The Effect of Manipulating Perceived Action Boundaries On Catching Performance

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ABSTRACT

Technology has an ever-growing role in sports. To explore how technology can improve training practice, there is the need to explore the usefulness of real-time augmented visual information in guiding motor behavior. This paper will investigate if the affordance of catchability can be influenced by presenting volleyball players with a manipulated action boundary and will measure the impact on behavior (distance covered, response time) and performance (catch or not). An experiment is described where 26 participants were presented with a smaller- or larger-than real action boundary in an attempt to manipulate affordance before they were given the task to catch an incoming fly ball. No significant effect was found between the two manipulation groups on behavior or performance.

Keywords

Affordance; Action Boundary; Behavior; Sports; Training; Interaction Technology; Visual Information;

1. INTRODUCTION

Technology has an ever-growing role in sports and a major role in training for players of both amateur level and professional level [8]. It has even been predicted that future progress in sports performance will mainly rely on technology or technical innovations [1].

The Human Computer Interaction community too is extensively paying attention to the technology that supports sports training [5]. The Human Media Interaction department of the University of Twente is coordinating a project related to technology in sports: the Smart Sports Exercises (SSE) project. One of its aims is to update traditional perspectives on movement, training, and exercise [12]. They state that to explore how technology can improve training practice, it is needed to explore the usefulness of real-time augmented visual information in guiding motor behavior [12].

This paper aims to contribute to the SSE project, as it will further explore the possible effect of real-time augmented visual information on the behavior of a volleyball player. In particular, it will investigate if there is an effect on the *affordance of catchability* (can a ball be caught or not) when volleyball players are presented with manipulated visuals that represent their action range, so-called *action boundaries*. The results of this research can be used to help develop new interactive training exercises.

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2. BACKGROUND

Objects, places, and events permit one to carry out acts or behaviors. These possible acts or behaviors constitute *affordances* [7]. For example, a chair has the affordance of sitting on for human beings. Or for this paper, a ball flying toward us can afford catching depending on certain factors of both ball and the agent attempting to catch. One agent might be able to catch a ball that another cannot catch; affordances are different for every person [7].

Affordances depend on the abilities of a person; where their action boundaries lie. *Action boundaries* are a reference to what a person can or cannot do. Postma et al. designed a model to calculate whether a fly ball is catchable or not, based on the maximum distance that can be covered within a certain time frame by that certain individual [11]. This maximum distance can be seen as a personalized action boundary, or as an *omnidirectional locomotor range.* The range is formed by the limits of all planes together: forwards, backward, and sideways.

A person's perception influences affordance too: affordance is *perceived* [3]; it depends on the detection of useful information [7]. Perception of affordances is key for an agent to act adequately [11]. If we want to influence behavior for training purposes, we need to be able to provide useful information. Thus, we need to find a way to visualize the action boundaries in such a way that it contains useful information for the player.

Summarizing, perception influences actions, behavior, and affordances. Furthermore, affordance can influence how we move. Can we then also influence affordance using interaction technology? And if so, can this be used for training purposes? In this paper, we investigate whether interaction technology can be used to influence *serve interception* behavior (i.e. the interception of the ball during the first play) in volleyball. Specifically, can volleyball performance be influenced by displaying manipulated action boundaries (i.e. smaller than actual or larger than actual)?

3. RESEARCH QUESTIONS

The work described in this paper follows from the research questions and subquestions below, which will be addressed in an experimental study.

RQ1: Can the affordance of catchability be influenced by presenting volleyball players with a manipulated visualization of their action boundary?
a) Are volleyball player's behaviors influenced by showing their manipulated action boundary?

b) Is catching performance influenced by showing manipulated action boundaries?

Before we can answer these questions, two things are needed. Firstly, Existing methods to calculate action boundaries, such as Postma's model [11], are suitable for one dimensional only and need to be adapted to an omnidimensional model. Furthermore, the action boundaries need to be appropriately visualized on the floor, so the player can perceive them, understand them, and act on them. This leads to two additional research questions that are investigated by exploring related work.

RQ2: How can the bi-directional model of maximal effort sprinting by Postma et al. [11] be extrapolated to an omnidirectional model?

RQ3: What is the best way to visualize an action boundary such that it can be perceived by volleyball players?

4. RELATED WORK

4.1 Calculating Action Boundaries

As mentioned in section 2, Postma et al. designed a model to calculate whether a fly ball is catchable or not, based on the maximum distance that can be covered [11], see Figure 1. This distance is calculated using the maximum acceleration of a person. The formula is stated as follows:

$$\ddot{x} = a\dot{x}^{1.2} \cdot (\dot{x} - \dot{x}_{max})^2 \rightarrow \{\dot{x}|0 \leq \dot{x} \leq \dot{x}_{max}\}; a > 0$$

Here $\ddot{x}$ represents acceleration, $\dot{x}$ represents velocity, and a represents a constant used to constrain the polynomial so the acceleration never exceeds the maximum acceleration of a participant [11]. We can integrate this formula over time to predict a participant's position over time.

