A Study on VR Training of Baseball Athletes

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Abstract. As virtual reality (VR) technologies continue to mature and with VR headsets becoming widely available on the consumer market, more people are using VR for gaming, entertainment and skill training. It is inevitable that VR simulations have permeated sports training as a tool to enhance athletic performance. The present study is part of an ongoing program at Purdue University where short VR modules are routinely used by the coaching and sports medicine staff to train baseball players. For the present study, three VR simulations were developed to train a player's ability to recognize ball colors, type of ball trajectories, and strike vs. ball. Twenty-four baseball players took part in the study where half served as the control group and the other half received 12 sessions of VR training. The participants also completed two tasks before and after the main experiment. Although no significant difference was found between the pre- and post-tests, the participants did respond positively to a survey and found the VR training fun and useful for training their eyes. Future work will continue to assess the efficacy of VR training with Purdue baseball team players.

Keywords: VR sports training · Athletic training · User study

1 Introduction

Virtual reality (VR) is becoming an accessible tool for a wide array of applications. Sports teams are uniquely positioned to take advantage of VR technology. With VR, training can take place at any time, in any environment, regardless of physical limitations. Additionally, virtual simulations can be designed efficiently with a variety of open-source assets and software applications. Even complex simulations, such as those that attempt to elicit natural responses such as fear, can now be developed for training purposes using primarily commercially available VR technology [5]. Baseball is one sport where VR is particularly well suited due to the limited motion necessary to simulate a batter's experience. Specific apparatus and experiments have been developed to relate baseball performance with VR [11,19]. Previous studies have used VR training to improve athletic skills directly [20] and there is plenty of evidence that VR training is effective

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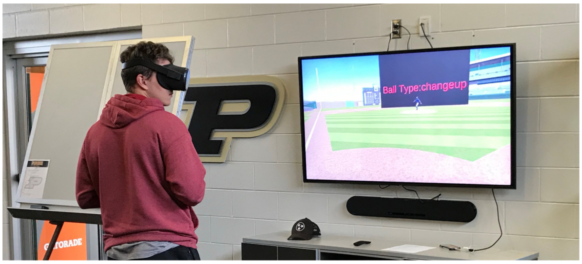

Fig. 1. A Purdue baseball player in a VR session. The player's view is projected on a monitor for the experimenter to keep track of his progress.

on real-world skill development [9]. We have developed a number of VR tasks to train different aspects of necessary baseball batting skills (see Fig. 1). The goal of the present study is to ascertain whether VR training will carry over to the players' performance during the regular season. Due to the COVID-19 pandemic, however, we were unable to collect season statistics as we had planned. We therefore report the study itself in this paper.

The present study focused on using VR as a tool to improve the recognition and reaction skills of Purdue baseball athletes. It was the second study in an ongoing research and development program to develop a suite of baseball-related training modules to supplement the baseball training program at Purdue University. It was unique in that the program was driven by the needs as identified by the Purdue baseball coaching and sports medicine staff, provided an excellent learning and research opportunity for undergraduate electrical and computer engineering majors, and had been incorporated into the daily activities of Purdue baseball athletes. There were many challenges in working with real athletes in a user study, especially given their busy training schedule. However, this was the only way to assess the efficacy of VR technology in real-world applications.

The rest of this article is organized as follows. We first present a literature review of virtual reality for training in general and its efficacy in sports training in particular. We then provide an overview of the tasks performed by the athletes during the study. The methods used in our study are presented next. This is followed by the results and a discussion and concluding section.

2 Literature Review

Virtual reality devices are becoming increasingly commonplace as the amount of potential applications increases. A variety of industries including sports, medicine, and entertainment have all begun to utilize VR for skill training and immersive experiences. Virtual reality has been proven to be an effective training tool in the medical industry. In one study by Seymour et al. (2002), 16 surgical residents were divided into two groups. The VR group received 10 sessions of VR surgical training each lasting one hour, in addition to standard training. The control group only received the standard training. The study concluded that while there was no initial significant difference between the groups, the control group was on average six times more likely to make an error than the VR group after the VR training [18]. Sewell et al. (2007) indicated a potential benefit of VR training on a surgical drilling task aimed at penetrating the temporal bone without damaging the structure behind it [17]. In a series of studies by Baillie et al., a visuohaptic simulation for bovine rectal palpation was shown to be effective at training veterinary students, and later successfully incorporated into an undergraduate curriculum for both training and assessment [2,3]. In the medical industry, VR training was utilized in therapy applications with one method designed for the rehabilitation of phantom limb pain [12]. In the construction industry, it has been shown that VR training was more effective at capturing a trainee's attention over other training methods such as lectures [16]. At the Virtual Reality Training Lab in NASA's Johnson Space Center, astronauts received VR training for a variety of tasks that would otherwise be difficult to conduct on Earth [8].

