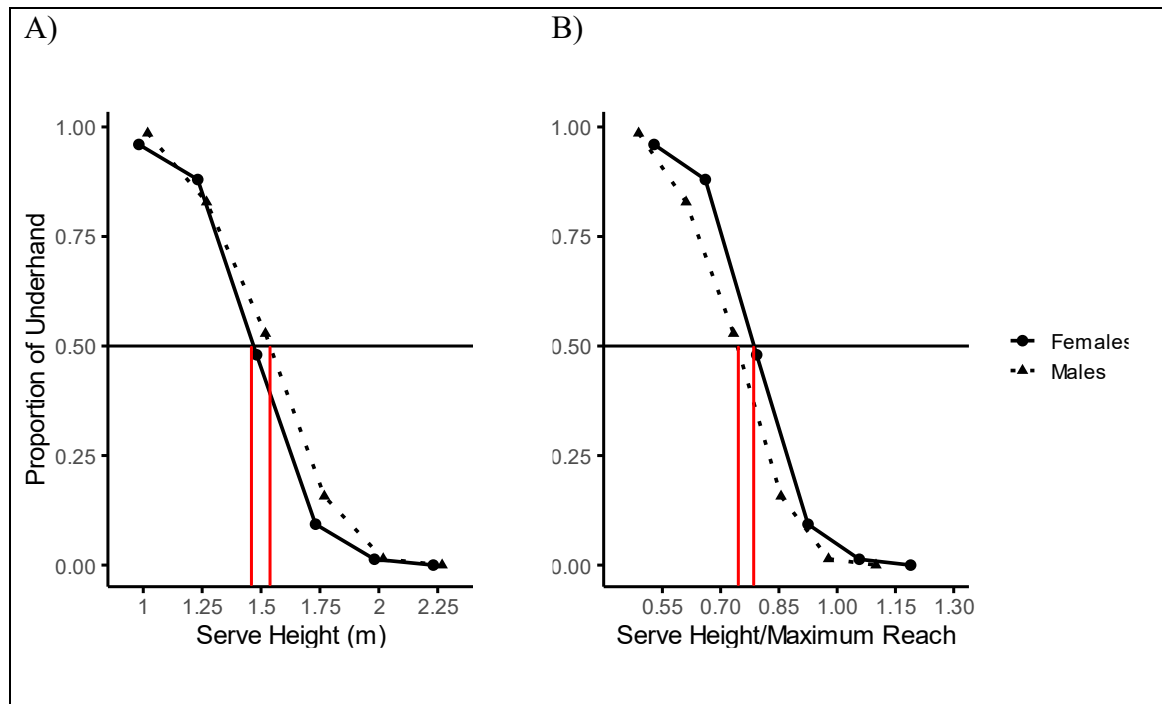


Figure 20 – Experiment 2. The proportion of underhand serve receives as a function of serve height and sex. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. The red vertical lines represent the hypothetical 50% action boundary. When considering the serve height in meters, males had a boundary of 1.53m and females 1.50m ($p > 0.05$). Considering the relative serve heights, males had a boundary of 0.74 and females 0.79, ($p > 0.05$)

Jump Proportion

Experimenter observation revealed that 71% of males jumped, and 73% of females jumped. When performing a chi-square test, the number of participants who jumped did not differ by sex, $X^2(1, N = 29) < 0.000$, $p = 1$.

When analyzing the proportion of trials on which participants jumped as a function of serve height in meters (Figure 21 – A), the main effect of serve height was significant, $B = 3.07$, $SE = 0.29$, $t(143) = 10.46$, $p < 0.000$. The main effect of sex and the serve height $\times$ sex interaction were not significant.

When analyzing the proportion of trials on which participants jumped as a function of serve height in units of maximum vertical reach (Figure 21 – B), the main effect of serve height was significant, $B = 22.52$, $SE = 2.25$, $t(143) = 9.99$, $p < 0.000$. The main effect of sex and the serve height $\times$ sex interaction were not statistically significant.

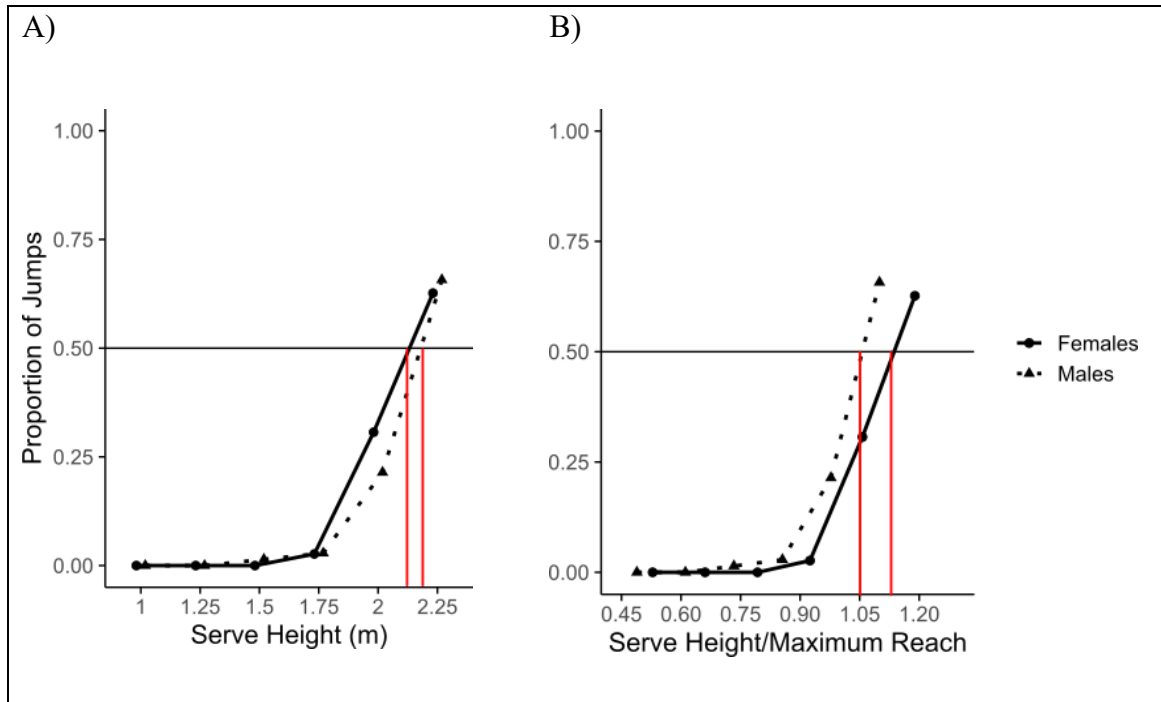


Figure 21 – Experiment 2. The proportion of jumps as a function of serve height and sex. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. The red lines represent the hypothetical 50% action boundary. When the data were scaled in meters (A)s, males had a boundary of 2.06 m and females 2.05m ($p > 0.05$). When the data were scaled in units of maximum reach (B), males had a boundary of 1.02 and females 1.08, ($p < 0.05$)

The correlation between the proportion of trials on which participants jumped and maximum reach was significant for males ($r(12) = -0.569$, $p = 0.034$) but not for females ($r(13) = -0.307$, $p = 0.266$). See Figure 22.

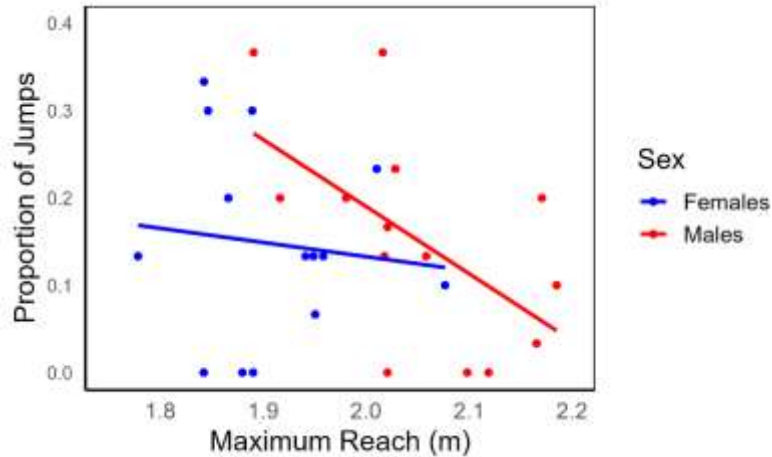


Figure 22 – Experiment 2. Correlation between proportion of jumps considering all trials and maximum reach for females and males. The correlation was significant for males ($p = 0.034$) but not significant for females ($p = 0.26$)

Anticipatory whole-body movement

When analyzing forward-backward movement, the main effect of serve height in meters was significant, $F(2.42, 65.25) = 98.43$, $p < .001$, partial eta-squared = .78, indicating that serve-height impacted the amount of displacement on that axis. Sex and the serve height $\times$ sex interaction were not significant (Figure 23 – A).

The relative serve height also significantly influenced the backward and forward displacement, $B = -0.21$, $SE = 0.01$, $t(143) = -14.041$, $p < 0.000$. The main effect of sex and the serve height $\times$ sex interaction were not significant (Figure 23 – B).

