



# Athletic Performance in Immersive Virtual Reality

## The Effect of Training Intensity

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**Abstract:** *Background:* In a goalkeeping task that entailed intercepting fast-approaching balls, the present research examined whether training under conditions more intense than those of a subsequent test yields a performance improvement. *Methods:* Fifty participants (38 males) carried out the goalkeeping task in two conditions: In the progressive-intensity condition, participants carried out three training sessions with increasing intensity (i.e., balls shot at increasingly faster speeds) that exceeded that of a pretest and a posttest; in the fixed-intensity condition, participants also carried out three training conditions but at a fixed intensity equal to that of both the pretest and the posttest. *Results:* Performance in the goalkeeping task improved from pretest to posttest equally under the two intensity conditions. Similarly, performance on a different task that required fast responses to visual targets also increased from pretest to posttest, likewise equally for the two intensity conditions. *Conclusions:* Overall, these results challenge the common belief in sports that more intense training than a subsequent test is beneficial for performance.

**Keywords:** cognition, attention, virtual reality, training, football

Today, many sports have grown into multi-billion-dollar industries, and much effort is put into optimizing athletic performance. These efforts aim primarily at improving physical fitness and tactics, although lately the importance of mental skills is increasingly being acknowledged (e.g., Romeas et al., 2016; Vestberg et al., 2017; see also Williams & Ford, 2008, for a review). In the present study, we examined the effectiveness of a training method under conditions that are increasingly more demanding than those of the subsequent test on improving performance on a task that relies on both physical and mental skills.

Even seemingly simple tasks in sports are in fact quite complex, relying on a variety of mental processes and motor skills (Williams & Ericsson, 2005). Take, for example, the task of a goalkeeper in soccer, whose task is to block an approaching ball. To do so, the goalkeeper must perceive that a ball has been shot and spatially orient their attention toward it, estimate its speed and trajectory, determine its potential landing position, decide whether to make an attempt to block the ball, and initiate a movement to block the ball at the right place and time. It follows from this example that, to perform such a task optimally, a goalkeeper must engage in elaborate perceptual and cognitive processing before executing any physical movement. Indeed, using

virtual reality, Shimi et al. (2021) showed that executing such a task efficiently relies on a variety of mental processes relating to basic and higher-order attentional processes and motor control, such as alertness, orienting, executive control, and response inhibition. Furthermore, Savelsbergh et al. (2002) showed that expert goalkeepers exhibit superior visual search and anticipation over novice goalkeepers when responding to penalty kicks presented on video, suggesting that additional mental skills may be involved.

By extending past research with tasks that entail the interception of approaching balls, the present study examined whether training in sessions with increased physical and mental intensity (i.e., balls shot at ever faster speeds, requiring thus ever faster cognitive processing and motor reactions) benefits performance in a subsequent less-intense test. The hypothesis is that gradually increasing the intensity of the training by increasing the speed of balls to be intercepted speeds up cognitive processing (i.e., the mental processes of alerting, orienting, executive control, and response inhibition), thus adapting the mind to intense conditions. This hypothesis is based on the progressive overload principle that is often used in resistance and aerobic training (Connaboy et al., 2018; Ramírez-Campillo et al., 2015). According to this principle, gradually

increasing the stress placed on the body during resistance or aerobic training – by increasing the load, frequency, or duration of training – causes the body to adapt to high levels of stress, yielding performance benefits for subsequent less-intense tests. Similarly, we posit that, by gradually increasing the speed of the balls, the mind may adapt to the increased demands of the training sessions and learn to function faster. However, unlike resistance and aerobic training, in which body adaptations may take weeks or months to become evident, here we were interested in mental adaptations that appear over the short term with training sessions lasting just a few minutes.

To test this hypothesis, we asked participants in a *progressive-intensity condition* to carry out a pretest and a posttest session with equal difficulty as well as three training sessions in-between, all of which were more intense than the pretest and the posttest (i.e., the balls were shot at a faster speed than in the pretest and the posttest). Moreover, intensity, defined here as the speed of the balls, increased from the first to the second training session and then further to the third, thus implementing a training regime of progressive difficulty. The performance of participants in this condition was compared to that of a separate group of participants who carried out the task with fixed intensity, i.e., the speed of the balls was the same across all three training sessions, the pretest, and the posttest. The main question of interest was whether the performance would improve from pretest to posttest and, importantly, whether this improvement would differ between the progressive and the fixed-intensity conditions. To examine whether any potential training benefits from the training task (i.e., intercepting fast-speed balls) transfer to a novel task, we also asked all participants to perform a different cognitive task, i.e., a reaction-speed task, in VR that involved fast detection and reactions to visual targets. This task required participants to move quickly to touch with either hand targets that lid up sequentially in a matrix. Participants performed this task both before and after the goalkeeping sessions (which included pretest and posttest and training sessions). Our interest was to examine whether participants would react faster to the visual targets in the reaction speed task after carrying out the goalkeeping sessions than before and, if so, whether the difference would be larger in the progressive than in the fixed-intensity condition. Our rationale is that, similar to blocking approaching balls, responding physically to abrupt visual targets is also a task that relies on perceptuomotor skills (Reigal et al., 2019), i.e., remaining alert throughout the task, scanning the environment, and perceptually detecting a target in the visual field, and executing a fast motor response. Therefore, a potential adaptation of the mind to increasing speeds in the goalkeeping training sessions would likely yield benefits in this other