For reasons similar to astronaut training on Earth, VR training is also an attractive alternative and supplement to sports training as it allows for focus on sub-skills (e.g., hand-eye coordination), maintenance during inclement weather, and customization for injuries. Baseball, basketball, American football, rugby, and rowing have all experimented with athlete training using VR [4,10,15,19,20], as it provides a unique opportunity to model complex situations that are difficult or costly to replicate in the real world. Athletes of many sports, such as baseball, basketball and football, rely heavily on their perception of a moving ball in order to perform well. Any method to improve their perceptual capability and decision making is always desirable. Tsai et al. (2019) demonstrated that the use of VR training resulted in a faster decision time in basketball players [20]. Software designed by Huang et al. (2015) for American football allowed football coaches to efficiently create plays and demonstrate them to their teams in VR. The VR software was tested with a short 3-day user evaluation. A 30% overall score improvement was shown between assessments on Day 1 and Day 3 [10].

Baseball coaches are perhaps the earliest and most enthusiastic adopters of VR technologies in athlete training, which is the focus of the present study. Promising evidence has been reported that supports the effectiveness of virtual environments in replacing standard baseball training environments [11]. VR simulations for baseball applications have previously been developed to assist athletes during their standard training. A notable VR baseball training method was discussed by Takahashi et al. (2019) and was designed around maximizing ease of use and providing user feedback [19]. The system operated by simulating a virtual environment where the participant could swing at a virtual baseball. The system tracked the participant's body position in 3D coordinates and provided swing timing feedback [19]. In another study by Isogawa et al. (2018), the effectiveness of the virtual environment was demonstrated where three skilled baseball players tested a variety of environments, including both virtual and real environments. Each participant's objective was to react to both fastballs and curveballs. No statistical differences were found in either pitch type for swing duration between the real and virtual environments, indicating that VR may be a suitable replacement for real baseball training environments [11]. Evidence of learning transfer from VR training to baseball fields has been presented by Gray (2017) in a study that involved 80 high school baseball athletes [9]. Four groups of 20 participants each were formed, with three training groups and one control group that only completed regular high school practices. All groups continued their standard high school training activities. Of the three training groups, the first group completed adaptive training in a virtual environment that adjusted task difficultly to match the participants' abilities, the second group completed additional non-adaptive training in the virtual environment, and the third group completed additional real environment batting practice sessions. The training sessions lasted 45 min each and occurred twice a week for six weeks. The adaptive VR training group achieved the greatest improvement. There was also a significantly higher batting performance for the adaptive training group during the following season with a higher proportion of participants advancing in baseball after high school [9]. Overall, this study demonstrated clearly the ability of virtual environments to complement standard baseball training activities.

Many factors influence the effectiveness of VR training outcomes, including access to athlete participants, study duration, participant motivation, and technological limitations. For example, Adolf et al. (2019) utilized VR to simulate a juggling training environment with beginning juggler participants separated into a VR group and a control group [1]. At the end of the study, the participants in the VR group reported having more fun and higher motivation to continue learning. However, there was no significant performance difference between the two groups in their juggling skill [1]. Zaal and Bootsma (2011) discussed several VR studies designed to train participants to catch fly balls (baseballs hit high and far into the outfield). They described the challenges encountered during these studies that were centered on technological limitations such as lack of haptic feedback or a reduced visual field of view [21].

