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# Attentional Skills in Soccer: Evaluating the Involvement of Attention in Executing a Goalkeeping Task in Virtual Reality

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**Featured Application: The findings of the study document the involvement of cognitive skills in the execution of a goalkeeping task in virtual reality, suggesting that virtual reality simulations can be a useful tool for goalkeepers to exercise their mental skills.**

**Abstract:** Physical abilities are essential to goalkeepers in soccer but the involved cognitive abilities for these players have only recently become the focus of extensive research. In this study, we investigated the role of different aspects of attention in a basic goalkeeping task in soccer. One hundred participants assumed the role of a goalkeeper in immersive virtual reality (VR) and carried out a task that entailed blocking balls shot towards their goal. In addition, they carried out two computerized tasks each assessing different attentional abilities: the Attention Network Test provided scores for three well-established networks of attention, namely the alerting, the orienting, and the executive control. The Whack-a-Mole task evaluated inhibitory control, by measuring performance in a classic Go/No-Go task and tapping on response inhibition. A regression analysis revealed that all three attention network scores contributed to performance in the VR goalkeeping task. Furthermore, performance in the Whack-a-Mole task correlated significantly with performance in the VR goalkeeping task. Overall, findings confirm that cognitive skills relating to attention play a critical role in the efficient execution of soccer-specific tasks. These findings have important implications for the training of cognitive skills in sports.

**Keywords:** goalkeeping; cognition; soccer; executive control; inhibitory control

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## 1. Introduction

Inherent to the execution of many tasks of everyday life is the ability to identify and respond to targets while at the same time inhibit responses to distractors. This ability, known as executive control, is fundamental for performance in fast-paced sports where reaction speed is of paramount importance. For example, goalkeepers in soccer must be able to quickly determine whether to initiate movement toward an approaching ball and then react quickly to make contact with the ball at the optimal time and position in space. Even seemingly simple tasks like this may rely on the efficient deployment of several cognitive mechanisms beyond executive control (e.g., remaining vigilant under the face of distraction, orienting attention quickly to the ball, tracking the trajectory of the moving ball, and executing a motor action to intercept the ball at the right place and time).

Indeed, past research in soccer has verified that cognitive skills, such as those related to attention, can differentiate elite players from amateurs both in adulthood and childhood (see [1] for a review). For example, the authors of [2] compared a group of soccer players between 8 and 16 years of age selected from a talent development program with age-matched amateur soccer players on a variety of measures including motor inhibition, visuospatial working memory, and three different sub-components of attention, namely alerting, orienting, and conflict resolution. Results indicated that the talented group outperformed the amateurs in motor inhibition and alerting, whereas no differences were found for orienting, conflict, and working memory. Furthermore, the authors of [3] showed that male and female players from the highest division Sweedish national leagues outperformed 3rd and 4th division players in a Design Fluency task that measures fast creativity and problem-solving, as well as in the Stroop task that indexes the ability to inhibit cognitive interference, and the Trail Making test that assesses other executive functions such as visual search/scanning, mental flexibility, and psychomotor speed. Notably, performance in these tasks correlated with the number of goals scored and the passes made by the players two years later, suggesting that the level of cognitive ability assessed with laboratory measures can predict future success in soccer in the field. Furthermore, other studies have documented that training with perceptual-cognitive tasks in the laboratory may elicit benefits for on-pitch performance. For example, in [4] the authors have shown that training for 10 sessions with a 3D-Multiple Object Tracking task improved passing in soccer players assessed on the pitch, compared to an active control group (see [5] for a review of the evidence for training transfer to real-world sport settings).

Although the evidence from the literature on soccer and sports in general documents the importance of cognitive skills for achieving elite performance ([3,6], see also [7] for a review of the role of perceptual-cognitive skills in expert performance), it is not yet fully clear which specific cognitive skills are implicated in particular tasks on the pitch. The use of different tasks, which may be thought to measure the same or different cognitive abilities across studies, makes it difficult to determine exactly which cognitive skills are more important and for which specific role on the pitch. To overcome this limitation, in the present study we focus on the specific task of blocking fast-approaching balls, in order to examine the involvement of specific attention-related abilities for goalkeeping performance.