task that is supported by the same, or at least partly similar, mental skills.

Both conditions tested here involved training sessions that were followed by short recovery periods, thus following the high-intensity interval training (HIIT) paradigm often employed in aerobic exercise. In HIIT, athletes train in burst-and-recover cycles that involve vigorous exercise in intervals of short to moderate duration (e.g., 10 seconds to 5 minutes) of higher intensity than the aerobic threshold, followed by brief recovery periods – ranging from a few seconds to a few minutes depending on the task – or low exercise periods (Laursen & Jenkins, 2002). Results from past studies show that HIIT can be more effective at improving exercise performance than the traditional continuous endurance training (CET), in which the athlete maintains a steady, moderate-intensity tempo (see Laursen & Jenkins, 2002, for a review). Positive effects of HIIT on athletic performance have been reported in soccer players (Dupont et al. 2004), swimmers (Kilen et al., 2014; Sperlich et al., 2010), rowers (Driller et al., 2009), cyclists (Laursen et al., 2002), and endurance runners (Hottenrott et al., 2012).

HIIT seems particularly useful for sports and activities that rely on endurance, such as long-distance running, swimming, and cycling, and it requires a training protocol that spans several weeks or months. Two questions then arise: (1) Does HIIT training under more challenging conditions than those required by an activity yield performance improvements in sports that rely on perceptuomotor skills than on endurance? (2) Can these improvements occur in the short-term as in the case of warming up to an activity? Studies on baseball suggest that the answer is “no” to both of these questions.

Traditionally, baseball players warm up with bats of weights that are heavier than the one used in the actual game, as they feel that this would help them swing with greater bat velocity during the game. However, results from studies with college players (Otsuji et al., 2002) and recreational athletes (Montoya et al., 2009) suggest otherwise. For example, in the study by Montoya et al. (2009), participants were asked to perform warm-up bat swings under three conditions of bat weight (light, normal, and heavy) before carrying out swings with a normal bat. Results showed that bat velocity during the post-warm-up session was greater when warm-up was carried out with the light and the normal bats compared to the heavy bat. Similarly, in the study of Otsuji et al. (2002), warming up with a heavy bat led to a slower first post-warm-up swing with a normal bat – even though players subjectively felt that the bat was lighter and they could swing faster. These results suggest that, at least in baseball, warming up under harder conditions than those encountered subsequently in the game

may in fact impair rather than improve performance, despite players feeling that the opposite is the case.

Given the negative results from past studies on the effect of warming up in physically demanding conditions in baseball, in the present study, we revisited this topic in the context of goalkeeping. It should be pointed out that, in contrast to goalkeeping, activities such as running, swimming, and cycling rely mostly on endurance and physical skills and less so on cognitive skills (which in these sports are most likely limited to focus and concentration). In that respect, blocking approaching balls in soccer (or similar sports like handball and futsal) lies closer to baseball batting. Still, past studies on training with heavier bats in baseball used as the main measure the velocity of the bat swing, which relies more on physical skills and coordination than mental skills. Thus, to our knowledge, this is the first study to examine the effects of intense progressive training on performance, using a task that has been demonstrated to rely heavily on mental skills (Shimi et al., 2021).

## Method

### Participants

Fifty participants (12 females, 38 males) took part in the study. These were either students from the University of Cyprus student community who participated in the study in exchange for course credit or volunteers from the local community who responded to an ad on social media. Students saw a description of the study on an online subject pool maintained by our lab and selected a timeslot for participating. People who responded to an ad on our Facebook page left their contact details on an online form and were then contacted by an experimenter to arrange the date and time for their participation. Participants were between 19 and 39 years of age, had normal or corrected-to-normal vision, and reported no health-related issues. Although 19 participants (32%) reported participating in various sports for leisure, none of them was a professional athlete. To maximize the possibility of observing performance improvements because of the intensity of the training, we deliberately chose not to test goalkeepers who may have developed idiosyncratic strategies and/or advanced skills for the goalkeeping task.