3 Overview of Tasks

All participants were tested at the beginning of the study (pre-test) and at the end of the study (post-test). The pre- and post-test consisted of two tasks: identification of pitch and ball/strike type using a GameSense software, and ball color call-out using a pitching machine. Scores of the two tasks from the pre-test and post-test were compared to assess any improvement in performance. During the main experiment, all participants engaged in typical fall training activities. One half of the participants completed additional VR training sessions, while the other half served as the control group. The tasks for the pre- and post-test, main experiment, and VR training were selected and developed with input from the Purdue baseball coaching and sports medicine staff. This section provides an overview of all the tasks conducted during the study.

3.1 Pre- and Post-Test Tasks

One of the tasks used in the pre-test and post-test is a tablet-based pitch recognition software developed by GameSense Sports (https://gamesensesports.com/).

Fig. 2. A participant completing the GameSense task

The same test was utilized for all participants. During the test, the participant was shown a series of video recordings from professional baseball pitchers. The participant's task was to determine the type of pitch and whether it was a ball or a strike (see Fig. 2). The difficulty of the GameSense task was adjusted by how much of the video clip was shown to the user (e.g., showing only the first third of the video clip made the task harder). Shorter clips required the participant to predict the pitch type from the pitcher's initial movements, the initial ball path and the initial spin rather than relying on such information over the entire trajectory of the pitched ball. The efficacy of GameSense as a training tool has been demonstrated by a positive correlation between the video-occlusion exercises and baseball statistics [13]. The method, based on occlusion and anticipation, was previously used to confirm the difference in predictive ability between experienced and novice baseball athletes [6].

The other task used in the pre- and post-test was a pitching machine test where the participant identified colored dots on baseballs that were inserted into a pitching machine. The task was setup as if the participant was in a batting practice session, where a coach would stand behind the pitching machine to feed in baseballs (see Fig. 3). Black cloths were hung over the protective nets in front of the pitching machine as visual shields. An additional, smaller cloth was hung right above the pitching machine (not shown) to prevent the participant from seeing the ball being fed into the machine. The participant, i.e., the batter, stood at a home plate approximately 60 ft and 6 in. from the pitching machine (same as a pitching mound) and was ready with a bat. Prior to the test, the participant was shown four baseballs each having two same-colored dots in red, green, blue and black, respectively. Pilot tests were conducted with an injured baseball athlete who was not in the study to determine an appropriate speed for the pitches thrown by the pitching machine. Seventy mph was deemed an acceptable pitch speed as it was neither too easy nor too difficult. During the

Fig. 3. Scenes from the pitching machine task: A participant in ready stance (left), and a sports medicine staff feeding balls to the pitching machine (right).

pitching machine test, the participant was asked to be in a batting stance. The participant was instructed not to follow the baseball with his eyes after it passed him, and not to swing. He was to call out the color of the dots on the baseball as it passed him. A total of 20 pitches were thrown for the participant.

3.2 Fall Season Training Activities

During the main experiment, all participants took part in the fall season training. The activities included Stretching, Open Field (free form hitting and fielding work), Agility Stations (agility ladders, hurdle jumping, hip mobility, and pilates), Arm Care (therapy bands and partner stretching), Throwing, Base Running, Individual Defense by Position, Team Defense, Batting Practice, Weights and Conditioning after Practice.

3.3 Virtual Reality Training Tasks

Half of the participants were randomly selected to take part in virtual reality training, in addition to their fall season training. This section covers the VR simulation environment and the three VR tasks that were iteratively developed with close collaboration between the Purdue baseball coaching and sports medicine staff and Purdue engineering students.

Simulation Environment. The VR simulations focused primarily on visual recognition of ball color, pitch and strike. The simulation utilized the Unity3D Game Engine as the primary software component. There were three simulated tasks, referred to as "Call Color", "Call Pitch", and "Call Strike." A tutorial was designed to introduce the participants to VR and the three tasks. The primary model presented in the scene was a pitcher in a baseball stadium. Additional models included the baseballs and a black wall behind the pitcher to simulate the "Batter's Eye" of a baseball field.