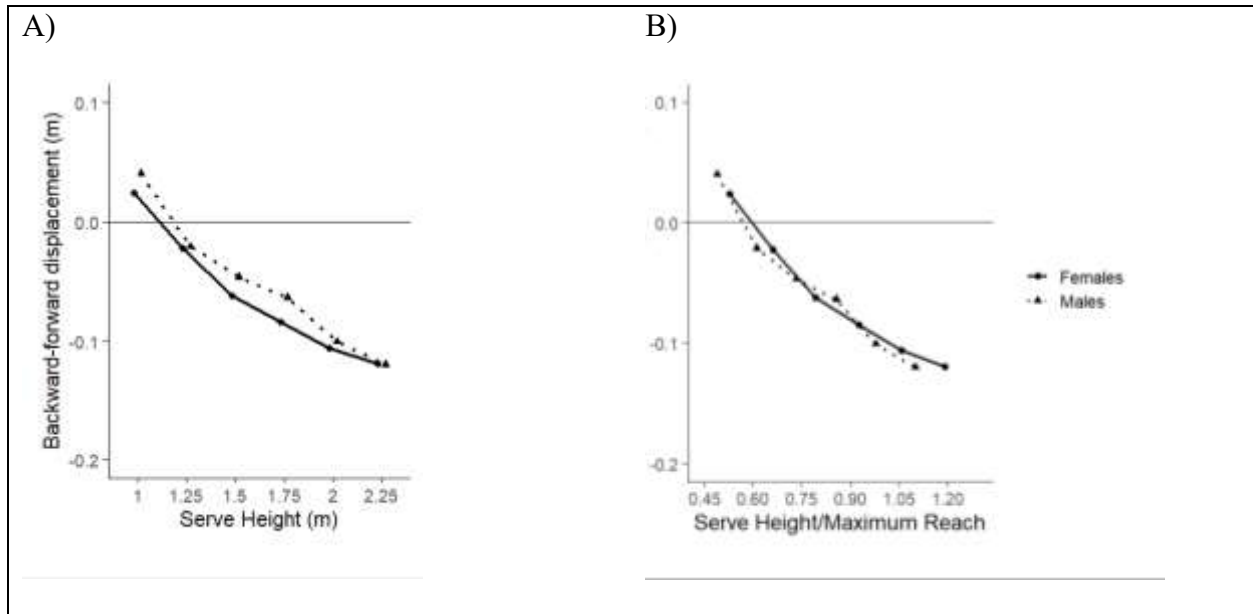


Figure 23 – Experiment 2. Headset displacement on the backward-forward under a movement constrained condition. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. Negative numbers indicate backward displacement whereas positive indicates forward displacement.

Regarding vertical displacement, serve height in meters exhibited a significant main effect ($F(2.21, 59.71) = 136.52, p < 0.001$, partial eta-squared = 0.83), while the effects of sex and the serve height $\times$ sex interaction were not statistically significant (Figure 24 – A).

Also, serve height in intrinsic units exhibited a significant main effect, Estimate = 0.4255, Std. Error = 0.02641, $t(143.86) = 16.111, p < 0.000$. The effect of sex also reached statistical significance (Estimate = -0.1191, Std. Error = 0.042, $t(116.51) = -2.81, p = 0.005$). Finally, the interaction was also significant, Estimate = 0.177, SE = 0.039, $t(143.79) = 4.480, p < 0.00$ (Figure 24 – B).

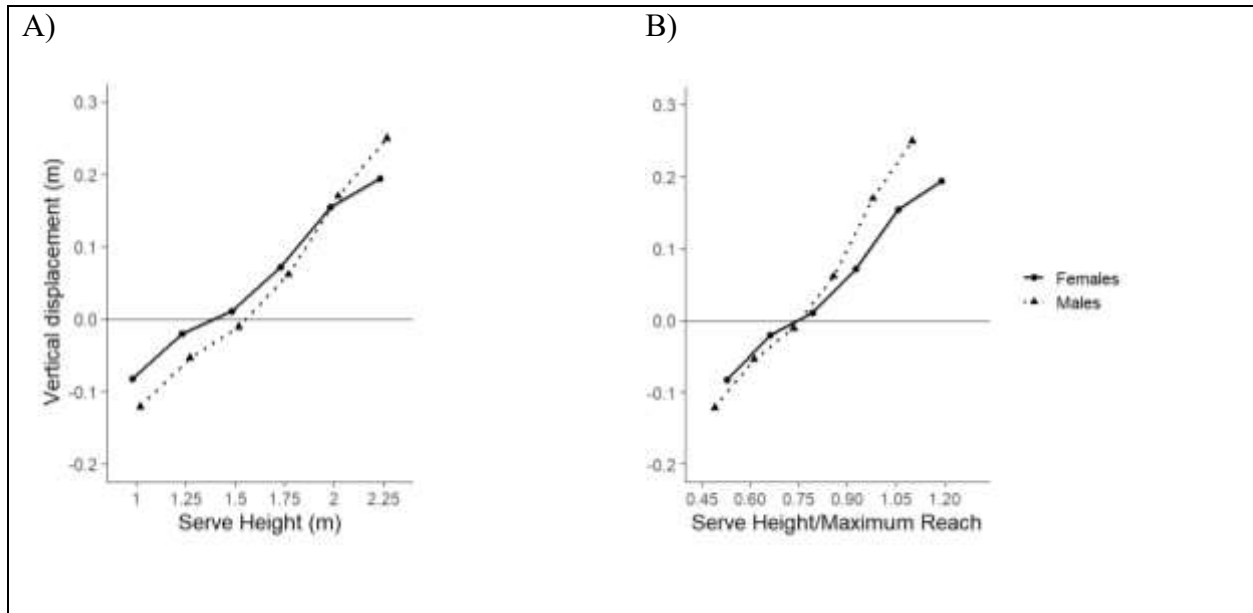


Figure 24 – Experiment 2. Headset displacement on the vertical axis under a movement constrained condition. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height. Negative numbers indicate downward displacements whereas positive indicates upward displacement.

Regarding headset lateral displacement, serve height in meters was a significant main effect, $F(2.68, 72.39) = 5.54$, $p = 0.003$, partial eta-squared = 0.17). Similarly, the main effect of sex was also significant, $F(1, 27) = 4.50$, $p = 0.043$, partial eta-squared = 0.14. The interaction between sex and serve height did not reach statistical significance (Figure 23 – A).

The lateral displacement was also analyzed considering the relative serve height. In that case, relative serve height was significant, Estimate = 0.1025, Std. Error = 0.02281, $t(144.30) = 4.498$, $p < 0.000$). The effect of sex also reached statistical significance (Estimate = -0.086, Std. Error = 0.034, $t(142.55) = 2.53$, $p = 0.012$). Finally, the interaction term was not significant (Figure 23 – B).

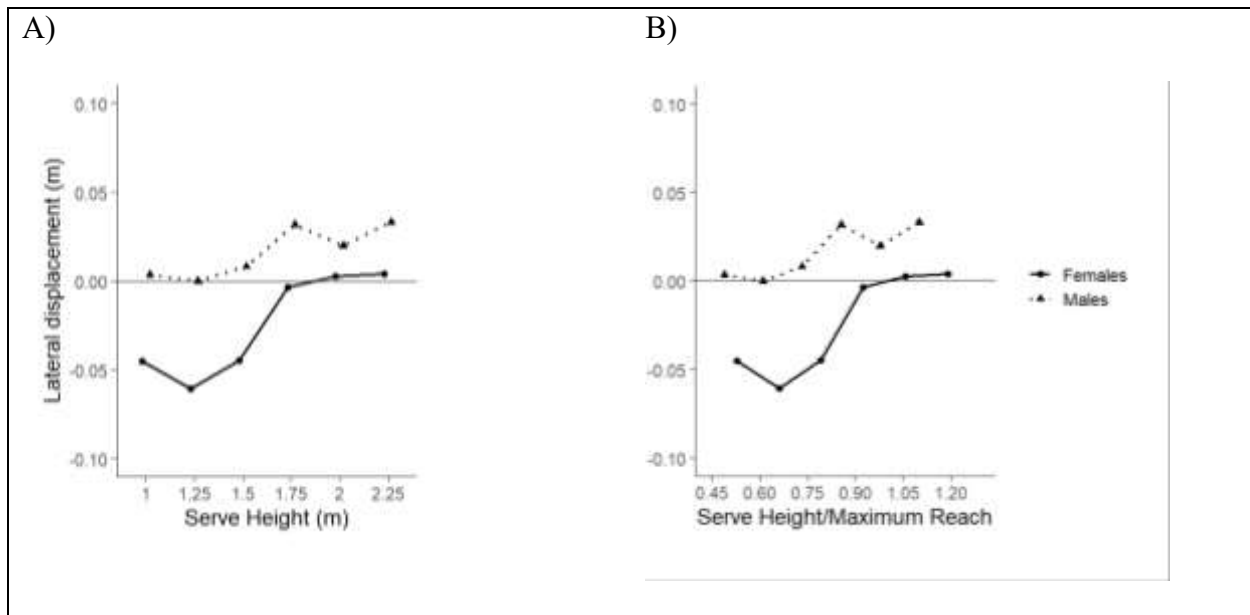


Figure 25 – Experiment 2. Headset displacement on the lateral axis under a movement-constrained condition. A) Serve height in meters. B) Serve height as a proportion of participant's maximum reaching height

Discussion

The goal of Experiment 2 was to investigate how limiting movement in serve-receive in volleyball impacts affordance perception for both males and females. Building upon results from Experiment 1, which revealed distinct reception types between the sexes, I discussed that these variations in technique were not directly attributed to anthropometric differences. Rather, I suggested a potential link to anticipatory movements. However, Experiment 1 lacked a manipulation of the movement axis, preventing the establishment of causal inference. To address this gap, Experiment 2 imposed restrictions on movement capabilities, specifically limiting players' stepping ability. This deliberate constraint aimed to elucidate a causal relationship between anticipatory movements and technique utilization. Additionally, I expected the

emergence of a new affordance, jump. I also hypothesized players with smaller maximum reach would display more jumps than the ones with a higher maximum reach.