### Materials

#### The Goalkeeper Task (GT)

We used an immersive VR task in which the user becomes a soccer goalkeeper in a virtual stadium and is asked to block with their hands balls that are shot toward the goal from

three cannons located outside the penalty box (Figure 1). The task is one of the drills included in the VkeepR app of MentisVR Ltd. ([www.mentis-vr.com](http://www.mentis-vr.com)). The task is presented in a VR head-mounted display (HMD) with body and hand movements tracked in real-time with 6° of freedom. The user stands at a predefined location in the center of the goalposts holding a VR controller in each hand. These controllers are mapped to goalkeeper gloves in the virtual environment so that participants can move their arms and hands in the virtual environment to block the balls. Pilot testing ahead of the experiment was carried out to determine the speed, frequency, and landing positions of the balls at the goalposts that were comfortable for the average participant. Frequency and landing positions were kept constant across participants. Speed differed based on condition (explained in the Procedure). The % of successful blocks in each session was registered by the computer running the app. This task was used in the three training sessions: In the *progressive-intensity condition*, the speed of the balls shot increased from training session 1 to training session 3, implementing thus a training regime of progressive difficulty; in the *fixed-intensity condition* the speed of the balls remained constant across the training sessions (cf. Procedure for the technical parameters adopted).

#### The Reaction Speed Task (RST)

To measure reaction speed, we adopted a task from the Speedpad app which was also developed by MentisVR Ltd. This task is an adaptation for VR of the Batak Pro machine (Quatronics Ltd.) used for reaction-speed training in various sports. Upon donning the VR HMD, the user is presented with an array of round discs that change their color to red sequentially in random order (Figure 2). Participants are asked to move their arms to touch with their hands each disc that changes color as fast as possible. The number of correct responses within a specified time interval is considered the score of the participant in the task.

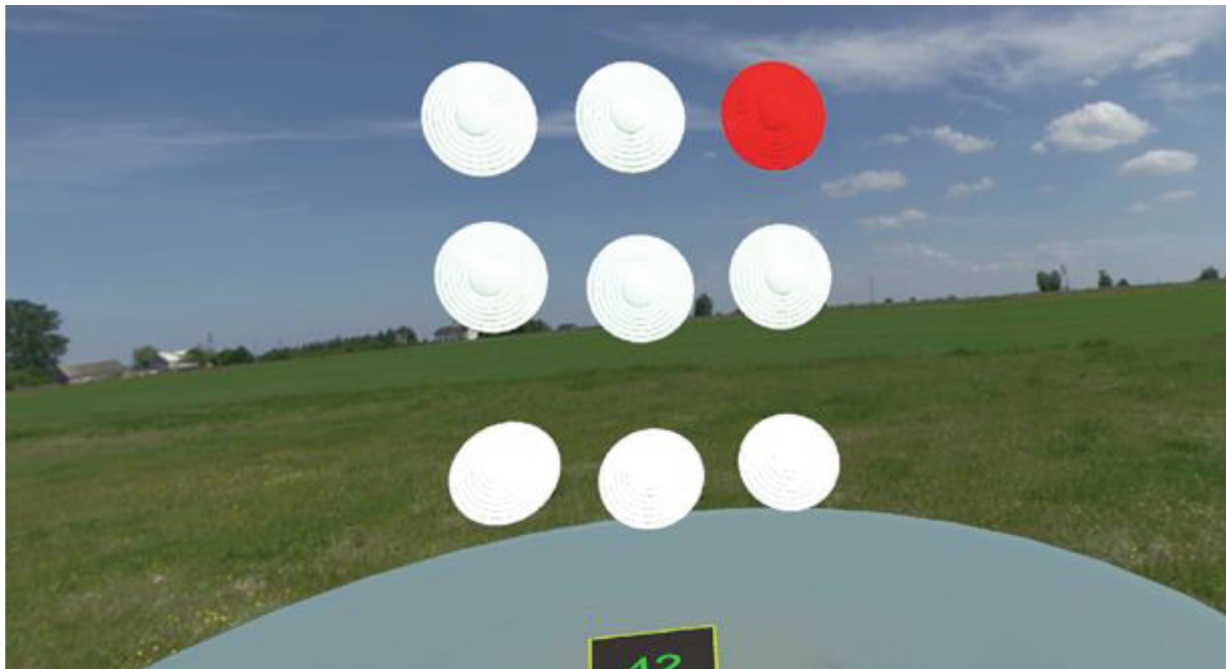
### Procedure

Participants were tested individually at a laboratory at the University of Cyprus. They all signed informed consent before participation and were thoroughly debriefed afterward.