Table 1. Range of parameters that define the four pitch types

Pitch Type	Start Velocity (**V**)	Start Spin (**S**)	Start Position (**P**)
Fastball	$V_x \in [0.3, 1.0]$	$S_x \in [2000.0, 2100.0]$	$P_x = -0.3$
	$V_y \in [-1.55, -1.25]$	$S_y = 0.0$	$P_y \in [2.25, 2.35]$
	$V_z \in [-38.0, -42.0]$	$S_z = 0.0$	$P_z = 18.5$
Curveball	$V_x \in [-2.0, -2.1]$	$S_x = 1000.0$	$P_x = -0.3$
	$V_y \in [0.7, 0.9]$	$S_y = -3000.0$	$P_y \in [2.25, 2.35]$
	$V_z \in [-33.0, -35.0]$	$S_z = 0.0$	$P_z = 18.8$
Slider	$V_x \in [-3.0, -3.5]$	$S_x \in [1050.0, 1150.0]$	$P_x = -0.3$
	$V_y \in [0.35, 0.7]$	$S_y \in [-4500.0, -4700.0]$	$P_y \in [2.25, 2.35]$
	$V_z \in [-33.0, -35.0]$	$S_z = 0.0$	$P_z = 18.5$
Changeup	$V_x \in [0.5, 1.0]$	$S_x \in [1700.0, 1800.0]$	$P_x = -0.3$
	$V_y \in [-0.7, -0.4]$	$S_y = 0.0$	$P_y \in [2.25, 2.35]$
	$V_z \in [-36.0, -38.0]$	$S_z = 0.0$	$P_z = 18.5$

The virtual ball's trajectory was generated by Unity3D's physics engine based on three vectors: start velocity, start spin, and start position. The parameter ranges of the three vectors (see Table 1) define the four pitch types: changeup, curveball, fastball, and slider. Variations within a pitch type was realized by randomly selecting parameter values within their respective ranges.

For Task 1 ("Call Color"), the pitch type was set to fastballs only and the color with which the ball flashed was randomly selected with equal *a priori* probabilities among six alternatives. For Task 2 ("Call Pitch") and Task 3 ("Call Strike"), the type of pitch thrown on each trial was randomly selected. The same two force vectors, the Magnus force due to the ball's rotation and the gravity force calculated from the ball's mass, were applied regardless of pitch type. Other natural forces, such as air resistance, were not modeled. The velocity and spin of the ball were continuously updated via Unity's rigid body component. They were then used to determine the Magnus force applied to the ball. This rendering method, along with the change in start position, resulted in the different pitch types. The force vectors on the ball were updated every 0.02 s, or equivalently at 50 times per second.

Overall, the VR simulation was designed to train the participant's ability to recognize specific details regarding the virtual baseball's color and trajectory. Focus was placed primarily on the experience rather than realism, as judged by the Purdue baseball coaching and sports medicine staff. The goal was to provide a training tool that could be used by athletes any time, anywhere, rain or shine, to improve their pitch recognition and reaction skills.

Task 1: "Call Color". In this task, a virtual baseball was thrown towards the participant by a virtual pitcher. During the first third of the ball's path, the baseball flashed in one of six colors for a short period of time: blue, green,

Fig. 4. Screenshots of "Call Color" Task: The response screen for color section (left) and the feedback screen after each response (right).

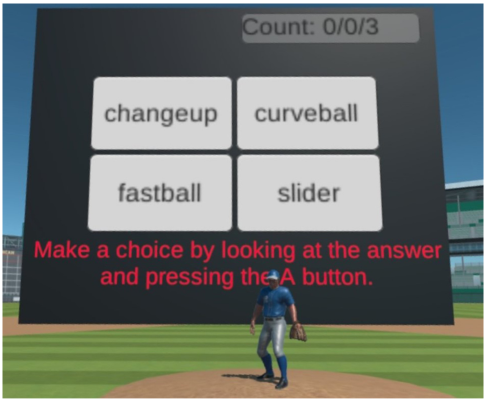

Fig. 5. The response selection screen in the "Call Pitch" Task

magenta, red, cyan, or yellow. Only fastballs were used in this task. The participant indicated the perceived color of the ball by selecting the corresponding response area shown on the black wall behind the pitcher (see the left image in Fig. 4). Trial-by-trial correct-answer feedback was provided (see the right image in Fig. 4). If the response was correct, the next pitch would start after a short pause. If the response was incorrect, the pitch was replayed before a new pitch was thrown. This process continued until 10 trials had been completed.