Serve reception techniques

Like Experiment 1, the serve height (both in meters and relative) influenced the reception type, underscoring participants' systematic perception of affordances across varying serve heights. The shape of the curves neatly matches the results reported by Warren (1984); for example, compare Figure 1 with Figure 20. This finding supports my hypotheses and also is concordant with findings from prior studies in volleyball, exemplified by Paulo et al. (2018), who reported that players tended to use underhand techniques for lower serves and overhead techniques for higher ones. This behavioral adaptation based on environmental cues is also a recurring theme in affordance literature. For instance, going over or under a bar based on its height (Comalli et al., 2017), grabbing objects with one or two hands depending on the size of the object (Lopresti-Goodman et al., 2011), and punching a bag with uppercut or jab in boxing depending on the target distance (Hristovski et al., 2006). These examples collectively demonstrate the pervasive influence of affordance perception on action selection and execution, illustrating how individuals adapt their behaviors in response to environmental affordances.

In contrast to Experiment 1, there were no sex effects on technique use. This suggests that the disparities in sex observed in Experiment 1, particularly concerning the relative serve, might be attributed to differences in the ability to move (stepping). The detailed comparison between experiments will be further discussed in chapter 4.

I also hypothesized that significant main effects of sex would arise when considering the extrinsic metrics. However, the findings contradicted that hypothesis, revealing no significant main effects of sex on reception type when considering extrinsic metrics. One plausible explanation for this result lies in the specific movement patterns exhibited by participants throughout the experiment, despite the prohibition of stepping, as will be elaborated upon in the subsequent sections. For example, it is possible that females and males exhibited distinct movement patterns, and consequently, mitigating potential anthropometric differences. Consider a situation in which the serve arrived at chest height. In that case, participants could either opt to bend down and employ the overhead technique or lean their torsos laterally and utilize the underhand technique (refer to Figure 19). These potential disparities will be further explored in subsequent sections, particularly in the analysis of anticipatory movements.

Proportion of jumps

In Experiment 1, participants were free to jump in receiving serves, but the use of jumps was rare. By contrast, in Experiment 2, 71% of males and 73% of females jumped at least once. This result supports my hypothesis that participants would utilize jumps to receive serves when stepping was prohibited. The emergence of this behavior nicely demonstrates the impact of environmental constraints on affordances. It is important to note that my ability to identify relationships between stepping and jumping, on the one hand, and the choice of serve reception techniques on the other hand was made possible by my use of action metrics (rather than verbal reports) in assessing the perception of affordances.

Upon analyzing the proportion of jumps in relation to serve height measured in meters (Figure 21 – A) and in relation to maximum reach (Figure 21 – B), a significant effect of serve

height was observed, whereas other effects did not reach significance. This indicates that regardless of sex and maximum vertical reach, participants used similar strategies to decide when to jump or not. That is, there were systematic relations between the choice to jump and the choice between serve reception techniques. This relationship is consistent with the hypothesis that participants perceived higher order affordances that emerged from relations between affordances for whole-body movement (in this case, jumping) and the affordances of different serve reception techniques.

The examination of jump proportion in relation to relative serve heights revealed a noteworthy trend. Sex differences appeared to amplify compared to the analysis based on serve height in meters. Although this discrepancy remained statistically insignificant, the hypothetical action boundary—representing the point at which overhead and overhead with jump occurrences each have a 50% chance—was found to be significant. In practice, what occurred was that males tended to transition into jumping for serve heights that were relatively lower compared to females (Figure 21 - B). This observation mirrors the findings of Experiment 1, where females exhibited a higher threshold for transitioning from underhand to overhead techniques (Figure 14 – B). Although the affordance literature on sex differences is scant, in many other fields those differences have been demonstrated. For instance, when investigating kinematics and muscle activation for volleyball swing, it was found that the differences between the sexes could not be explained only by the differences in anthropometrics or muscle strength (Fuchs et al., 2019). The lack of inclusion of sex as an independent variable in the affordance literature might stem from the assumption that solely accounting for anthropometrics suffices. While this assumption holds

true for many common actions (e.g., walking, reaching, jumping), it may not necessarily hold for other actions, such as actions that comprise external timing constraints (Zheng et al., 2022).

Another aspect of the analysis was the correlation between individual total proportion of jumps and maximum vertical reach. My initial hypothesis suggested that participants with smaller maximum vertical reach would jump more often. Interestingly, this relationship was confirmed solely among male participants, while for females, the correlation was not statistically significant (Figure 22). This result suggests a potentially more intricate strategy employed by females, wherein anthropometrics might not be the primary determinant. Instead, factors such as the strategic use of anticipatory movements could play a more pivotal role in optimizing their preferred passing technique.

Anticipatory whole-body movements

In Experiment 1, I argued that the sex effects on technique use were due to the fact that the sexes employed different anticipatory whole-body movements. In Experiment 2, I opted to restrict stepping to investigate its impact on reception technique selection. I hypothesized that sex differences in anticipatory whole-body movements would be observed primarily in the vertical axis.

The results revealed that serve height significantly affected anticipatory movements on all the three axes of analysis, and when expressed either in meters or in units of maximum vertical reach. As in Experiment 1, participants anticipatory whole-body movements varied systematically with serve height, and this was true despite the prohibition of stepping. I will describe some of those movements next when discussing each axis separately.

When examining anticipatory whole-body movements along the longitudinal axis, only serve height (both relative and in meters) emerged as a significant factor (Figure 23). Given the restriction on stepping in any direction, it is likely that the entirety of these movements stemmed from adjustments in torso positioning, leaning either forward or backward. However, the degree of displacement observed was smaller than Experiment 1, which indicates that the participants adhered to the instructions. Unlike Experiment 1, in Experiment 2 there was no significant sex effects, indicating that all participants adopted a similar movement strategy. This indicates that the difference in technique use between sexes in Experiment 1 could be attributed to anticipatory whole-body movements, such as stepping.

When serve height was expressed extrinsically (i.e., in meters), Analysis of vertical headset displacement indicated that a significant main effect of serve height (Figure 24 – A), but the main effect of sex was not significant, as was the interaction. This result is puzzling given the height disparity between men and women, which would typically result in varying degrees of vertical displacement. By contrast, when serve height was expressed intrinsically, both sex and the serve height $\times$ sex interaction were significant (Figure 24 – B). Changes in the vertical axis can be related to the fact that in Experiment 2 participants were prohibited from stepping but were permitted to jump. In Experiment 1, participants could step forward and backward, which in turn diminishes the need for moving vertically to reach the ball. Consider a player who prefers to use the underhand technique. In Experiment 1, even if the ball came at head height, this player could move backward, allowing the ball to drop and then using underhand. This situation would not be possible in Experiment 2, in which the only way to reach the ball would be not to move, and potentially having an increased vertical displacement. Regarding serve height expressed

intrinsically, Experiments 1 and 2 yielded similar results, with distinct patterns of vertical displacement observed between sexes. This consistency across experiments suggests that women may display less vertical movement, potentially in favor of other anticipatory movements, as described in the previous example.

The analysis of lateral displacement revealed that both serve height and sex were significant factors (Figure 25), and that this was true both when serve height was expressed intrinsically and extrinsically. This finding contrasts with the Experiment 1, where the main effect of serve height was significant but there were no significant effects relating to sex. The results of Experiment 2 suggest that due to the restriction on stepping, men and women may have adopted distinct strategies for laterally leaning to receive the ball. Women may have, in effect, used lateral displacement to create an action boundary (between overhead and underhand techniques) that was similar to that of men (Figure 19). For instance, for balls coming at chest height, instead of bending the knees and using the overhead technique, women might have leaned to the side so they would have space to employ the underhand technique.

Chapter 4: General Discussion

In volleyball, the dynamic interplay between players and their environment shapes the available affordances. While previous research has predominantly inferred the perception of affordances from verbal reports (e.g., Warren, 1984), this method is inadequate for many situations that include external timing constraints, such as receiving a serve in volleyball. Thus, in this dissertation, I elected to infer the perception of affordances from actions.

Given the non-existent literature examining affordances in volleyball, the first objective was to ascertain whether virtual environments can faithfully replicate the intricate behaviors observed in real-world volleyball scenarios. Also, recognizing that affordances can encompass subordinate affordances, such as anticipatory movements in the context of serve receive in volleyball, another goal was to delve into higher-order affordances within this specific domain by manipulating the ability to move within the task. Finally, considering that previous investigations into affordances have primarily focused on anthropometric or physical capacities, this study uniquely incorporates sex as an independent variable to explore whether sex differences in affordance perception are only related to differences in anthropometrics (maximum reach) or not.