First, participants carried out a practice session with the RST. After the experimenter had explained the task, they donned an HTC Vive Pro HMD and were immersed in a virtual environment that portrayed an empty field with a stage in the center. Once they had assumed a position at the center of the stage, the participants were presented with an array of nine discs, arranged in front of them as a 3 × 3 grid. They were asked to respond as quickly as possible by



**Figure 1.** Participant view in the GT. The task requires participants to block with their arms balls that are shot from three cannons located outside the penalty box.



**Figure 2.** Participant view in the RST. The task requires participants to touch as fast as possible each disk that becomes red.

moving their arms to touch every disc that became red. Participants carried out this practice session for 15 seconds. Then, they took a short break, and when they felt ready again, they started the pretest session of the RST. This session was identical to the practice session except that (1) 15 discs were presented as a 5 (width)  $\times$  3 (height) grid,

and (2) participants carried out the task for 60 seconds. As soon as they finished the task and before removing the HMD, the experimenter measured their heartrate (HR) using a pulse oximeter on the index finger of their dominant hand. Participants then removed the HMD and took a 5-minute break.

Following the break, participants carried out a series of sessions with the GT, each separated by a break of 5 minutes. Participants were immersed in a virtual stadium, assuming the role of a goalkeeper defending their goalposts. They were instructed to move their arms and hands to block each ball shot in their direction without moving their body away from the initial standing position between the goalposts. It should be noted that the balls could only land inside the goalposts and could be reached by extending one's arms without moving away from the standpoint. The first session was a practice session lasting 15 seconds, during which the balls were shot at a set speed mark of 4 (as defined in the app). Then, all participants carried out the pretest (baseline) session in which they blocked balls shot at speed 6 for 30 seconds. Following this pretest session, participants in the fixed-intensity condition carried out another three training sessions at speed 6 for 30 seconds each. Those in the progressive-intensity condition also carried out three training sessions but with higher and increasing speeds of 7, 8, and 9 for the training sessions 1, 2, and 3, respectively. Following these three training sessions, all participants carried out the posttest session of the GT with speed 6 (i.e., the same speed as the pretest). The experimenter measured participants' HR with the pulse oximeter at the end of each session, including the pretest and the posttest.

Finally, and after a 5-minute break, all participants carried out the posttest of the RST. The posttest was identical to the pretest: Participants viewed the same array of 15 discs and responded to targets changing color for 60 seconds. Again, the experimenter measured participants' HR with a pulse oximeter. For both the GT and the RST, data were recorded by the computer used to administer the tasks. HR was manually entered into a spreadsheet by the experimenter.

## Data Analysis

To examine whether participants' performance improved with training in the GT, and to determine whether the magnitude of the improvement differed between the two intensity conditions, we carried out a mixed-design analysis of variance (ANOVA) with session (pretest, training 1, training 2, training 3, posttest) as the within-subjects variable and training condition (fixed intensity vs. progressive intensity) as the between-subjects variable.<sup>1</sup> Data from one participant from the fixed-intensity condition were discarded from this and subsequent analyses because of very low accuracy across all sessions (< 10% on average).

To determine whether there was an improvement in performance in the RST from pretest to posttest, and whether

this improvement differed depending on the type of training carried out in the GT, we carried out a repeated-measures ANOVA with session (pretest vs. posttest) as the within-subjects variable and training condition (fixed intensity vs. progressive intensity) as the between-subjects variable. To examine the potential relations between the GT and the RST, we carried out correlations on performance scores and gain scores (i.e., the difference in performance between pretest and posttest sessions).