Task 2: "Call Pitch". The "Call Pitch" task was utilized to train the participant's ability to identify pitch type in the virtual environment. Four types of pitches were modeled: changeup, curveball, fastball, and slider. After each pitch was thrown, the participant responded by selecting the perceived pitch type from the four choices shown on the black wall (see Fig. 5). Similar to the "Call Color" task, trial-by-trial correct-answer feedback was provided and a total of 10 randomly-selected pitches were thrown.

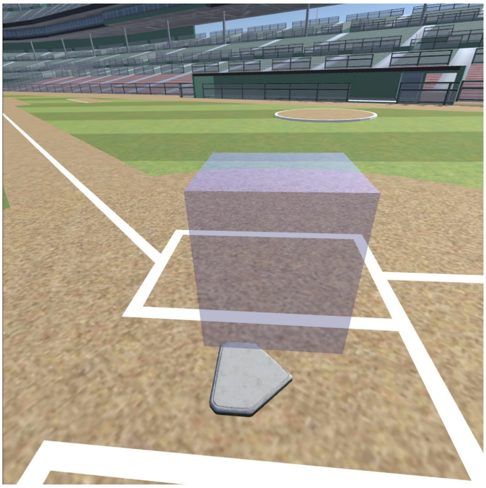

Fig. 6. The strike zone in the "Call Strike" Task

Task 3: "Call Strike". The final task trained the participant's ability to judge whether a pitch thrown was a strike or a ball. After each pitch, the participant was prompted to respond whether the pitch had passed through the simulated strike zone (see Fig. 6) or it had missed and was a ball. The participant indicated "strike" or "ball" by pressing the right or left trigger on a hand controller, respectively. The strike zone was shown to the participant before the first pitch and after each incorrect response. As was the case with the other two tasks, if the response was incorrect, the same pitch was shown again with the strike zone visible and the ball's flight path illuminated with a brightly colored trail. Again, a total of 10 balls were thrown for this task.

4 Methods

Now that we have explained the tasks performed by the participants in the present study, this section presents the methods including participants, equipment, procedures and data analysis.

4.1 Participants

The study was conducted with the athletes of the Purdue Boilermakers varsity baseball team. Twenty-five participants (males, age range 18–22 years old) were recruited and one dropped out after pre-test. The participants included infielders, outfielders, and catchers. As will be explained later, the remaining 24 participants were randomly assigned to a control group and a VR group, each consisting of 12 participants. Both groups completed the pre-test tasks, fall training activities, and post-test tasks. The VR group took some time out of

Fig. 7. Diamond Training Series baseballs (image from www.sportsadvantage.com)

their fall training to receive VR training 2–3 times per week for 3–4 weeks for a total of 12 sessions. Each session lasted for 15–20 min. Each participant signed an informed consent form that was approved by the Purdue Institute Review Board.

4.2 Equipment

Pitching Machine. A HomePlate Premier Hand Fed Pitching Machine by Sports Tutor was utilized in the pre- and post-test tasks. The pitching machine is capable of throwing 9 different pitch types at a velocity ranging between 40 and 90 mph. The exit height of the ball above the ground is approximately 56 in..

Baseballs with Color Dots. Diamond Training Series baseballs with colored dots (see Fig. 7; sourced from Sports Advantage) were used with the pitching machine. Each baseball had two same-colored dots that were approximately 1-inch in diameter. There were four color variations: red, green, blue and black.

Oculus Quest. The Oculus Quest headset was selected because it operates without any tether and allowed the participants to move around in a more realistic manner (see Fig. 8). The headset contains two 1600×1440 OLED displays controlled by a Qualcomm Snapdragon 835 chipset that allows the displays to run at 72 frames per second [14]. The participants interacted with the virtual environment through the use of two wireless hand controllers. Responses were received wirelessly by the headset through the use of the controller's buttons and triggers. The VR simulations were developed first on a PC and then stored in the Quest headset. Data were collected for each trial and stored on the Oculus Quest headset temporarily. At the end of each day, the data were backed up and stored on the PC. The relevant data collected included participant's ID, a trial-by-trial record of stimulus and response pairs for each task ("Call Color," "Call Pitch," "Call Strike"), and time stamps for the start and end of each trial during the VR sessions.