To address these objectives, two experiments were designed utilizing HMD. Participants were asked to simulate volleyball passes given different serve heights in VR. In Experiment 1, participants were allowed to move freely akin to real volleyball scenarios, while in Experiment 2, players were prohibited from stepping in any direction. The results demonstrated that participants' responses in the virtual environment were similar to expected responses in real volleyball. Also, reception types and anticipatory movements were directly correlated with the

height of the serve, underscoring the immediate influence of environmental cues on affordance perception. When stepping was prohibited, participants showed different anticipatory whole-body movements than when stepping was permitted, indicating the players perceived higher order affordances for receiving serves in volleyball. Finally, the investigation revealed sex-related disparities in reception type and anticipatory movement, indicating that these differences cannot be solely attributed to anthropometric variations. In this chapter, I will be discussing each one of those findings in detail.

Affordances

Overhead vs. underhand

Volleyball, like most team sports, has multiple, perhaps infinite, affordances (Araújo et al., 2019). However, to receive serves, two techniques are conspicuously used, the overhead and underhand techniques. Those techniques represent two affordances that are commonly perceived and used by volleyball players. Therefore, my goal was to understand whether volleyball players' choice between those two serve reception techniques would be systematically related to controlled variations in serve height. In both experiments, I found this to be the case (Figures 14, 20). Across experiments and sexes, participants exhibited a discrete transition from underhand for lower serves to overhead for higher serves. In this critical sense, my results closely replicated the foundational findings of Warren (1988) and extended them not only to volleyball but to the perception of volleyball affordances presented via a head-mounted display.

Barsingerhorn et al. (2013) studied relations between characteristics of serve trajectories and the choice between the overhead and underhand serve reception techniques. Rather than manipulating serve height, they manipulated the position that the ball landed. Some balls were

tossed in front of the participants and some behind. The results suggested a similar transition from overhead to underhand, varying with the nominal landing location of serves. Participants predominantly utilized the underhand technique for balls in front of them and the overhead technique for balls behind them. It seems likely that the manipulation in serve location (in front, behind) used by Basingerhorn et al. (2013) entailed a corresponding variation in serve height, such that serve location was a proxy for serve height. The results in the current study are also in accordance with observational data. For instance, Paulo et al. (2016) who observed male volleyball players receiving float serves and noted what technique they utilized to contact the ball. Given the technique use, the authors developed a model to predict the technique use based on the position of the player on the court. Specifically, players positioned closer to the net exhibited a higher likelihood of employing overhead passes, whereas those situated further from the net tended to utilize underhand techniques more frequently. It's noteworthy that the servers in the study of Paulo et al. (2016) study were not directed to intentionally vary the height of their serves, making direct comparisons to our experiment challenging. Nevertheless, it is plausible that when players were closer to the net, the serves tended to reach them at higher heights, whereas being deeper on the court resulted in serves arriving at lower heights, influencing their choice of passing technique.

The aforementioned volleyball literature clearly demonstrates that the serve's characteristics (e.g., direction, height) directly impact the utilization of the two techniques to receive serves, leading to systematic responses. Although my study corroborates with this literature, my study is unique in systematically varying the height of serve, and in considering the anthropometrics of the players, which is a method commonly used in affordance literature but

absent in the studies analyzing technique use in volleyball. In summary, given the systematic transitions in serve reception techniques found in this study, it is possible to conclude that HMDs might be a useful tool for replicating a volleyball scenario. Certainly, this has many implications that I will discuss later in this chapter.

Stepping versus jumping

During the design phase of Experiment 1, I had not considered the potential emergence of stepping or jumping. Thus, the observation, in Experiment 1, that all participants stepped but that jumping was rare highlights an advantage of employing action as a measure of affordance perception—the capacity to uncover affordances that researchers might not initially anticipate. The discovery of those affordances can occur when performers have the opportunity to interact naturally with their environment, free from constraints imposed by the experimenter.

In Experiment 1, jumps were permitted but participants rarely took advantage of this option. That is, jumps were afforded but that affordance was not selected. By contrast, in Experiment 2, jumps were common, being used by more than 70% of participants. The emergence of jumps in Experiment 2 suggests that the affordance landscape changed from Experiment 1. Although participants were not prevented from jumping in Experiment 1, they selected other anticipatory whole-body movements (e.g., stepping backward). In fact, in the volleyball coaching literature there is an extensive discussion on the role of movement, especially footwork, to optimize serve reception (FIVB, 2011; Reynaud, 2015). However, the discussion on using jumps for passing is nearly non-existent. This suggests that in volleyball, there is a preference for avoiding jumps while receiving serves, which could explain the rare use of jumps in Experiment 1.

When analyzing the correlation between the proportion of jumps and maximum reach, significance was observed only among male participants, showing that lower maximum vertical reach was associated with more jumps. It might be the case that women do not consider their maximum reach for using that affordance. This possibility will be discussed later in this chapter when I discuss sex differences.

Higher order affordances

In the context of receiving serves in volleyball, players typically begin to move before making contact with the ball. This sequence could be understood in terms of the separate perception of two distinct affordances: first, the perception of available time and space to initiate movement, and second, the perception of the ball's relative trajectory for serve reception (e.g., overhead vs. underhand). In such a scenario, any systematic relation between anticipatory whole-body movements and the choice of serve reception techniques could be achieved only by internal processing, separately perceiving affordances for anticipatory whole-body movements and affordances for serve reception. Alternatively, there might exist (and be perceived by participants) higher order affordances, emerging from relations between stepping and jumping, on the one hand, and serve reception techniques, on the other. The existence and perception of such higher order affordances for stepping or jumping to optimize a preferred serve reception technique would naturally lead to systematic relations between anticipatory whole-body movements and serve reception techniques. Consistent with this latter perspective, I hypothesized that participants would perceive (and act upon) different higher order affordances in Experiments 1 and 2.

Research on higher order affordances has demonstrated that when lower order affordances are manipulated, the perception of higher order affordances change in predictable ways, that are not explained by the separate perception of lower order affordances (Peker et al., 2023; Seifert et al., 2021b; Wagman & Stoffregen, 2020). In the current study, the ability to move was manipulated in Experiment 2. In previous sections, I argued that volleyball players employ movement to optimize the execution of one technique over another. Experiment 1 most closely resembled actual volleyball, in that players were free to move as they chose in receiving serves. Thus, the emergence of stepping in Experiment 1, and its systematic relation to both serve height and the choice of serve reception techniques suggests that this particular higher order affordance would be familiar to skilled volleyball players and would be preferred (i.e., relative to other movements that were also permitted). By contrast, Experiment 2 was conspicuously unnatural relative to actual volleyball games, in that stepping was prohibited. For skilled volleyball players, jumping to receive serves would be less familiar and (based on the results from Experiment 1) not preferred. Thus, the use of jumping in Experiment 2 suggests that participants could perceive the utility of this unfamiliar higher order affordance (jumping to optimize a preferred serve reception technique) and were able successfully to implement it despite its relative unfamiliarity.

Affordances: Sex differences

Relative to most previous research on affordances, a novel aspect of my dissertation was the inclusion of sex as an independent variable in experimental design and data analysis. Women and men engage in many of the same actions. Yet, it is no secret that there are differences between the sexes—presumably, this is why in competitive volleyball there are men's and

women's leagues (cf. basketball, gymnastics, etc.). Studies of affordances in sport are increasingly common, but few of those studies have considered the likelihood of sex differences in sport-specific affordances, or in the perception of sport-specific affordances. Following Perez (2019), in Chapter 1, I argued for a new default in which sex would be included as an independent variable in research on affordances.

One early study of possible sex differences in sport-related affordances was reported by Pepping and Li (2000b). Their study arose from their interest in sports but was not related to an actual sporting action. They assessed perception of affordances for maximum vertical reach. Maximum vertical reach is important in many sporting contexts (including volleyball), but affordances for maximum vertical reach may differ from affordances for (for example) receiving volleyball serves. They found no differences between the sexes when perceptual reports were scaled in intrinsic units. They interpreted that result as suggesting that sex differences were equivalent to differences in static anthropometrics, such as height. I suggested, instead, that their result may have arisen from the fact that the affordance under study (i.e., reaching to maximum height) was not defined in relation to any external timing constraint.

While my experiments replicated the classical affordance transition (compare Figures 1, 14, and 20), I did not consistently replicate findings regarding differences between participants. In Experiment 1, I compared groups that were taller and shorter (men and women, respectively), but I failed to find a main effect of group (i.e., sex) when the data were expressed in extrinsic units (meters; Figure 14 – A). I also failed to replicate the classical consequence of expressing the data in intrinsic units (Figure 14 – B); here, the group effect was significant. My results, precisely the opposite of those classically reported (e.g., Warren, 1984) raised the possibility that

there could be sex differences in affordances for serve reception in volleyball that do not arise primarily from static anthropometrics or factors (such as strength) that are correlated with static anthropometrics. In Experiment 2 (see Figure 20 – A), I again failed to replicate the classical group effect that has been observed when the data were expressed in extrinsic units, again suggesting that sex differences in affordances for receiving serves in volleyball may not be limited to static anthropometrics or factors correlated with static anthropometrics.

A novel feature of my study was my analysis of anticipatory whole-body movements. Here, too, I identified significant differences between women and men. In general, those differences were consistent with the effects observed in relation to serve reception techniques. In Experiment 1 women and men did not differ for forward-backward headset displacement (Figure 15), suggesting that they did not differ in the use of stepping for serve reception. Similarly, in Experiment 2, when the data on jumping were expressed extrinsically the main effect of groups (i.e., sex) was not significant (Figure 21), as was also the case when data on vertical headset displacement were expressed extrinsically (Figure 24). Those key aspects of anticipatory whole-body movement are, thus, consistent with the data on serve reception techniques in suggesting that sex differences likely cannot be explained in terms of static anthropometrics or factors correlated with static anthropometrics.