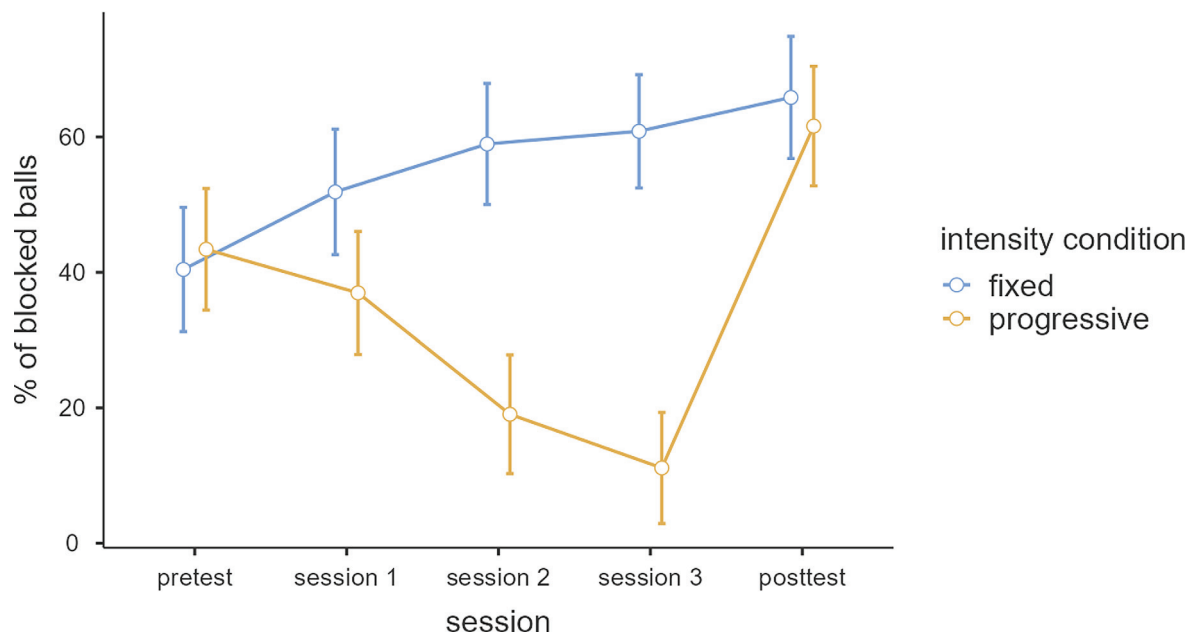
## Results

The ANOVA on GT scores revealed main effects for both session and intensity condition,  $F(4, 188) = 32.9, p < .001, \eta^2 = .12$  and  $F(1, 47) = 16.4, p < .001, \eta^2 = .15$  respectively. More importantly, a significant Session  $\times$  Intensity condition interaction was also obtained,  $F(4, 188) = 35.8, p < .001, \eta^2 = .14$ . As shown in Figure 2, the interaction was driven by differences between the two training conditions across the three training sessions but not in the pretest or posttest. Specifically, performance in the fixed-training condition was better than the progressive-training condition in all three training sessions. Furthermore, whereas in the fixed-training condition, performance increased with every subsequent training session, in the progressive-intensity condition, performance decreased from pretest to the third training session and then increased at the posttest.

Pairwise *t*-tests indicated that the performance difference between the pretest and the posttest was significant in both fixed and progressive-intensity conditions,  $t(23) = 5.68, p < .001$  and  $t(24) = 5.15, p < .001$  respectively. Although the mean difference between the pretest and the posttest was somewhat bigger in the fixed-intensity condition (Figure 2), it was not significant,  $t(47) = .95, p = .35$ .

The lower performance in the three training sessions of the progressive intensity group, compared to the fixed intensity group, could perhaps be because of participants exhibiting less effort when the task became too demanding. Although the experimenter, who was present during testing, observed no indication thereof, we analyzed participants' HR, measured as beats-per-minute (bpm), after each session to rule out this possibility. If participants found the three training sessions of the progressive-intensity condition too difficult and, as a result, did not exert much effort, we should observe lower HR in the three training sessions compared to the pretest and the posttest. Therefore, an ANOVA with terms for training condition and session was carried out on HR measures. Results revealed a significant main effect for session,  $F(4, 156) = 8.14, p < .001, \eta^2 = .03$ .

<sup>1</sup> All analyses were first carried out including sex as a variable. None of them revealed any significant main effect or interaction involving sex. Therefore, we report analyses that collapsed data from all participants.



**Figure 3.** Mean accuracy as a function of session and intensity condition in the GT. Error bars represent 95% CI.

Neither the effect of Condition nor the Condition  $\times$  Session interaction were significant,  $p = .29$  and  $p = .10$ , respectively (Figure 3).

HR in the progressive-intensity condition was numerically higher than in the fixed-intensity condition and increased from pretest to session 2. Even in the most demanding session 3, HR was as high as in session 2 and dropped somewhat at the easier posttest session (Figure 4).

We then carried out a repeated-measures ANOVA with terms for session (pretest vs. posttest) and training condition to examine the potential improvement in performance in the RST from pretest to posttest. Results revealed a significant main effect for session, documenting substantial improvement from pretest to posttest,  $F(1, 47) = 94.22$ ,  $p < .001$ ,  $\eta^2 = .16$ . However, neither the effect of Training condition nor the Training condition  $\times$  Session interaction was significant,  $p = .84$  and  $p = .81$ , respectively (Figure 5).