Fig. 8. Oculus Quest headset with controllers (image from www.amazon.com)

4.3 Procedures

The study took place in three phases: pre-test, main experiment, and post-test. It was conducted from Oct. 21st to Dec. 3rd, 2019 (see Fig. 9). This section describes the procedures of the entire study.

Fig. 9. VR baseball study timeline (Fall 2019)

Pre-Test. All participants performed the GameSense task first, followed by the pitching machine task. The GameSense test was conducted with the participant seated at a table, wearing headphones to block surrounding sound, and interacting with an iPad (Apple Inc.). The participant completed a short tutorial first, followed by the GameSense test. The test presented the participant with 56 pitches from 4 different pitchers. Two sets of 24 occluded pitches each and one set of 8 non-occluded pitches were shown. The occlusion difficulty was either one-sixth or one-third of the ball's entire trajectory. At the end of the test, the participant's performance was displayed as a score out of 1000. The scores for all participants were recorded and analyzed. The GameSense task took around 5 min to complete for each participant.

During the pitching machine test, a Purdue sports medicine staff member stood behind the pitching machine to feed the balls with color dots into the machine. A researcher stood next to the feeder and had a full view of the participant as well. Before each trial, the feeder raised his hand above the curtain covering the pitching machine to signal the participant to get ready. A ball with colored dots was randomly picked from a container and shown to the researcher while being hidden from the participant. The researcher recorded the ball color on a pre-printed form. The feeder fed the ball into the pitching machine, and the participant called out a response as the ball passed him. The response was recorded by the researcher. No correct-answer feedback was provided to the participant. After the ball passed the participant, it was collected in a net and occluded from view with a black cloth. When a total of 20 balls had been fed into the pitching machine, the researcher informed the feeder to stop the session. A percent-correct score was computed by dividing the number of correctly-recognized balls by the total number of 20 balls. The average time taken to complete the pitching machine task was 5–10 min per participant.

After all 24 participants had completed both the GameSense and pitching machine tasks, their scores from the two tasks were combined to obtain weighted total scores as described in Sect. 4.4. The participants were then equally divided into a control group and a VR group, as follows. The participants were first rank-ordered by their weighted total scores. The two highest-scoring participants were randomly assigned to the control and VR groups, respectively. The next two best performing participants were randomly assigned to the two groups, etc., until all 24 participants had been assigned to either the control or the VR group. It follows that each group had 12 participants. This procedure ensured that the two groups of participants had similar skill levels according to their pre-test performance.

Main Experiment. All 24 participants took part in the same baseball training activities as part of their fall season training. The 12 participants in the VR group took 15–20 min out of their daily training to conduct VR training tasks when their schedule allowed. Each participant in the VR group was able to complete 12 VR sessions. The 12 days were not necessarily consecutive and not all participants completed the VR sessions on the same 12 days. Before the first VR session, each participant familiarized himself with the Oculus Quest headset and the controllers. A 3-min tutorial in the virtual reality environment walked the participant through each step of the three tasks. For each VR session, the participant started with the scene of a baseball stadium with a pitcher standing at the center in a location referred to as the pitching mound. Each participant completed all three VR tasks in one session. One of the researchers monitored the participant's progress via live casting from the Oculus Quest headset to a mobile phone or a television screen (see Fig. 10). Trial-by-trial stimulus-response data were logged.

Post-Test. After the main experiment, all participants completed the GameSense and pitching machine tasks again in a post-test. The same procedure was followed in the pre- and post-tests.