Overhead vs. Underhand

In Experiment 1 (natural condition), females had a relatively higher action boundary (relative serve) than males. This result is contrary to Pepping and Li (2000b), who found that males and females did not differ when scaling affordances by their anthropometrics, indicating that both sex perceived affordances for maximum overhead reaching similarly. However, a

significant distinction in the present experiment lies in the participants' ability to move. Consequently, participants possessed the capability to engage in anticipatory movements, enabling them to contact the ball at varying heights and changing the available of affordances. For instance, advancing forward was associated with a higher likelihood of utilizing the overhead technique, because the ball would be higher, whereas retreating backward was more conducive to employing the underhand technique, given the lower positioning of the ball (refer to Figure 10 in Chapter 2). This was further demonstrated in Experiment 2, when stepping was not allowed, reducing the movement ability. In that case, there were no sex effects, indicating that the movement was responsible for the sex differences found in Experiment 1.

Thus, there remains the logical possibility that there might be sex differences in the perception of affordances that arise from factors that are not solely (or primarily) related to anthropometrics. The sex differences observed in Experiment 1 (Figure 14 – B) suggest that affordances for serve reception may not be defined solely in terms of anthropometrics, such as maximum vertical reach. Thus, other types of differences between women and men might exist in the affordances, themselves, such as differences that are not related to maximum reach, but which differentially influence the availability of underhand and overhead serve reception techniques.

In this dissertation, I demonstrated that those sex effects found in technique use were because males and females adopted different movement strategies. Similarly to the goalkeepers in Zheng et al. (2022) that female goalkeepers had inferior performance when blocking deceptive kicks than males. The authors attributed this difference to the fact that females adopted a different movement strategy that allowed them to succeed in regular kicks but decreased their

performance for deceptive kicks. The authors further explained that it may be the case that in women's soccer deceptive kicks are less frequent and the female athletes developed different movement strategies than men. Therefore, it might be the case that males and females developed distinct control laws (a strategy to use available information in the environment) to guide their movement in volleyball due to differences in volleyball.

A control law represents the relationship between the informational variables available in the environment (e.g., the visual rate of change of objects on the retina) and the actions produced by an organism (e.g., running velocity) (Warren, 2006). Put simply, a control law encapsulates how an individual regulates their movements based on the perceptual information available to them in a given situation. Therefore, male and female players might use different control laws, which have been developed and refined through their respective playing experiences and skill acquisition processes (Jacobs & Michaels, 2007). However, formulating a hypothesis suggesting that the sexes employ different control laws does not fully address the underlying question; rather, it prompts further inquiry into the reasons behind such divergence.

A difference between men's and women's volleyball that might lead to different control laws is the net height. Although the court size is the same, the men's net is set at 2.43m, the women's net is set at 2.24m (FIVB, 2011). Despite the fact that men are taller and jump higher than women, the net height difference is believed to generate distinct serving dynamics (Kountouris et al., 2015; Palao et al., 2009). Since the net is lower for women and women tend to serve slower than men (Çinar Medeni et al., 2019), It is probable that in women's volleyball, the ball tends to land closer to the net, whereas in men's volleyball, it tends to land closer to the endline or deep court, as suggested by Kitsiou et al. (2020). Therefore, it is plausible that women

are more comfortable using the underhand technique, given its higher likelihood of occurrence in their playing experience due to factors such as net height and serve velocities. It is important to highlight that in the present study, the net height was the same for both sexes. However, unlike many tasks typically examined in affordance research – involving a single affordance – serve reception offers a degree of flexibility, in a way that the players can decide which technique to use. There is no compelling rationale to anticipate players altering their favored technique when both options (e.g., overhead and underhand) remain viable choices. For instance, Comalli, Persand, and Adolph (2017) conducted a study illustrating humans' innate inclination towards upright locomotion. They observed that participants consistently preferred to navigate over a raised bar rather than underneath it, despite experimental manipulations such as wearing ankle weights, conducting trials on padded surfaces, and even being prompted to crawl following the traversal of the bar. Therefore, the sex differences might stem from the player's preference for using a specific technique, which are not solely dictated by individual anthropometrics. Rather, these preferences emerge as a result of their experience in playing volleyball, where they adapt to distinct serving dynamics influenced by net height constraints.

Additionally, maximum vertical reach provides crucial body-scaled information for players to effectively intercept serves in volleyball. However, beyond positioning their arms for interception, players must also exert control over the ball and direct it to another location (FIVB, 2011). Therefore, in the case of serve receive, it is likely that only perceiving our actions in terms of maximum reach is incomplete, as the task involves more constraints than merely reaching the ball. For instance, Konczak, Meeuwsen, and Cress (1992) investigated affordances for stair climbing including both tall and short young adults, as well as tall and short older adults.

Participants were required to judge the maximum riser height they could climb, followed by performing the task. The findings revealed that while intrinsic measures of leg length (riser height divided by leg length) suggested similar action boundaries perceived by tall and short young individuals, they fell short in explaining the behavior of older participants. Instead, for older adults, a model incorporating intrinsic measures of leg length, hip flexibility, and leg strength demonstrated to be a more accurate predictor of the action boundaries. Perhaps, the sex differences observed in the current study may arise from factors beyond those reflected solely in differences in maximum reach. One such factor, particularly relevant for overhead passing, is finger strength. For example, if you consider a male and female of the same height, the male will exhibit greater finger strength (Steiber, 2016). Given the velocity of float serves, players should have strong fingers to appropriately control and propel the ball toward the target (Kosty, 2018). Perhaps those strength disparities also lead to different players preferences by men's and women's players. For instance, women might choose to utilize the underhand technique, even when the ball is positioned relatively high (at head height), given they have sufficient time to adjust their position accordingly.

It is conceivable, and perhaps probable, that the observed sex differences stemmed from an interplay of those previously described various factors, and maybe others. Our tendency to dissect phenomena for better study might create a misleading perception that results are solely attributable to individual variables (Fang & Casadevall, 2011). In practice, affordances arise from the interplay of multiple characteristics of both the individual (e.g. body-scaled and action capabilities) and the environment (Barsingerhorn et al., 2012).

Limitations

One notable limitation of my study pertains to the scope of the kinematic analysis, which focused solely on data collected from the headset. While the information derived from the headset is valuable, a more comprehensive analysis that incorporates additional body segments such as the arms and legs could potentially yield significant insights.

Another limitation arises from my use of VR technology. While the results obtained in the VR setting may offer valuable insights, there remains uncertainty regarding their generalizability to real-world volleyball scenarios. Although it is likely that similar findings would be replicated in actual volleyball gameplay, further investigation is required to ascertain the transferability of the results from the virtual environment to real-world settings.

Future Research

Considering the results of my study, there are several promising directions for future research that could deepen our understanding of affordance perception, particularly in sports and volleyball. Firstly, researchers could explore the effects of additional manipulations within the same experimental framework. For instance, varying the direction of serves or adjusting serve velocities could provide valuable insights into how environmental factors influence affordance perception and anticipatory whole-body movements. Similarly, investigating the impact of altering players' positions on the court (e.g., far from or close to the net) could shed light on the role of spatial positioning in shaping affordances. Moreover, integrating comprehensive movement analysis into future studies could offer a more comprehensive understanding of higher order affordances, through the investigation of anticipatory movements that drives action selection and performance optimization. By examining athletes' kinematic profiles during

perceptual-motor tasks, researchers can gain valuable insights into the biomechanical and strategic factors influencing the use and emergence of affordances. Additionally, running similar research protocols with novice participants could elucidate whether the observed sex differences are specific to individuals with volleyball training or are more broadly applicable across varying skill levels. Furthermore, a dedicated investigation focusing specifically on the use of jumps to receive serves in volleyball could provide valuable insights into potential sex differences and higher order affordances for receiving serves. Lastly, researchers could explore the implications of imposing constraints on athletes' affordance selection by comparing situations where athletes are forced to use a specific affordance versus situations where they have the freedom to choose. This comparative analysis could offer insights into the flexibility and adaptability of athletes' perceptual-motor systems in response to environmental constraints. By addressing these avenues for future research, we can further advance our understanding of affordance perception in dynamic and complex skills.

Conclusion

Affordances are opportunities for action that are available for a given person in a given environment. When receiving serves in volleyball, players commonly use one of two techniques; overhead (hands pronated above the head) or underhand (hands supinated near the waist). The relative utility of those techniques is influenced by characteristics of each serve, including its height. At the same time, the importance of serve height varies with the height of the player.

In asking for males and females to receive serves of varying heights in VR, I found discrete transitions between techniques, in relation to serve height. Separately, I found evidence for sex differences in serve reception that were related to sex differences in height, but also

others that were not related to sex differences in height. Finally, I found systematic relationships between serve height, patterns of whole-body anticipatory movement, and use of the overhead and underhand techniques. I interpreted those relationships as evidence for the perception of higher order affordances for the use of anticipatory whole-body movement to optimize the utility of particular serve reception techniques.