However, this model is limited to the forward- and backward plane, and it does not include the plane directed sideways. For our work, players can also move sideways, as they will have to catch balls aimed straight at them, but also at their sides. Therefore an extrapolation to include this sideways plane in action boundaries will be discussed.

Figure 1. The current model of Postma et al. [11] is limited to the maximum distance that can be covered in the forward- and backward plane.

4.2 Interaction Technology for Training

Extensive research into interactive training, in which steering behavior constitutes a major role, exists. Hadlow et al. designed a framework aimed to predict the effectiveness of an interactive training tool, called the Modified Perceptual Training Framework [4], by performing an extensive literature review. It is based on three factors. The first factor targeted perceptual function, the framework predicts that the effectiveness of the training method will increase if it trains a "sport-specific, perceptual-cognitive" skill. The second factor is the stimuli' degree of correspondence with the sport. More generic stimuli will not be as effective as sport-specific stimuli. Lastly, the framework predicts that a training method will be more effective if the response is required to be sport-specific.

4.3 Steering Behavior in Physical Activity Through Visual Feedback

Interaction technology can be applied in many ways. Soler-Adillon and Parés designed an interactive slope aimed to engage children in social and physical activities [14]. They presented a game-like experience where users had to collaborate to achieve the goal of building a robot. The game was controlled by a tempo, essentially managing the speed of the game. It was hypothesized that a higher tempo would result in more physical activity, but formal prove could not be provided due to technical issues. Previous research, however, does show that the system should help children engage in social activities.

Van Delden et al. used an interactive playground to steer the behavior of players in a game of Tag [15]. They mention that steering a player's behavior is relevant to promote certain behaviors when designing games. An "enticing" strategy to steer proxemic behavior in a game of Tag was implemented (e.g. distance, orientation, identity, movement, and location) aiming to get runners closer to a tagger. The runners could collect particles, displayed by visuals on the floor, that were emitted periodically by the tagger. Once runners collected enough particles, the visuals around them became more complex and gained beauty. When a player got tagged, their visual got reset. The study is interesting because it showed that visuals can be used to steer player behavior in a game. However, our study will not be conducted in a game format, nor will it use an enticing strategy to steer behavior.

Sato et al. investigated the effectiveness of visual information on reaction speed and accuracy when intercepting serve balls in volleyball [13]. They designed a system that visualized the landing position of a serve ball, to help beginners develop the skill to predict this position. Through an experiment, they showed that it significantly improved participants' response time if the ball was aimed at their left or right side, although this improvement was about 0.01 seconds. They also showed that the system helped participants move in the right direction, resulting in a higher percentage of balls caught. Again, this was only if the ball was aimed at the participant's right or left side. The work of Sato et al. shows it is possible to influence response time and catching performance by providing visual information. However, their system is focused on helping to predict the landing position of the ball. Our study involves the judgment of the catchability of a fly ball. One could say that the skill to predict the landing position is therefore already required, as one needs to know the position before catchability can be judged.

Adding information can influence behavior and performance, but the same goes for removing information. Bennett et al. investigated if constraining visual information from children when learning a new skill, in this case one-handed catching, can influence performance [2]. They showed that restricting somebody's vision can benefit skill acquisition, suggesting that restricted vision improves the ability to exploit additional information sources instead of dominant information sources.

Visual information does not always have to be provided during the performance of a task. Pagé et al. used video simulations to investigate the effect on decision-making [10]. Participants were split up into three groups: Virtual Reality (VR), Computer Screen (CS), or Control. The VR and CS groups observed videos where basketball players performed variations of offensive basketball plays from a first-person perspective, using either a Virtual Reality headset or a computer screen. The control group got to watch different basketball games. It was shown that after four sessions of observing videos, participants from the VR group made gains in decision-making skills, also in untrained plays. The CS group only showed gains in trained plays. This difference is explained by the different levels of immersiveness between the VR and CS groups.

4.4 Steering Perceived Affordance by Manipulating Intrinsic Information

Research into the manipulation of affordance by altering perception exists too. Leonard S. Mark designed a study to investigate the judgment of action boundaries [6] by manipulating intrinsic player information, namely how tall the player was. By having the participants stand on 10 cm blocks, they were made taller. They then had to make perceptual judgments of the affordance of surfaces regarding sitting on and climbing, and guess the height of the blocks that they were standing on. At first, participants made errors in their judgments of action boundaries, but after a while they were able to calibrate them. The research proved that the judgment of action boundaries is based on the scaling of size and distance information in reference to the eyesight of the participant. It also shows how affordance can be impacted, and that people can (re)calibrate the perception of affordances. Our study is aimed at the effect on affordance by manipulating information, but not through adjusting intrinsic information (body height), but through extrinsic information (visuals).