Fig. 10. Research assistant and participant during VR training

4.4 Data Analysis

After the pre-test, the scores from the GameSense and pitching machine color identification tasks were normalized and combined, as follows. For each participant, the GameSense score (GS_{raw}) was first normalized to obtain (1), where min and max indicate the minimum and maximum scores among the 24 participants. Likewise, the ball-color identification score using the pitching machine (PM_{raw}) was also normalized to obtain (2). A weighted total score was then computed as (3). The GameSense score had a higher weight than the color identification score as the former used video clips of recorded ball trajectories from real pitchers and its efficacy had been validated earlier.

$$GS_{norm} = (GS_{raw} - min)/(max - min) \tag{1}$$

$$PM_{norm} = (PM_{raw} - min)/(max - min) \tag{2}$$

$$Score = 0.6 * GS_{norm} + 0.4 * PM_{norm} \tag{3}$$

After the main experiment was completed, the data from the pre-test and post-test were averaged over the 12 participants in the control and VR groups. An analysis of variance (ANOVA) was conducted to compare performance from the pre-test and post-test and between the control and VR groups. For the VR group, the percent-correct scores for each of the 12 sessions were averaged across the 12 participants, to examine possible learning effects for each of the three VR tasks.

5 Results

The participants' performance before and after the main experiment can be compared for the two tasks of GameSense and pitching machine testing. Figure 11 shows the GameSense scores (left panel) from pre-test and post-test for the two groups of participants. At a first glance, it appears that the control group

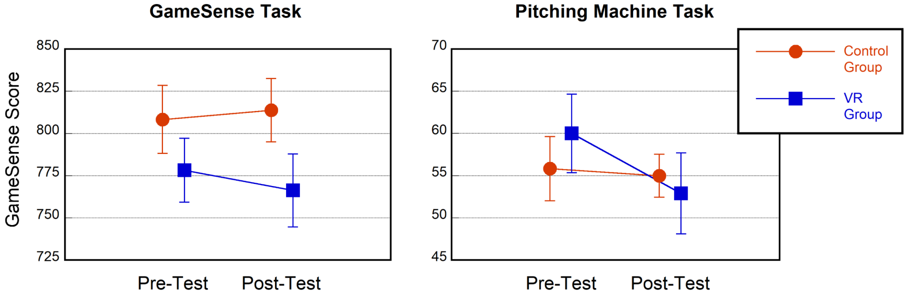

Fig. 11. Mean pre- and post-test scores for GameSense (left) and pitching machine ball-color recognition (right). The data for the control and VR groups are slightly offset from each other for clarity. Error bars indicate standard errors.

started at a higher level than the VR group at pre-test (808.3) and improved slightly at post-test (813.8). The VR group shows a slight decrease in performance score from pre-test (778.3) to post-test (766.3). However, a two-way analysis of variance (ANOVA) with factors test (pre, post) and group (control, VR) shows that test type did not have a significant effect on the GameSense scores [$F(1,1)=0.03$, $p=0.866$], but group type was borderline significant [$F(1,1)=3.86$, $p=0.056$]. Note that there were significant between-participant differences in the GameSense scores during both pre- and post-tests. This is reflected in the large standard errors in the left panel of Fig. 11 and the borderline difference between the two groups even though care was taken to split the participants with similar pre-test scores into different groups. Based on these results, we conclude that neither group improved significantly from pre- to post-test in the GameSense task.

The results were similar for the color recognition task using the pitching machine. As seen from the right panel of Fig. 11, the percent-correct scores for the control group started at a lower level than the VR group at pre-test (55.8%) and remained roughly the same at post-test (55.0%). The VR group shows a drop in percent-correct score from pre-test (60.0%) to post-test (52.9%). However, similar to the GameSense scores, an ANOVA with factors test and group failed to show either factor to be significant [test: $F(1,1) = 0.97$, $p = 0.330$; group: $F(1,1) = 0.07$, $p = 0.797$]. There were again large between-participant differences as seen in the large standard errors. We therefore concluded that the pitching machine ball-color recognition performance did not improve significantly from pre-test to post-test for either the control group or the VR group.

The VR group's performance on the "Call Color," "Call Pitch," and "Call Strike" tasks are summarized in Fig. 12. Shown are the average percent-correct scores by the order of VR sessions. It can be observed that the participants in the VR group were very good at the simulated "Call Color" and "Call Pitch" tasks in VR, and performed well on the "Call Strike" task as well. The percent-correct scores for the three VR tasks did not change much over the course of the 12 VR sessions.