The ANOVA on HR also revealed a main effect for session,  $F(1, 39) = 40.24$ ,  $p < .001$ ,  $\eta^2 = .14$ . HR was higher in the posttest ( $M = 149$ ,  $SE = 4.38$ ) than in the pretest ( $M = 126$ ,  $SE = 4.38$ ). Neither the effect of Training condition nor the Training condition  $\times$  Session interaction were significant,  $p = .45$  and  $p = .21$  respectively.

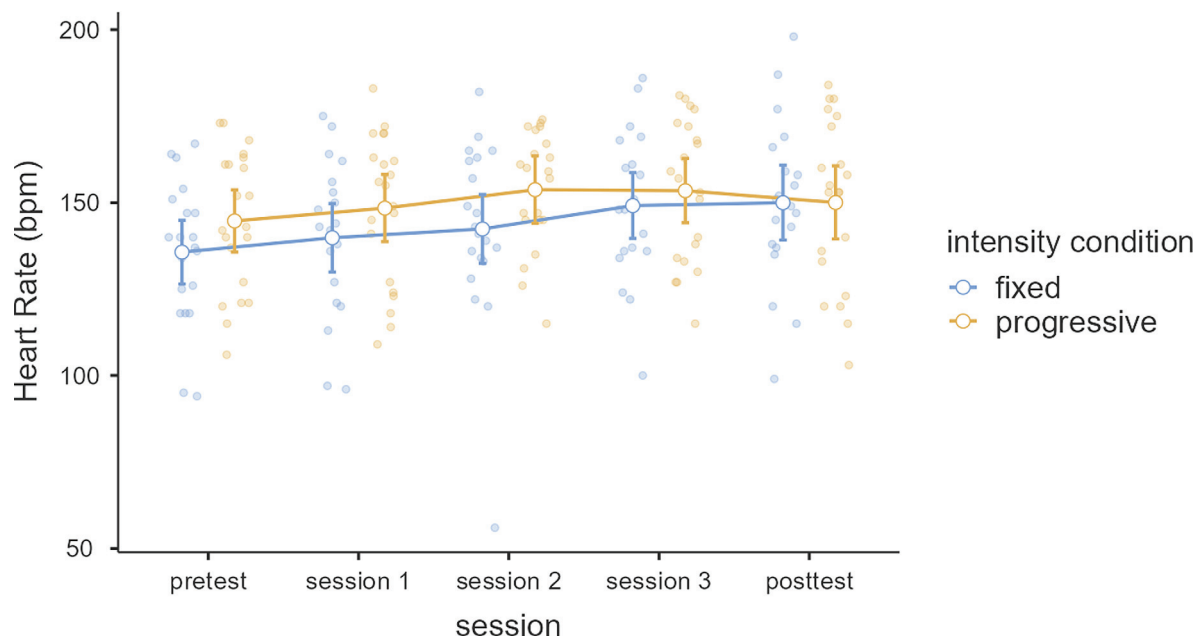
Finally, to examine the potential relations between the GT and the RST, we carried out correlations on performance scores and gain scores (i.e., the difference in performance between pretest and posttest sessions). As Table 1 shows, we obtained several interesting associations. For example, performance in the GT – as measured in either the pretest or the posttest – correlated significantly with performance in the RST. More importantly, though, the gains in

the two tasks were positively correlated. In other words, participants who benefited the most by training in the GT showed the greatest improvements in the RST task. This pattern of results suggests that there is overlap in the processes – motor and/or cognitive – the two tasks entail. However, another notable result is that a negative correlation was obtained between age and both pretest and posttest scores on the RST, but not the GT task. This suggests that the RST also recruits processes or is dependent on skills that are impaired with age and that are not relevant to the execution of the GT.

## Discussion

The study examined whether training in progressively more demanding conditions than the actual test improves performance in a goalkeeping task (GT), compared to training in fixed conditions that were as equally demanding as the test. Training intensity was manipulated by varying the speed of balls shot toward the goalkeeper in three training sessions carried out in between a pretest and posttest. In the progressive-intensity condition, balls were shot with increasing speed across training sessions 1, 2, and 3, all of which were faster than in the pretest and the posttest. In the fixed-intensity conditions, balls were shot in all three training sessions at the same speed as in the pretest and the posttest.

Although performance indeed improved from the pretest to the posttest of the GT task in the progressive-intensity condition, the gains were equal to those of the fixed-intensity condition. This finding indicates that perceptuomotor



**Figure 4.** Mean heartrate (in bpm) as a function of session and intensity condition in the GT. Error bars represent 95% CI.