4.5 Providing Visual Information That Is Easy To Perceive

For our study, we require visualization that is easy to perceive for the participants to manipulate affordance. Jensen et al. found that graphics have an impact on the difficulty to perceive targets in a training game [5]. The game consisted of target practice, at a handball goal. Participants approached the goal and when one of multiple targets was displayed they had to shoot the ball at the target. Three distinct visuals were tested for their perceivability and distinguish-ability. The first one being *YellowBlack*, where the goal was black and the targets were yellow. The second one, *CounterStripes*, also used yellow and black but integrated stripes. The last visual was *ColorMatch*, where there were eight colored targets with multiple colors. Participants regarded YellowBlack to be the easiest visual to perceive. CounterStripes elicited participants to aim for the largest target due to the complexity of the visual, and ColorMatch showed that participants found it difficult to identify different targets while moving. In our study we will not visualize different targets, but only one action boundary. This action boundary must be easy to perceive while moving, making a visual like YellowBlack most suitable to display it. This solves RQ3.

5. METHODOLOGY

5.1 Study Design

To answer RQ1 an experiment was set up that employs a between-subjects design with two conditions. All participants were charged with the task of catching fly balls after their action boundaries were displayed on the floor. Using this study we measured behavior (response time, distance covered) and performance (catch or not, touch or not) in relation to manipulated action boundaries.

5.2 Materials

5.2.1 Playground

The experiment was performed in 'The Playground' of the University of Twente. This area is equipped with two projectors, situated 4 m apart from each other [9]. Together they can cover an area of approximately 7 x 6 m, and were used to display the action boundary by visualizing a white area by a white area, see figure 2. We used only two colors with high contrast, as section 4.5 showed was best.

Figure 2. Used visualization of action boundary, where the action boundary is presented as a white area with fading edges. The floor of the playground is black, hence the black background.

In addition to the projectors, the Playground is equipped with a tracking system [9] that uses four Kinect cameras. The Kinects are 4 meters apart from each other and 5.3 m above the Playground area. Together they can track a participant in an area of approximately 7 x 6 m. This system will be used to log the movement of players.

5.2.2 Determining Participants Action Boundaries

A short experiment was performed to answer RQ2, where one participant performed five maximum effort sprints in four different directions. He started facing the same direction and then sprinted directly towards a target that was 0, 30, 60 or 90 degrees to his left. Using the Playground's tracking system we observed no significant differences in either maximum acceleration or maximum velocity, which lead to the belief that the bi-directional model of maximal efforts of Postma et al. [11] could be used in the omnidirectional range without applying extrapolation. However, since only one participant performed the experiments, this cannot be supported with formal evidence.

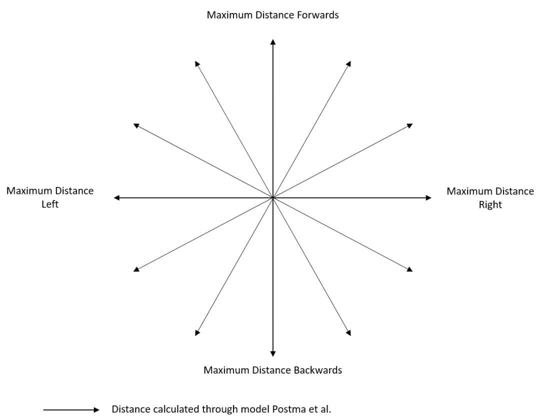

Figure 3. Postma's Model [11] will be used in the omnidirectional range, where it is assumed that the maximum distance forward equals the maximum distance sideways.

The tracking system of the playground was used to calculate the maximum speed and acceleration of each participant. The model of Postma et al.[11] was then used with this data and a ball's flight time (see section 5.2.3) to calculate the omnidirectional locomotor range.

5.2.3 *Ball Shooting Machine*

A tennis ball machine (brand: Lobster, model: Elite Liberty [1]) was used to provide fly balls aimed at one of seven targets, see Figure 4. The distance from the targeted ball position to the participant is equal for all balls, as they are located on the participant's real action boundary. The machine was tested by aiming 49 balls at the same position and showed to be very accurate as landing positions had a standard deviation of 9,2 cm. However, as we had to aim it by changing its position and angle during the experiment, it is expected that the actual landing positions deviated more than 9 cm.

During the experiment, the ball machine was hidden from participants using a wall of cloth of about 1.7 meters high and 1.5 meters wide, as the participants should not be able to predict the direction of the ball too soon. When the ball was visible, a flight time of 1,3 seconds was left. As people need time to respond to a ball, we subtracted an estimated response time of 400 milliseconds from this time, leaving 0,9 seconds for participants to cover any distance.