In summary, I concluded 1) that incoming serves in volleyball can be perceived in terms of their affordances, 2) that head-mounted virtual reality is a useful method for the study of affordance perception in time-constrained domains, such as volleyball, 3) that sex differences in volleyball arise from anthropometric sex differences but also from sex differences that are not related to anthropometrics, and 4) that skilled volleyball players can perceive incoming serves in terms of higher order affordances in which anticipatory movements are relative to techniques for serve reception. The findings of this research have also practical applications. Since individuals could perceive transitions between serve receive techniques through virtual reality (VR), then VR-based training methods could be employed to enhance their sensitivity to height-related boundaries, thereby improving their overall performance in volleyball reception.

References

- Alfonso, J., Mesquita, I., & Marcelino, R. (2010). *ANALYSIS OF THE SETTER'S TACTICAL ACTION IN HIGH-PERFORMANCE WOMEN'S VOLLEYBALL*.
- Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., & Davids, K. (2019). Ecological cognition: Expert decision-making behaviour in sport. *International Review of Sport and Exercise Psychology*, 12(1), 1–25. <https://doi.org/10.1080/1750984X.2017.1349826>
- Arruda, D. G., Barp, F., Felisberto, G., Tkak, C., Wagman, J. B., & Stoffregen, T. A. (2023). Perception of Affordances in Female Volleyball Players: Serving Short versus Serving to the Sideline. *Research Quarterly for Exercise and Sport*, 1–8. <https://doi.org/10.1080/02701367.2023.2279989>
- Asai, T., Ito, S., Seo, K., & Hitotsubashi, A. (2010). Aerodynamics of a new volleyball. *Procedia Engineering*, 2(2), 2493–2498. <https://doi.org/10.1016/j.proeng.2010.04.021>
- Barsingerhorn, A. D., Zaal, F. T. J. M., & De Poel, H. J. (2013). Shaping decisions in volleyball. An ecological approach to decision-making in volleyball passing. *International Journal of Sport Psychology*, 44, 197–214. <https://doi.org/10.7352/IJSP.2013.44.197>
- Barsingerhorn, A. D., Zaal, F. T. J. M., Smith, J., & Pepping, G. J. (2012). On possibilities for action: The past, present and future of affordance research. *Avant*, 3(2), 54–69.
- Benerink, N. H., Bootsma, R. J., & Zaal, F. T. J. M. (2015). Different temporal bases for body and arm movements in volleyball serve reception. *Scandinavian Journal of Medicine & Science in Sports*, 25(5), 603–609. <https://doi.org/10.1111/sms.12384>

- Bhargava, A., Lucaites, K. M., Hartman, L. S., Solini, H., Bertrand, J. W., Robb, A. C., Pagano, C. C., & Babu, S. V. (2020). Revisiting affordance perception in contemporary virtual reality. *Virtual Reality*, 24(4), 713–724. <https://doi.org/10.1007/s10055-020-00432-y>
- Bradley, P. S., Dellal, A., Mohr, M., Castellano, J., & Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Human Movement Science*, 33, 159–171. <https://doi.org/10.1016/j.humov.2013.07.024>
- Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, 80, 1–28. <https://doi.org/10.18637/jss.v080.i01>
- Cabarkapa, D., Cabarkapa, D. V., Philipp, N. M., Eserhaut, D. A., Downey, G. G., & Fry, A. C. (2022). Impact of Distance and Proficiency on Shooting Kinematics in Professional Male Basketball Players. *Journal of Functional Morphology and Kinesiology*, 7(4), Article 4. <https://doi.org/10.3390/jfmk7040078>
- Chiu, C.-H., Wang, J.-C., & Chin-Fa, C. (2009). Minimum Energy Expenditure of Arm and Leg Motions. *International Journal of Sport and Exercise Science*, 1(2), 33–40.
- Chung, H. C., Kim, S. H., Choi, G., Kim, J. W., Choi, M. Y., & Li, H. (2020). Using a Virtual Reality Walking Simulator to Investigate Pedestrian Behavior. *Journal of Visualized Experiments*, 160, 61116. <https://doi.org/10.3791/61116>
- Çinar Medeni, Ö., Akarçeşme, C., Çerezci, S., Özünlü Pekiyaş, N., Çolakoğlu, F. F., & Baltacı, G. (2019). EFFECTS OF SERVE TYPE, POSITION, AND GENDER ON THE SERVE SPEED OF ELITE VOLLEYBALL PLAYERS. *Spor ve Performans Araştırmaları Dergisi*, 10(2), 131–139. <https://doi.org/10.17155/omuspd.473025>

- Cole, W. G., Chan, G. L. Y., Vereijken, B., & Adolph, K. E. (2013). Perceiving affordances for different motor skills. *Experimental Brain Research*, 225(3), 309–319.
<https://doi.org/10.1007/s00221-012-3328-9>
- Comalli, D. M., Persand, D., & Adolph, K. E. (2017). Motor decisions are not black and white: Selecting actions in the “gray zone.” *Experimental Brain Research*, 235(6), 1793–1807.
<https://doi.org/10.1007/s00221-017-4879-6>
- Correia, V., Araújo, D., Cummins, A., & Craig, C. M. (2012). Perceiving and Acting Upon Spaces in a VR Rugby Task: Expertise Effects in Affordance Detection and Task Achievement. *Journal of Sport and Exercise Psychology*, 34(3), 305–321.
<https://doi.org/10.1123/jsep.34.3.305>
- Croft, J. L., & Bertram, J. E. A. (2017). Affordance Boundaries Are Defined by Dynamic Capabilities of Parkour Athletes in Dropping from Various Heights. *Frontiers in Psychology*, 8. <https://www.frontiersin.org/articles/10.3389/fpsyg.2017.01571>
- Duncan, M., Martins, R., Noon, M., & Eyre, E. (2022). Perception of Affordances for Dribbling in Soccer: Exploring Children as Architects of Skill Development Opportunity. *Sports*, 10(7), 99. <https://doi.org/10.3390/sports10070099>
- Echeverría, C. J., Ortega, E., & Palao, J. M. (2019). Evolution of reception efficacy and execution in women’s volleyball according to level of competition – a descriptive study aged from 14-year-old to adult professional players. *Central European Journal of Sport Sciences and Medicine*, 27, 55–64. <https://doi.org/10.18276/cej.2019.3-05>

- Era, P., Sainio, P., Koskinen, S., Haavisto, P., Vaara, M., & Aromaa, A. (2006). Postural Balance in a Random Sample of 7,979 Subjects Aged 30 Years and Over. *Gerontology*, 52(4), 204–213. <https://doi.org/10.1159/000093652>
- Fang, F. C., & Casadevall, A. (2011). Reductionistic and Holistic Science. *Infection and Immunity*, 79(4), 1401–1404. <https://doi.org/10.1128/IAI.01343-10>
- Fink, P. W., Foo, P. S., & Warren, W. H. (2009). Catching fly balls in virtual reality: A critical test of the outfielder problem. *Journal of Vision*, 9(13), 14. <https://doi.org/10.1167/9.13.14>
- FIVB, O. (2011). *Coaches Manual I,(2011)*. English.
- Fuchs, P. X., Menzel, H.-J. K., Guidotti, F., Bell, J., von Duvillard, S. P., & Wagner, H. (2019). Spike jump biomechanics in male versus female elite volleyball players. *Journal of Sports Sciences*, 37(21), 2411–2419. <https://doi.org/10.1080/02640414.2019.1639437>
- Gagnon, H. C., Zhao, Y., Richardson, M., Pointon, G. D., Stefanucci, J. K., Creem-Regehr, S. H., & Bodenheimer, B. (2021). Gap Affordance Judgments in Mixed Reality: Testing the Role of Display Weight and Field of View. *Frontiers in Virtual Reality*, 2, 654656. <https://doi.org/10.3389/frvir.2021.654656>
- Gardner, D. L., Mark, L. S., Ward, J. A., & Edkins, H. (2001). How Do Task Characteristics Affect the Transitions Between Seated and Standing Reaches? *Ecological Psychology*, 13(4), 245–274. https://doi.org/10.1207/S15326969ECO1304_01
- Giatsis, G., Tilp, M., Hatzimanouil, D., Dieckmann, C., & Stergiou, N. (2022). Beach volleyball spike arm swing techniques of Olympics and world championships winners (1996–2019) reveal gender differences. *International Journal of Sports Science & Coaching*, 17(2), 391–399. <https://doi.org/10.1177/17479541211024151>

- Gibson, J. J. (1986). *Ecological Approach to Visual Perception*. Psychology Press.
- González-Silva, J., Fernández-Echeverría, C., Conejero, M., & Moreno, M. P. (2020). Characteristics of Serve, Reception and Set That Determine the Setting Efficacy in Men's Volleyball. *Frontiers in Psychology, 11*, 222. <https://doi.org/10.3389/fpsyg.2020.00222>
- Hajnal, A., Clark, J. D., Doyon, J. K., & Kelty-Stephen, D. G. (2018). Fractality of body movements predicts perception of affordances: Evidence from stand-on-ability judgments about slopes. *Journal of Experimental Psychology: Human Perception and Performance, 44*(6), 836–841. <https://doi.org/10.1037/xhp0000510>
- Harrison, H. S., Turvey, M. T., & Frank, T. D. (2016). Affordance-based perception-action dynamics: A model of visually guided braking. *Psychological Review, 123*(3), 305–323. <https://doi.org/10.1037/rev0000029>
- Heras-Escribano, M. (2020). The evolutionary role of affordances: Ecological psychology, niche construction, and natural selection. *Biology & Philosophy, 35*(2), 30. <https://doi.org/10.1007/s10539-020-09747-1>
- Hileno, R., González-Franqué, M., Iricibar, A., Laporta, L., & García-de-Alcaraz, A. (2023). Comparison of Rally Length between Women and Men in High-Level Spanish Volleyball. *Journal of Human Kinetics, 89*, 171–185. <https://doi.org/10.5114/jhk/167053>
- Hove, P., Riley, M. A., & Shockley, K. (2006). Perceiving Affordances of Hockey Sticks by Dynamic Touch. *Ecological Psychology, 18*(3), 163–189. https://doi.org/10.1207/s15326969eco1803_2