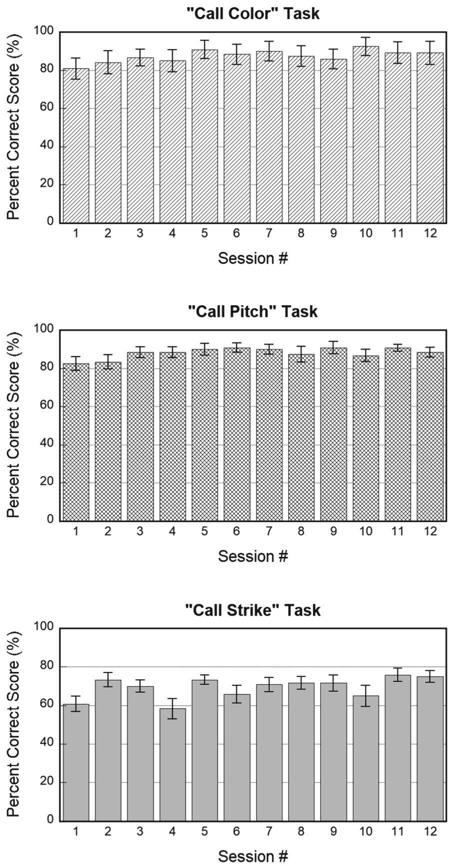

Fig. 12. Percent-correct scores for the “Call Color,” “Call Pitch,” and “Call Strike” tasks, averaged over the 12 participants in the VR group. Error bars indicate standard errors.

After the study was completed, the participants in the VR group were asked to fill out a survey on aspects such as simulation realism, effectiveness, and entertainment value. The responses were generally positive. The percentages of positive responses on the effectiveness of each VR task as a training tool were 66%, 91%, and 91% for the “Call Color”, “Call Pitch”, and “Call Strike” tasks, respectively. When asked to describe the overall experience, all participants responded positively with descriptions such as “Very good experience and helped me train my eyes...,” “Helped my eyes and focus,” “Loved every second,” and “...felt like I got better as time went on.”

6 Discussion

We have presented a study on the efficacy of VR training for college baseball athletes during the Fall 2019 training season. A total of 24 baseball players participated in the study. The VR modules developed for the present study have since been incorporated into the Purdue baseball team's routine practice. Our results do not show a statistically significant improvement from pre- to post-tests. This was expected due to the relatively short period of time during which we had access to the student athletes for VR training (12 VR sessions, approx. 10 min per session per participant). We had planned to track the participants and collect season statistics during their regular season in Spring 2020 as other studies have done [7]. However the COVID-19 pandemic cut the Spring 2020 season short and we were unable to complete our data collection.

Isogawa et al. (2018) provided evidence to the effectiveness of virtual reality environments in simulating a real world baseball environment in their study conducted with three skilled baseball participants. Each participant attempted to swing at a virtual baseball thrown as either a fastball or curveball. The participant's swing duration was measured in each environment. No significant differences were found between the real and virtual environments. This result was taken as evidence that the participants were able to judge the accuracy of the ball's trajectory in similar manners in the virtual and real environments [11]. Gray (2017) utilized virtual environments in a study designed to evaluate their effectiveness in training high school baseball players. Four groups, one control group and three test groups, were formed. In additional to standard practice activities, the first test group had an adaptive virtual environment, the second conducted non-adaptive VR sessions, and the third group completed additional real environment batting practice. Eight dependent variables, such as number of strikes correctly identified, were used to evaluate the improvement of each group. The results of the study indicated the adaptive VR group improved the most with a significant increase in 7 of the 8 dependent variables. A five year follow-up study was conducted with the study participants. The adaptive VR group had more than twice the number of participants play at least one full season at a level higher than high school when compared with the other groups [9]. Compared to these studies, our study has yet to track performance of Purdue baseball players in their future regular seasons in order to observe any positive changes in their performance in baseball fields using the metrics proposed by Gray (2017).

The long-term goal of our ongoing project is to provide Purdue baseball coaching and sports medicine staff with state-of-the-art VR simulations aimed at improving the overall performance of baseball players. As such, we will continue to assess the effectiveness of VR training with Purdue baseball players to gain a better understanding of when and how VR modules contribute to performance enhancement in the baseball field. The data collected in this study and the continued use of the VR modules by the Purdue baseball team will open the door for potential long-term benefits of VR training in the years to come.

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