5.2.4 *Video Recorder*

Video recordings were made during the experiment to measure response time, and for post hoc analysis.

5.3 Conditions

The experiment was carried out with two groups of participants: one group was presented with a smaller-than-real action boundary (the 0.75 group), the other group was presented with a larger-than-real action boundary (the 1.25 group). Each participant's boundaries were calculated beforehand and multiplied with the ratio of their manipulation group to determine the size of the visual information.

5.4 Participants

26 participants have been recruited. This number was based on an overly simple power analysis for which many assumptions have been made. They were recruited from the University of Twente, or through social relations, and had no previous knowledge of the experiment.

5.5 Measures

Participants were presented with 21 balls, in a randomized order, targeting seven different positions located at their real action boundary. Each position was targeted three times. For each ball, the following was measured:

5.5.1 *Behavior*

Using the tracking system (see Section 5.2.1) the distance covered was recorded to see if there is a correlation between the action boundary and the distance covered. Furthermore, response time was measured to give insights into how fast players respond to a ball in regards to their manipulation group. Response time was seen as the difference in time between the moment the ball was visible and the moment a participant had moved his second foot from the ground. The second foot was chosen as this foot was usually used to generate movement into the direction of the landing position of the ball.

[1]https://www.lobstersports.com/products/el0l.htm

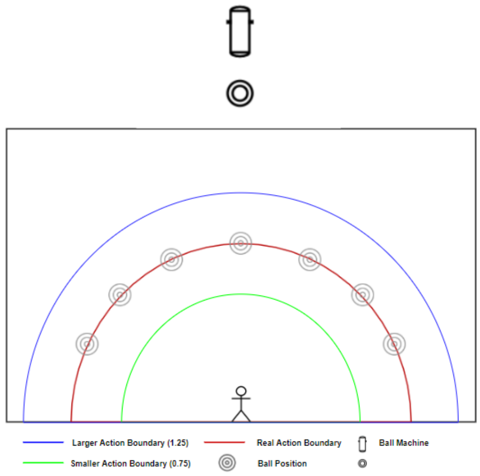

Figure 4. The designed experiment setup: participants start at the position represented by 'participant' while their manipulated action boundary is displayed around them. They then attempt to catch a ball shot from the ball-shooting machine aimed at one of the seven landing positions.

5.5.2 *Performance*

Performance was measured by observing if a ball was caught or not. During the first stages of the experiment, it was noticed that some participants had a hard time catching a ball, even though they were in range of the ball. This is why a second variable was added that recorded if the ball was touched. Both outcomes were immediately noted by the experimenter. It was expected that the size of the action boundary correlated positively with performance.

5.5.3 *Possible Insights Through Interviews*

An anecdotal, semi-structured interview was performed at the end of the experiment. It evaluated the participants' opinion and answered the following questions:

- What is your experience with ball sports?
- What is your experience with volleyball in particular?
- What did you think of the experiment?
- Did you think the action boundaries represented your abilities?
- Did you notice that the action boundary was being manipulated?
- Did you notice that there were only seven different balls?
- Do you think using manipulated action boundaries can be used to influence behavior?

5.6 Protocol

5.6.1 *Before The Experiment*

Ethical approval had been granted previously by the ethical board of the Electrical Engineering, Mathematics, and Computer Science faculty of the University of Twente. For each participant, a separate appointment was made. At the start of this appointment, action boundaries were explained, and that balls needed to be caught. Participants were not informed about the two different conditions or the targets of the ball, as this might have affected results. After providing the necessary information, they were asked to sign a consent form. Following, they had to perform six maximum effort sprints. Three sprints started directly under the tracking system, as maximum acceleration occurs at the first moments of a sprint. The other three started 30 meters away from the tracking system, as we expected that maximum velocity would be achieved after this distance. Using this data we then calculated the action boundary to aim the ball machine and for the (manipulated) visualization during the remainder of the experiment.

5.6.2 During The Experiment

Participants had to stand in a designated position at the start of each run. While they were setting up, their action boundary was displayed on the floor. About three seconds before the ball was shot, the visual disappeared. We thought this would give the participants a better chance to absorb and use the visual information. Otherwise, they would have had to look up to see an incoming ball while the information is presented on the floor. Furthermore, they might have become aware of the manipulation if we showed it while attempting to catch, as they can compare the action boundary with the distance they actually traveled. Performance and behavior were recorded for each run following the aforementioned criteria.

5.6.3 After The Experiment

After the experiment, a short interview (see section 5.5.3) was performed. The participants were also debriefed and told that their action boundary was manipulated.