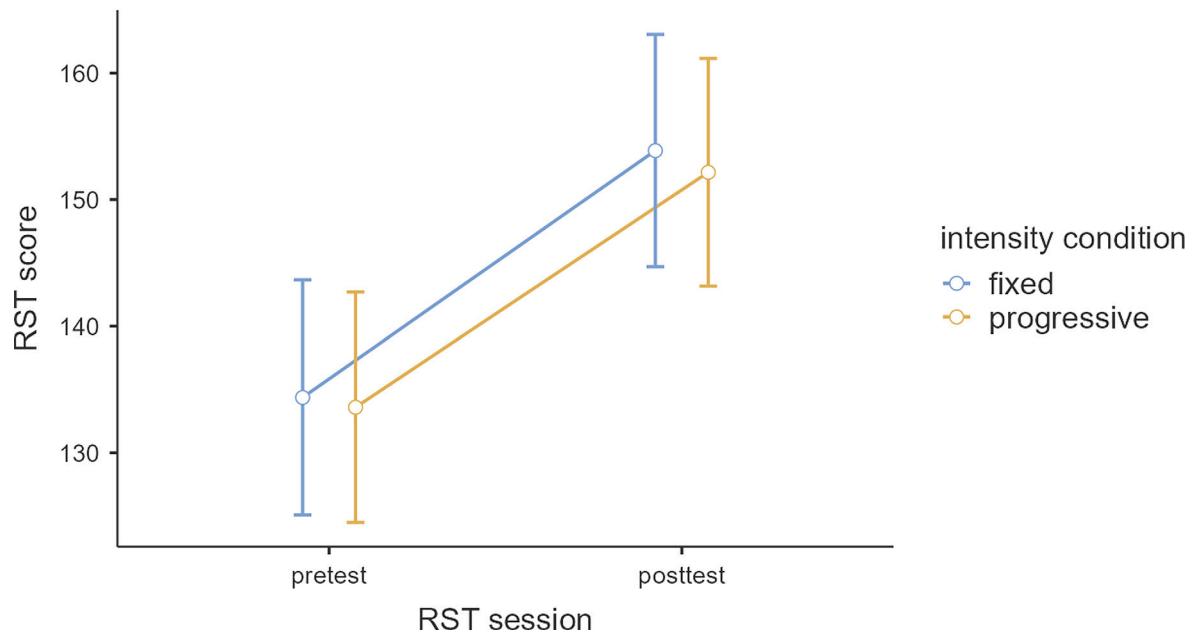
**Table 1.** Correlation matrix for measurements on GT and RST

	Age	GT pre-test	GT post-test	GT gain	RST pre-test	RST post-test
Age						
Pearson's <i>r</i>	–					
<i>p</i> -value	–					
GT pre-test						
Pearson's <i>r</i>	–0.076	–				
<i>p</i> -value	0.605	–				
GT post-test						
Pearson's <i>r</i>	–0.015	0.587***	–			
<i>p</i> -value	0.921	< .001	–			
GT gain						
Pearson's <i>r</i>	0.019	–0.460***	0.402**	–		
<i>p</i> -value	0.899	< .001	0.004	–		
RST pre-test						
Pearson's <i>r</i>	–0.300*	0.565***	0.462***	–0.150	–	
<i>p</i> -value	0.036	< .001	< .001	0.303	–	
RST post-test						
Pearson's <i>r</i>	–0.391**	0.477***	0.537***	0.029	0.814***	–
<i>p</i> -value	0.006	< .001	< .001	0.844	< .001	–
RST gain						
Pearson's <i>r</i>	–0.142	–0.153	0.115	0.295*	–0.321*	0.289*
<i>p</i> -value	0.330	0.294	0.432	0.040	0.025	0.044

Note. \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

training under conditions more intense than those encountered in the subsequent test provides no further benefit than training under the same conditions of the test. Notably, performance in a nonrelated reaction time task (RST) also

increased from pretest to posttest but equally so for the two training intensity conditions, indicating that training with either a fixed or increasingly difficult speed provides the same performance gain. Thus, overall, our findings



**Figure 5.** Mean RST scores as a function of session. Error bars represent 95% CI.

challenge a common belief among athletes and coaches that training under harder than normal conditions benefits performance, at least for tasks that do not rely on endurance. Of course, this finding may be limited to the type of tasks we used, which, although physical, rely heavily on the efficient deployment of short-term attentional skills. Therefore, training under more intense conditions than those of the subsequent test may still be beneficial for activities that rely heavily on stamina such as running, swimming, and cycling.

Our findings are in line with past research from baseball, showing that, despite the belief of players, training with bats that are heavier than normal induces no further benefit in performance compared to training with a normal bat (Montoya et al., 2009; Otsuji et al., 2002). Why could this be the case?