- Hristovski, R., Davids, K., & Araujo, D. (2006). Affordance-controlled bifurcations of action patterns in martial arts. *Nonlinear Dynamics, Psychology, and Life Sciences*, 10(4), 409–444.
- Hughes, G., Watkins, J., & Owen, N. (2010). Differences between the sexes in knee kinetics during landing from volleyball block jumps. *European Journal of Sport Science*, 10(1), 1–11. <https://doi.org/10.1080/17461390903108117>
- Ishak, S., Adolph, K. E., & Lin, G. C. (2008). Perceiving affordances for fitting through apertures. *Journal of Experimental Psychology: Human Perception and Performance*, 34(6), 1501–1514. <https://doi.org/10.1037/a0011393>
- Jacobs, D. M., & Michaels, C. F. (2007). Direct Learning. *Ecological Psychology*, 19(4), 321–349. <https://doi.org/10.1080/10407410701432337>
- Khanna, A., & Koley, S. (2020). Comparison of anthropometric profile and handgrip strength between inter-university volleyball players and a reference group. *Biomedical Human Kinetics*, 12(1), 82–90. <https://doi.org/10.2478/bhk-2020-0011>
- Kim, J.-W., Kwon, M.-S., Yenuga, S. S., & Kwon, Y.-H. (2010). The effects of target distance on pivot hip, trunk, pelvis, and kicking leg kinematics in Taekwondo roundhouse kicks. *Sports Biomechanics*, 9(2), 98–114. <https://doi.org/10.1080/14763141003799459>
- Kitsiou, A., Sotiropoulous, K., Drikos, S., Barzouka, K., & Malousaris, G. (2020). Tendencies of the volleyball serving skill with respect to the serve type across genders. *Journal of Physical Education and Sport*, 20(2 preprint83), 564–570.
- Konczak, J., Meeuwssen, H. J., & Cress, M. E. (1992). Changing affordances in stair climbing: The perception of maximum climbability in young and older adults. *Journal of*

- Experimental Psychology: Human Perception and Performance*, 18(3), 691–697.
<https://doi.org/10.1037/0096-1523.18.3.691>
- Kosty, J. (2018, June 23). Passing with the Hands. *Volleyball Toolbox*.
<https://volleyballtoolbox.net/skills/passing-with-the-hands>
- Kountouris, P., Drikos, S., Aggelonidis, I., Laios, A., & Kyprianou, M. (2015). Evidence for Differences in Men's and Women's Volleyball Games Based on Skills Effectiveness in Four Consecutive Olympic Tournaments. *Comprehensive Psychology*, 4, 30.50.CP.4.9.
<https://doi.org/10.2466/30.50.CP.4.9>
- Lee, D. N., Young, D. S., & McLaughlin, C. M. (1984). A roadside simulation of road crossing for children. *Ergonomics*, 27(12), 1271–1281.
<https://doi.org/10.1080/00140138408963608>
- Lenoir, M., Vansteenkiste, J., Vermeulen, J., & de Clercq, D. (2005). Effects of contrasting colour patterns of the ball in the volleyball reception. *Journal of Sports Sciences*, 23(8), 871–879. <https://doi.org/10.1080/02640410400022722>
- Lima, R., Palao, J. M., Moreira, M., & Clemente, F. M. (2019). Variations of technical actions and efficacy of national teams' volleyball attackers according to their sex and playing positions. *International Journal of Performance Analysis in Sport*, 19(4), 491–502.
<https://doi.org/10.1080/24748668.2019.1625658>
- Lithio, D., & Webb, E. (2006). Optimizing a Volleyball Serve. *Rose-Hulman Undergraduate Mathematics Journal*, 7(2).

- Lopresti-Goodman, S., Kallen, R. W., Richardson, M. J., Marsh, K. L., & Johnston, L. (2010). The influence of heightened body-awareness on walking through apertures. *Applied Cognitive Psychology*, 24(4), 557–570. <https://doi.org/10.1002/acp.1568>
- Lopresti-Goodman, S. M., Richardson, M. J., Baron, R. M., Carello, C., & Marsh, K. L. (2009). Task Constraints on Affordance Boundaries. *Motor Control*, 13(1), 69–83. <https://doi.org/10.1123/mcj.13.1.69>
- Lopresti-Goodman, S. M., Turvey, M. T., & Frank, T. D. (2011). Behavioral dynamics of the affordance “graspable.” *Attention, Perception, & Psychophysics*, 73(6), 1948–1965. <https://doi.org/10.3758/s13414-011-0151-5>
- Mark, L. S. (1987). Eyeheight-Scaled Information About Affordances: A Study of Sitting and Stair Climbing. *Journal of Experimental Psychology*, 13(3), 361–370.
- Mark, L. S., Balliett, J. A., Craver, K. D., Douglas, S. D., & Fox, T. (1990). What an Actor Must Do in Order to Perceive the Affordance for Sitting. *Ecological Psychology*, 2(4), 325–366. https://doi.org/10.1207/s15326969eco0204_2
- Mark, L. S., Nemeth, K., Gardner, D., Dainoff, M. J., Paasche, J., Duffy, M., & Grandt, K. (1997). Postural dynamics and the preferred critical boundary for visually guided reaching. *Journal of Experimental Psychology: Human Perception and Performance*, 23, 1365–1379. <https://doi.org/10.1037/0096-1523.23.5.1365>
- Masoner, H., Hajnal, A., Clark, J. D., Dowell, C., Surber, T., Funkhouser, A., Doyon, J., Legradi, G., Samu, K., & Wagman, J. B. (2020). Complexity of postural sway affects affordance perception of reachability in virtual reality. *Quarterly Journal of Experimental Psychology*, 73(12), 2362–2375. <https://doi.org/10.1177/1747021820943757>

- Millán-Sánchez, A., Madinabeitia, I., de la Vega, R., Cárdenas, D., & Ureña, A. (2023). Effects of emotional regulation and impulsivity on sports performance: The mediating role of gender and competition level. *Frontiers in Psychology, 14*, 1164956.
<https://doi.org/10.3389/fpsyg.2023.1164956>
- Moras, G., Buscà, B., Peña, J., Rodríguez, S., Vallejo, L., Tous-Fajardo, J., & Mujika, I. (2008). A comparative study between serve mode and speed and its effectiveness in a high-level volleyball tournament. *The Journal of Sports Medicine and Physical Fitness, 48*(1), 31–36.
- O’Neal, E. E., Jiang, Y., Franzen, L. J., Rahimian, P., Yon, J. P., Kearney, J. K., & Plumert, J. M. (2018). Changes in perception-action tuning over long time scales: How children and adults perceive and act on dynamic affordances when crossing roads. *Journal of Experimental Psychology: Human Perception and Performance, 44*(1), 18–26.
<https://doi.org/10.1037/xhp0000378>
- Osiurak, F., Rossetti, Y., & Badets, A. (2017). What is an affordance? 40 years later. *Neuroscience and Biobehavioral Reviews, 77*, 403–417.
<https://doi.org/10.1016/j.neubiorev.2017.04.014>
- Oudejans, R. R. D., Michaels, C. F., Bakker, F. C., & Dolné, M. A. (1996). The relevance of action in perceiving affordances: Perception of catchableness of fly balls. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 879–891.
<https://doi.org/10.1037/0096-1523.22.4.879>
- Palao, J. M. (2014). Normative profiles for serve speed for the training of the serve and reception in volleyball. *Sport Journal, 1*–1.

- Palao, J. M., Manzanares, P., & Ortega, E. (2009). Techniques used and efficacy of volleyball skills in relation to gender. *International Journal of Performance Analysis in Sport*, 9(2), 281–293. <https://doi.org/10.1080/24748668.2009.11868484>
- Paulo, A., Davids, K., & Araújo, D. (2018). Co-adaptation of ball reception to the serve constrains outcomes in elite competitive volleyball. *International Journal of Sports Science & Coaching*, 13(2), 253–261. <https://doi.org/10.1177/1747954117722727>
- Paulo, A., Zaal, F. T. J. M., Fonseca, S., & Araújo, D. (2016). Predicting Volleyball Serve-Reception. *Frontiers in Psychology*, 7. <https://www.frontiersin.org/articles/10.3389/fpsyg.2016.01694>
- Paulo, A., Zaal, F. T. J. M., Seifert, L., Fonseca, S., & Araújo, D. (2018). Predicting volleyball serve-reception at group level. *Journal of Sports Sciences*, 36(22), 2621–2630. <https://doi.org/10.1080/02640414.2018.1473098>
- Peker, A. T., Böge, V., Bailey, G. S., Wagman, J. B., & Stoffregen, T. A. (2023). Perception of higher-order affordances for kicking in soccer. *Journal of Experimental Psychology: Human Perception and Performance*, 49(5), 623–634. <https://doi.org/10.1037/xhp0001108>
- Peker, A. T., Böge, V., Bailey, G., Wagman, J. B., & Stoffregen, T. A. (2020). Perception of Affordances in Soccer: Kicking for Power Versus Kicking for Precision. *Research Quarterly for Exercise and Sport*, 0(0), 1–9. <https://doi.org/10.1080/02701367.2020.1812494>
- Peker, A. T., Erkmen, N., Kocaoglu, Y., Bayraktar, Y., Arguz, A., Wagman, J. B., & Stoffregen, T. A. (2020). Perception of Affordances for Vertical and Horizontal Jumping in Children:

- Gymnasts Versus Non-Athletes. *Research Quarterly for Exercise and Sport*, 1–9.
<https://doi.org/10.1080/02701367.2020.1775768>
- Pepping, G.-J., Heijmerikx, J., & de Poel, H. J. (2011). Affordances shape pass kick behavior in association football: Effects of distance and social context. *Revista de Psicología Del Deporte*, 20, 709–727.
- Pepping, G.-J., & Li, F.-X. (2000a). Changing action capabilities and the perception of affordances. *Journal of Human Movement Studies*, 39, 115–140.
- Pepping, G.-J., & Li, F.-X. (2000b). Sex Differences and Action Scaling in Overhead Reaching. *Perceptual and Motor Skills*, 90(3_suppl), 1123–1129.
<https://doi.org/10.2466/pms.2000.90.3c.1123>
- Perez, C. C. (2019). *Invisible Women: The Sunday Times number one bestseller exposing the gender bias women face every day*. Random House.
- Pijpers, J. R., Oudejans, R. R. D., & Bakker, F. C. (2007). Changes in the perception of action possibilities while climbing to fatigue on a climbing wall. *Journal of Sports Sciences*, 25(1), 97–110. <https://doi.org/10.1080/02640410600630894>
- Podstawski, R., Markowski, P., & Clark, C. (2020). Sex-mediated differences and correlations between the anthropometric characteristics and motor abilities of university students. *Journal of Physical Education and Sport*, 20(1), 86–96.
<https://doi.org/10.7752/jpes.2020.01011>
- Postma, D. B. W., Lemmink, K. A. P. M., & Zaal, F. T. J. M. (2018). The affordance of catchability in running to intercept fly balls. *Journal of Experimental Psychology. Human Perception and Performance*, 44(9), 1336–1347. <https://doi.org/10.1037/xhp0000531>

- Reynaud, C. (2015). *The Volleyball Coaching Bible, Volume II*. Human Kinetics.
- Salci, Y., Kentel, B. B., Heycan, C., Akin, S., & Korkusuz, F. (2004). Comparison of landing maneuvers between male and female college volleyball players. *Clinical Biomechanics*, 19(6), 622–628. <https://doi.org/10.1016/j.clinbiomech.2004.03.006>
- Sarpeshkar, V., Mann, D. L., Spratford, W., & Abernethy, B. (2017). The influence of ball-swing on the timing and coordination of a natural interceptive task. *Human Movement Science*, 54, 82–100. <https://doi.org/10.1016/j.humov.2017.04.003>
- Sattler, T., Hadžic, V., Dervišević, E., & Markovic, G. (2015). Vertical Jump Performance of Professional Male and Female Volleyball Players: Effects of Playing Position and Competition Level. *The Journal of Strength & Conditioning Research*, 29(6), 1486. <https://doi.org/10.1519/JSC.0000000000000781>
- Seifert, L., Dicks, M., Wittmann, F., & Wolf, P. (2021a). The influence of skill and task complexity on perception of nested affordances. *Attention, Perception, & Psychophysics*, 83(8), 3240–3249. <https://doi.org/10.3758/s13414-021-02355-5>
- Seifert, L., Dicks, M., Wittmann, F., & Wolf, P. (2021b). The perception of nested affordances: An examination of expert climbers. *Psychology of Sport and Exercise*, 52, 101843. <https://doi.org/10.1016/j.psychsport.2020.101843>
- Seifert, L., Orth, D., Mantel, B., Boulanger, J., Hérault, R., & Dicks, M. (2018). Affordance Realization in Climbing: Learning and Transfer. *Frontiers in Psychology*, 9. <https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00820>

- Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared Knowledge or Shared Affordances? Insights from an Ecological Dynamics Approach to Team Coordination in Sports. *Sports Medicine*, 43(9), 765–772. <https://doi.org/10.1007/s40279-013-0070-9>
- Sparrow, W. A., & Newell, K. M. (1998). Metabolic energy expenditure and the regulation of movement economy. *Psychonomic Bulletin & Review*, 5(2), 173–196. <https://doi.org/10.3758/BF03212943>
- Stefanucci, J. K., Saxon, M., & Whitaker, M. (2021). Embodied Perception and Action in Real and Virtual Environments. In M. D. Robinson & L. E. Thomas (Eds.), *Handbook of Embodied Psychology: Thinking, Feeling, and Acting* (pp. 311–336). Springer International Publishing. https://doi.org/10.1007/978-3-030-78471-3_14
- Steiber, N. (2016). Strong or Weak Handgrip? Normative Reference Values for the German Population across the Life Course Stratified by Sex, Age, and Body Height. *PLOS ONE*, 11(10), e0163917. <https://doi.org/10.1371/journal.pone.0163917>
- Stoffregen, T. A. (2003). Affordances as Properties of the Animal-Environment System. *Ecological Psychology*, 15(2), 115–134. https://doi.org/10.1207/S15326969ECO1502_2
- Stoffregen, T. A., Yang, C.-M., Givens, M. R., Flanagan, M., & Bardy, B. G. (2009). Movement in the Perception of an Affordance for Wheelchair Locomotion. *Ecological Psychology*, 21(1), 1–36. <https://doi.org/10.1080/10407410802626001>
- Street, J. A. (2018). *APPLYING SPORTS ANALYTICS TO DIVISION I WOMEN'S VOLLEYBALL: SERVE RECEIVE PASS RATING RELATIVE TO SERVER LOCATION, SPEED OF THE SERVE, LOCATION OF THE PASSER, AND PASSING ANGLE* [Miami University].

[https://etd.ohiolink.edu/acprod/odb_etd/etd/r/1501/10?clear=10&p10_accession_num=mi
ami1533309130969035](https://etd.ohiolink.edu/acprod/odb_etd/etd/r/1501/10?clear=10&p10_accession_num=mi
ami1533309130969035)

VolleyTalk. (2007). *Overhand serve receive* | *Volley Talk* [Forum].

<https://volleytalk.proboards.com/thread/14961/overhand-serve-receive>

Wagman, J. B., Caputo, S. E., & Stoffregen, T. A. (2016). Hierarchical nesting of affordances in a tool use task. *Journal of Experimental Psychology: Human Perception and Performance*, 42(10), 1627–1642. <https://doi.org/10.1037/xhp0000251>

Wagman, J. B., & Stoffregen, T. A. (2020). It doesn't add up: Nested affordances for reaching are perceived as a complex particular. *Attention, Perception, & Psychophysics*, 82(8), 3832–3841. <https://doi.org/10.3758/s13414-020-02108-w>

Walter, H., Wagman, J. B., Stergiou, N., Erkmén, N., & Stoffregen, T. A. (2017). Dynamic perception of dynamic affordances: Walking on a ship at sea. *Experimental Brain Research*, 235(2), 517–524. <https://doi.org/10.1007/s00221-016-4810-6>

Warren, W. H. (1984). Perceiving Affordances: Visual Guidance of Stair Climbing. *Journal of Experimental Psychology*, 10(5), 683–703.

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review*, 113(2), 358–389. <https://doi.org/10.1037/0033-295X.113.2.358>

Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance*, 13(3), 371–383. <https://doi.org/10.1037/0096-1523.13.3.371>

Weast, J. A., Shockley, K., & Riley, M. A. (2011). The influence of athletic experience and kinematic information on skill-relevant affordance perception. *Quarterly Journal of*

- Experimental Psychology*, 64(4), 689–706.
<https://doi.org/10.1080/17470218.2010.523474>
- Yasuda, M., Wagman, J. B., & Higuchi, T. (2014). Can perception of aperture passability be improved immediately after practice in actual passage? Dissociation between walking and wheelchair use. *Experimental Brain Research*, 232(3), 753–764.
<https://doi.org/10.1007/s00221-013-3785-9>
- Yonas, A., & Hartman, B. (1993). Perceiving the Affordance of Contact in Fourand Five-Month-Old Infants. *Child Development*, 64(1), 298–308. <https://doi.org/10.1111/j.1467-8624.1993.tb02911.x>
- Zhao, H., Zhao, Q. H., & Ślusarczyk, B. (2019). Sustainability and Digitalization of Corporate Management Based on Augmented/Virtual Reality Tools Usage: China and Other World IT Companies' Experience. *Sustainability*, 11(17), Article 17.
<https://doi.org/10.3390/su11174717>
- Zheng, R., van der Kamp, J., Song, X., & Savelsbergh, G. (2022). Affordance-based control in deceptive and non-deceptive penalties in soccer goalkeeping: Gender matters! *Psychology of Sport and Exercise*, 58, 102096.
<https://doi.org/10.1016/j.psychsport.2021.102096>
- Zhu, Q. (2013). Perceiving the affordance of string tension for power strokes in badminton: Expertise allows effective use of all string tensions. *Journal of Sports Sciences*, 31(11), 1187–1196. <https://doi.org/10.1080/02640414.2013.771818>