6. RESULTS

6.1 Results of Calculating Participant's Action Boundaries

For each participant, we measured their maximum velocity and maximum acceleration. The mean of the maximum velocity was 7,15 m/s, with a standard deviation of 1,31 m/s, and maximum acceleration had a mean of 5,05 m/s^2 with a standard deviation of 0,88 m/s^2, see figure 5. The measures resulted in locomotor ranges between 2,92 meters and 2,11 meters (ignoring two outliers of 2,02m and 3,15m). A mean range of 2,59 meters was reported with a standard deviation of 0,25 meters, see figure 6.

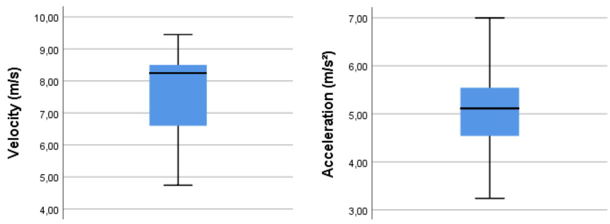

Figure 5. Boxplot representing the maximum velocity and acceleration achieved by participants

6.2 Dataset 1

A total of 26 participants (n=26) took part in the experiment. One participant dropped out due to an injury, these results were therefore not included in the analyzed data. This initial data, called Dataset 1, contained 25 participants (n=25), and 524 cases (n=524). 12 of the participants were in the .75 group, and 13 were in the 1.25 group. Due to sample size and upon inspection of skewness it was assumed that the data was not normal-distributed.

6.2.1 Participant Division

To check whether all participants had equal running capabilities, and thus if they were divided evenly between the two groups, the maximum acceleration and the maximum velocity were compared between the groups. A Mann-Whitney U test showed that maximum acceleration did

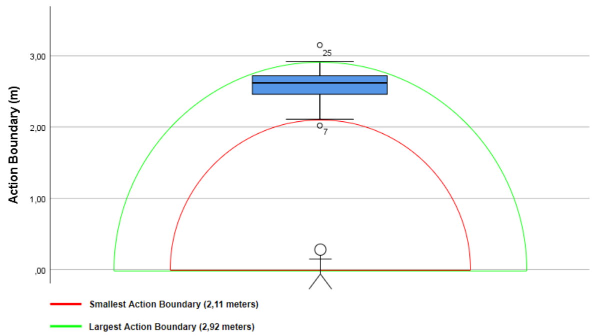

Figure 6. Boxplot representing the achieved locomotor ranges calculated with Postma's Model [11]. The colored lines display the minimum and maximum action boundaries used in the experiment, ignoring outliers.

not differ significantly between the 0.75 group (*Mdn* = *5,10* m/s^2) and the 1.25 group (*Mdn* = *5,18* m/s^2), *U* = *70,00*, *z* = *-,098*, ns, *r*= *-0,224*. Maximum velocity did not differ significantly either between the 0.75 group (*Mdn* = *8,31* m/s) and the 1.25 group (*Mdn* = *7,50* m/s), *U* = *75,50*, *z* = *-,137*, ns, *r*= *-0,027*.

6.2.2 Measures

Catching Performance – To see if there was any difference in the number of balls caught between the groups, a Mann-Whitney U test was performed. No significant difference was found between the 0.75 group (*Mdn* = *10,50*) and the 1.25 group (*Mdn* = *11,00*), *U* = *69,50*, *z* = *-0,466*, ns, *r*= *-0,093*.

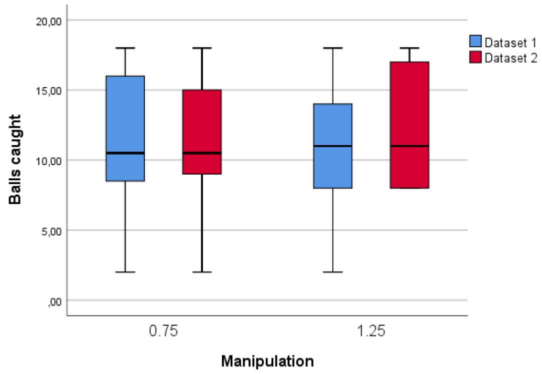

Figure 7. Boxplot representing the number of balls caught per participant in Dataset 1 and Dataset 2. Dataset 2 was created in an attempt to reduce data variance, based on reported ball sports experience.

Touching Performance – The difference in the number of balls touched too was analyzed with a Mann-Whitney U test. No significant difference was found between the 0.75 group (*Mdn* = *17,50*) and the 1.25 group (*Mdn* = *15,00*), *U* = *63,00*, *z* = *-0,820*, ns, *r*= *-0,164*.