One possibility is that training with heavier bats in baseball or with faster balls in our goalkeeping task induces physical exhaustion that counteracts any mental benefits this training mode might provide. In both our study and those of Montoya et al. (2009) and Otsuji et al. (2002), participants carried out the critical posttest shortly after the demanding training. Therefore, although training under harder conditions can make the subsequent test appear easier to participants, physical fatigue may have compromised their performance. In our study, this hypothesis is corroborated by our HR findings: Participants in both training conditions exerted significant effort during training (144 bpm and 150 bpm on average under fixed and progressive intensity, respectively), ruling out motivational or effort differences that could potentially explain the results.

Although we cannot evaluate the hypothesis of physical (or even cognitive) exhaustion with the current data, future studies with shorter or less intense training sessions may be able to shed light on this possibility. For example, the present study could be repeated with a single training session between the pretest and the posttest to reduce possible exhaustion.

Several other results from the current study are also noteworthy. First, results showed that, in the GT task, performance improved substantially from pretest to posttest. Moreover, in the fixed-training condition, the improvement was incremental for each training session. Overall, these results indicate that practice effects can be obtained on this VR task in the short term and suggest that it could be an efficient tool for training goalkeepers or other athletes in sports entailing fast reactions to targets. That said, future studies should examine whether the practice effects obtained here with a sample of nongoalkeepers generalize to amateur and professional goalkeepers.

One limitation of the current study is that pretest and posttest were carried out in VR, using the same setup as the training sessions. Future studies should investigate whether these short-term practice effects obtained in VR also translate to improved performance under real conditions. For example, a future study could examine whether training using the GT yields benefits for goalkeeping performance assessed with a real ball launcher. Replicating current results in real-life settings would document the ecological value of VR as a valid training tool for goalkeepers and their coaches and lead to more widespread adoption in the field.

Second, our findings revealed that scores on the RST task correlated significantly with accuracy in the GT. Notably, this was the case for both the pretest and posttest sessions in the two tasks. Moreover, the performance gains in the two tasks (i.e., increase in performance from the pretest to the posttest) were positively correlated, suggesting that the execution of the two tasks recruits some common cognitive and/or motor processes. Shimi et al. (2021) showed that a more complex version of the VR goalkeeping task we used here recruited basic and higher-order attentional skills such as alerting, orienting, cognitive and response inhibition. To successfully execute the SRT task, one presumably needs to remain alert throughout the task, scan the visual field and detect a perceptual target before executing a fast motor response. Collectively, these results indicate that performance in the goalkeeping task could be predicted by performance in another task that entails detecting and executing fast movements toward targets (and vice versa).

Third, a negative correlation was observed between age and both pretest and posttest scores on the RST, but not the GT task. Although, as already mentioned, the two tasks may have underlying commonalities, this finding suggests that they do not fully overlap in terms of the cognitive and/or motor processes that subservise them. Instead, the RST seems to recruit processes that are impaired with age and that are less important to goalkeeping. One notable difference between the GT and the RST is that in the former the user has more time to physically react to the target as the ball is shot from a cannon located at some distance, compared to the RST where a speeded manual response is required as soon as the target is lit. Thus, RST may rely more on the execution of fast manual responses than the GT. Research on motor control and aging documents motor declines, including movement slowing with age, which may be linked to progressive atrophy of motor cortical regions and degeneration of the dopaminergic neurotransmitter system of the brain (see Seidler et al., 2010, for a review). Another possibility is that the RST relies more heavily than the GT on attentional processes relating to visual search. That is, in the RS task, participants need to quickly locate the target among 14 distractors, while in the GT task the ball is shot from one of only three possible locations, with the user having more time to orient their attention to the ball. Past research indicates that, indeed, visual search ability deteriorates with age (Madden et al., 1999; Scialfa & Joffe, 1997). Regardless of why GT performance but not RST performance was immune to aging effects, our findings highlight the need to thoroughly research the tasks that are used for training athletes to delineate the physical and mental skills they involve. Such research would allow the design of targeted tools that can improve performance by boosting the functioning of specific mental and physical processes.

Overall, our findings document that performance in a goalkeeping task requiring the interception of fast-approaching balls improves in the short term, as evidenced by the continuous increase in scores from the pretest to the posttest of the fixed-training condition. Although no evidence is found for an advantage of training under harder than test conditions compared to training with the same as test conditions, this finding suggests that VR could be a useful tool, complementary to live training, for enhancing the assessment and exercise in tasks that rely on physical and mental skills. The particular goalkeeping task we used here may be used not just by goalkeepers and their coaches as a training tool, but also by psychologists and other health-care professionals as a more engaging way to assess attentional skills in both children and adults.

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### Open Data

All data and analyses scripts are available on the Open Science Framework: <https://osf.io/z56sp/>

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