Distance Covered – Due to technical difficulties the distance for seventeen cases could not be measured. Using the remaining cases there was no significant difference on the average distance covered found between the 0.75 group (*Mdn* = *2,18m*) and the 1.25 group (*Mdn* = *2,21m*), using a Mann-Whitney U test *U* = *69,00*, *z* = *-0,490*, ns, *r*= *-0,098*. To see if there was an interaction effect between ball position and manipulation on the distance covered, a

Mixed Anova was performed. It indicated no significant interaction effect, $F(3,47) = 1{,}420$, $p > 0.05$.

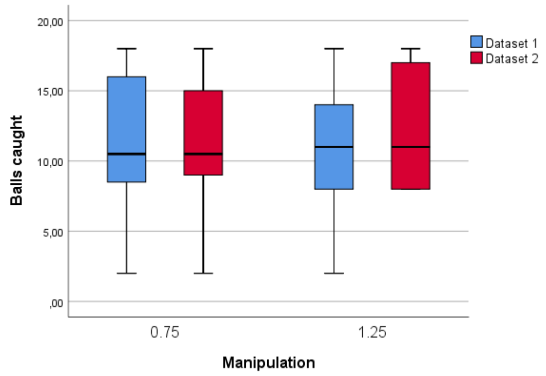

Figure 8. Boxplot representing the average distance covered per participant in Dataset 1 and Dataset 2.

Response Time — Finally, the average response time was analyzed using a Mann-Whitney U test. Again, no significant difference was found between the 0.75 group ($Mdn = 533{,}9\ ms$) and the 1.25 group ($Mdn = 515{,}24$), $U = 70{,}50$, $z = -0{,}408$, ns, $r = -0{,}082$. Furthermore, a Mixed Anova test was performed to see if there was an interaction effect between the ball position and manipulation on the response time. The analysis indicated no significant interaction effect, $F(6{,}138) < 1$, $p > 0{,}05$.

6.3 Dataset 2

During the experiment, some participants struggled to respond adequately to an incoming ball, which resulted in spread-out data. This is why a new dataset is proposed, called Dataset 2. It only includes participants who reported experience with ball sports, as it was assumed that they are more likely to accurately predict their capabilities and the trajectory of the ball. The dataset contained 399 cases from 19 participants (n=19), of which nine (n=9) were in the 1.25 manipulation group, and ten (n=10) were in the .75 manipulation group. The dependent variables of this set were assumed to be non-normally distributed after inspection of the skewness and due to the small sample size of 19 participants.

6.3.1 Division of Participants

A Mann-Whitney U test was performed on both the recorded maximum acceleration and maximum velocity of participants of Dataset 2. Maximum acceleration did not differ significantly between the 0.75 group ($Mdn = 5{,}20\ m/s^2$) and the 1.25 group ($Mdn = 5{,}32\ m/s^2$), $U = 33{,}00$, $z = -{,}980$, ns, $r = -0{,}224$. Maximum velocity did not differ significantly either between the 0.75 group ($Mdn = 8{,}31\ m/s$) and the 1.25 group ($Mdn = 8{,}50\ m/s$), $U = 36{,}00$, $z = -{,}751$, ns, $r = -0{,}170$.

6.3.2 Measures

Catching Performance — Out of 398 balls shot (one ball was left out due to people disturbing the experiment), the participants managed to catch 224 balls. In the 0.75, group 112 balls were caught, and 98 balls were not caught. In the 1.25 group, the participants also managed to catch a total of 112 balls and failed to catch 76 balls (Note that there was one participant less in the .75 group). A Mann-Whitney test on the mean of the balls caught per participant reported no significant difference between the 0.75 group (*Mdn = 10,50 balls caught*) and the 1.25 group ($Mdn = 11{,}00$)), $U = 41{,}00$, $z = -0{,}330$, ns, $r = -0{,}076$.

Touching Performance — The 0.75 managed to touch 159 out of 210 balls, whereas the 1.25 group managed to touch 145 out of 188 balls. The Mann-Whitney U test reported no significant difference in the amount of balls touched between the 0.75 group ($Mdn = 17{,}50$) and the 1.25 group ($Mdn = 17{,}00$), $U = 43{,}50$, $z = -0{,}124$, ns, $r = -0{,}028$.

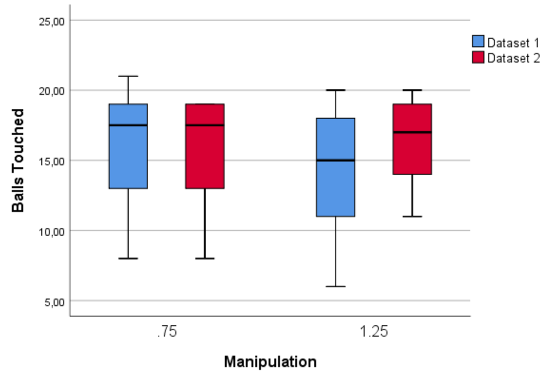

Figure 9. Boxplot representing the average amount of ball touched per participant in Dataset 1 and Dataset 2.

Distance Covered — A Mann-Whitney U test was performed to see if there was a significant difference in the distance covered between the two groups. No significant difference was discovered between the 0.75 group ($Mdn = 2{,}26m$) and the 1.25 group ($Mdn = 2{,}64m$), $U = 35{,}00$, $z = -0{,}816$, ns, $r = -0{,}187$. Furthermore, a Mixed Anova indicated that there was no significant interaction effect between the ball position and manipulation, indicating that the distance covered for each ball position was similar between the conditions, $F(3.33,\ 56.64) = 1{,}43$, $p > 0{,}05$.

Response Time — No significant difference in response time was reported by the Mann-Whitney U test between the 0.75 group ($Mdn = 534ms$) and the 1.25 group ($Mdn = 515\ ms$), $U = 36{,}50$, $z = -0{,}694$, ns, $r = -0{,}159$. Also, no significant interaction effect was shown by a Mixed Anova between the ball position and manipulation on response time, $F(3.33,\ 56.64) < 1$, $p > 0.05$.

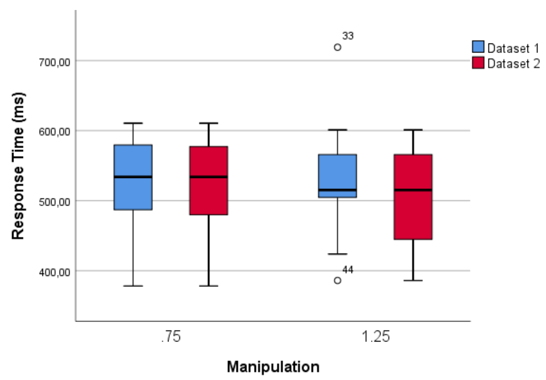

Figure 10. Boxplot representing the average response time per participant in Dataset 1 and Dataset 2.

6.4 Dataset 3

During the experiment, participants reported that they were forced to hold back when a ball was directed to their right, due to obstacles close to the landing position of the ball. A Mixed Anova confirmed that the direction of the ball had a significant effect (p = *0,013*) on the number of balls caught, *F(6,102)* = *2,842*, which is why Dataset 3 was proposed. It consists of only five ball positions, leaving out two aimed to the right of a participant. This new dataset consisted of 19 participants and 285 balls. As the participants remained the same, there is no need to test if they were divided fairly between groups. Analysis of the new data using a Mixed Anova indicated that the effect of the ball position on the number of balls caught was removed, *F(4, 68) = 1,353, p > 0,05.*

No significant difference in catching performance was discovered in Dataset 3 using a Mann-Whitney U test, U = *37,50*, z = *-0,619*, ns, r = *-0,142*. Touching performance had no significant difference either according to a Mann-Whitney U test, U = *42,50*, z = *-0,208*, ns, r = *-0,047*. No significant difference was found on the distance covered using the Mann-Whitney U test: U = *38,00*, z = *-0,572*, ns, r = *-0,131*. A Mixed Anova analysis also indicated no interaction effect, *F(4,68) < 1, p > 0,05*. Finally, response time was not significantly different. The Mann-Whitney U test reported: U = *39,00*, z = *-0,490*, ns, r = *-0,112*. The Mixed Anova analysis also indicated no significant interaction effect, *F(4,68) < 1, p > 0,05*.

7. DISCUSSION

No significant differences were found between the two conditions on any of the tested variables. Different possible explanations will be discussed below.

7.1 Limitations

7.1.1 Differences Between Participants

Participants with and without ball experience were recruited, leading to a dataset containing a lot of deviation. It was not expected that this difference would impact results since each ball position was located on a participant's action boundary. Therefore it was reasoned that all balls could be caught. How is it then still possible that some participants barely caught any balls, while others caught almost all of them?

To calculate somebody's locomotor range, we used Postma's model. It is based on three factors, maximum acceleration, maximum velocity and the time that the ball is flying [11]. Before a person can start moving, it needs to perceive the ball and respond adequately to it. Therefore, this response time needs to be subtracted from a ball's flight time. However, we did not measure this time for each participant and used an estimate instead, which might have lead to an inaccurate action boundary.

Furthermore, the model does not incorporate arm-length. Using our arms we can extend our reach, which can be used to catch a ball when we are not yet at the landing position. Some participants even attempted to catch the ball with one hand instead of two, to further increase their range. Someone's reach, and thus arm-length, can influence whether a ball can be caught. Future research could incorporate this together with response time in Postma's model to calculate a more precise locomotor range.

7.1.2 Lack of Autonomy

As explained in section 2, affordances are *possible* actions or behaviors [7]. We asked our participants to attempt to catch an incoming ball, which is where a critical problem arises: a task was given, leaving them only one action to perform. By doing this, we remove any possible decision making on what to do. Because we remove this autonomy, one could argue that no attempt was made to manipulate affordance. This could explain the lack of results. Future work can benefit from this finding by involving some sort of decision making. This could be done by simply asking a participant if they think they can catch the ball, or by using two participants instead of one, and thereby forcing a decision on who will attempt to catch the ball (see section 7.3).

7.1.3 Interpretation of Action Boundary

Participants were asked how they used the visual information, which resulted in an interesting insight: they mentioned that an action boundary can be experienced as a challenging factor (they would try to reach or extend the visualized boundary), or as a limiting factor (they would be discouraged by the size of the boundary). We hypothesized that a smaller boundary would limit behavior and performance, while this size might also have increased it. The lack of effect could be due to the two different interpretations leveling each other out.

7.1.4 The Playground Area

During the experiment, it became clear that the Playground had several limitations. Objects were limiting participants' movement, which was a reason to leave two ball positions out of Dataset 3. This meant that Dataset 3 had an even smaller sample size, decreasing the chance for any significant effect.

Many participants also complained about the lights in the Playground. The area was dimly lit, whereas the hallway attached to it was lit brightly, and the ball machine was positioned in this hallway. Therefore, participants had to look from the dark into the light, making it hard to perceive the ball and thus slowing down their response time. One participant, for example, noted: "Looking into the light is annoying, I feel like I see the ball too late". This may have influenced our results.

It also became apparent that the tracking system could not track objects going faster than 8 m/s. If participants went faster than this speed, we had to estimate their maximum velocity using their maximum acceleration and previous data. This meant that their action boundaries became less precise, and therefore our data became noisier.

7.1.5 Visual Information

Visual information was our instrument to manipulate affordance. It needed to contain useful information [7], and appropriate graphics [5] to be perceived. When asking participants how they used the visual, most of them indicated that they only used it to know when a new ball was coming, as it would disappear right before a ball was shot. They would "brace" themselves for a new ball, which was an unintended application of the visual information, but it does show the possibilities of visuals on behavior since we managed to get participants in their preferred stance to catch a ball. However, as the behavior was not intended we can say that our visuals did not contain useful information for the specified task. Future research should invest time in creating visuals that contain the appropriate information for the desired action.

Furthermore, the timing of the visuals could have influenced the results. We showed the visual information before a ball was shot, since we thought this would give participants a better chance to absorb and use it. On the other hand, showing information when performing a task could make it more salient and could increase the chance that it is being used since we look for any resourceful information on our task when we perform an action.

7.2 New Insights Regarding The Development of Interactive Training Tools

The Modified Perceptual Training Framework [4] identified three factors that predict the effectiveness of an interactive training tool, one of which was the type of response. The types were described as either generic (verbal or written) or sport-specific (performance of a skill). However, the amount of decision-making also appears to impact the effectiveness of an interactive training tool, and therefore this factor could be included in the Modified Perceptual Training Framework to predict the effectiveness of an interactive training tool.

7.3 Future Work: How should we do it next time?

Key limitations and factors have been identified, which we attempt to address by proposing a new and improved experiment. The setting will be similar to the one discussed in this paper, but it will involve two participants to force decision making, and it will incorporate response time into Postma's model to improve the accuracy of action boundaries. Furthermore, it should be performed in a larger area to provide freedom of movement, that will be split into two halves, each participant should stand in the middle of one. We will aim a ball in between the players that will land on the intersection of their action boundaries, enabling both participants to catch the ball. We will try to steer who will attempt to catch the ball by showing manipulated action boundaries, and expect that the participant with a larger boundary can be persuaded to catch an incoming ball, instead of the participant with the smaller one. This can be measured by recording who caught or touched the ball, and the distance covered for each participant. A within-subjects design could be employed using three conditions (smaller, larger or real action boundary) to remove any differences in capabilities between participants, but the manipulation should remain hidden. It can remain hidden by making the visuals display the real-time boundaries, meaning they will shrink until they disappear during the flight time of the ball. These real-time boundaries could also make the information more appropriate and salient.

8. CONCLUSION

This study aimed to investigate if there is an effect on the affordance on catchability when players are presented with manipulated visuals representing their action boundaries. In particular, it was tested if a player's performance and behavior can be influenced by displaying manipulated action boundaries. An experiment was conducted with 26 participants, but no significant effects on performance or behavior were found between manipulation groups. Thus, we have to conclude that we were not able to influence affordance by displaying manipulated action boundaries in our study. Several limitations that might have impacted the experiment have been identified and addressed by proposing a new experiment, that could be performed in the future.

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