As the task of a goalkeeper in an actual soccer match is complex and possibly entailing multiple cognitive skills (e.g., tracking the ball to undertake action, tracking the locations of players on the pitch, ignoring fans to maintain focus on the play), we isolated a simple task to use in our study that pertains to a key responsibility for a goalkeeper, that of blocking a fast-moving ball that is shot directly towards the goal from outside the penalty box. To carry out this task, we assume that a goalkeeper must employ different attentional processes. First, the goalkeeper will need to maintain a heightened level of alertness to anticipate the shot. Second, s/he must orient her/his attention quickly to the ball that is shot in order to initiate a motor response in time. In addition, s/he must exercise executive control to respond to the ball while ignoring potentially distracting and/or interfering information in the environment (e.g., other players, soccer fans, passing balls from players warming up on the sideline, etc.). Finally, s/he must exercise inhibitory control when deciding whether or not to react to the approaching ball. That is, in an actual match, the goalkeeper does not react to all the balls shot towards her/his goal. For example, if s/he estimates that the ball is going out or will be blocked by a defender, the goalkeeper may choose to refrain from intercepting the ball. In order to evaluate both executive and inhibitory control within the context of the goalkeeper's duty, we used a task in which participants were asked to respond only to a particular ball-type. Thus, the task required participants to ignore interfering distractors and withhold a motor response to them.

As we aimed to understand the rudimentary attentional processes that are involved in this particular task, in our study we tested non-athlete participants rather than expert goalkeepers who may have developed idiosyncratic strategies with executing such a task. Past studies with goalkeepers have shown an expert advantage in goalkeepers in a similar task of anticipating the direction of a ball in a penalty kick. For example, the authors of [8] showed that expert goalkeepers were better than novices at predicting the direction of the penalty kick by processing more efficiently the visual kinematic information from the penalty-taker's body as well as non-kinematic information from directional cues.

Electroencephalography measures from this study suggested that the expert goalkeepers may have more advance early attentional processing and conflict monitoring skills that allow them to respond more efficiently, particularly when there is a conflict between kinematic and non-kinematic information.

Thus, to get a "purer" account of the role of attention in this basic goalkeeping task, in the present study we tested non-goalkeeper participants and we administered the task in immersive VR where we could remove body-related kinematic information by having ball launchers shoot the balls. Although VR alters some of the characteristics of blocking actual balls on the real pitch (e.g., haptic feedback from contacting a ball), it allowed us to run the task in a highly-controlled manner in the lab (e.g., specifying the speed, frequency, and landing locations of the balls), while recording a variety of data that is more difficult to obtain in the real world (e.g., accuracy and acceleration data). It should be noted that VR has been used successfully in several past studies in various sports showing that VR tasks can be implemented to provide a close approximation to those executed in the real world (e.g., [9,10]) and demonstrate high convergent validity (e.g., [11]). For example, using immersive VR, the authors of [11] showed that performance in soccer-specific drills (e.g., passing accuracy, composure, reaction time, etc.) administered in VR, could successfully differentiate professional, academy, and novice soccer players.

In the current study, we asked participants to assume the role of a goalkeeper and to block balls shot at them for 2 min. We also asked them to carry out the Attention Network Test (ANT) [12,13], a well-known computerized task that provides separate scores for three distinct attentional networks: alerting, orienting, and conflict/executive control. These scores are believed to index rather independent functional components of attention [14,15] (but see [16,17] for evidence for interactions across the three networks) and have been studied extensively from a behavioral and neuropsychological perspective (e.g., [12,18,19]). Furthermore, past studies have differentiated these three networks of attention based on their genetic underpinnings and the neurotransmitters involved ([20–23]).

The alerting network refers to the ability of an individual to maintain alertness in order to perceive and process an upcoming stimulus faster [24]. This ability relies on superior parietal, right frontal and thalamic brain areas [14] and is typically present by 3 months of age [25]. The ANT measures what is known as phasic alertness, which refers to the ability of an individual to develop response readiness to a target after the appearance of a warning signal, in tasks where reaction time is measured [26]. Studies have shown that blocking the norepinephrine system in the brain prevents the normal function of warning signals (e.g., [27]), verifying the involvement of this neurotransmitter in alerting [25].

The orienting function of attention refers to the ability of an individual to transfer focus from the central fixation to the expected location of the upcoming stimulus [16,28]. Findings from past research indicated that there is no change in orienting efficiency to an upcoming perceptual target after the age of 6 compared to adulthood [13]. Ref. [29] suggested that the orienting network is related to activity in the temporal–parietal junction, frontal eye fields (FEF), and superior parietal lobule. Using the ANT, the authors of [30] verified the existence of activations in such areas, except for the right temporal–parietal junction. The orienting network is believed to implicate the cholinergic neurotransmitter system [31].

The executive control network is the attentional system responsible for identifying and resolving cognitive conflicts and exerting cognitive inhibition. Thus, its efficiency is typically examined with tasks that require responding to a target while suppressing other conflicting stimuli that are presented simultaneously as distractors. It is supported by activity in the lateral prefrontal cortex and the anterior cingulate [32]; both areas rely heavily on the dopaminergic neurotransmitter system [19]. Studies have shown that although executive control develops substantially through childhood, there is little change in conflict scores from 7 years of age and onwards [13].

Although we considered all three networks of attention relevant to the VR Goalkeeper task we used in the current study, we expected that orienting would be the most likely from the three attentional skills to predict successful performance. Given that the balls are shot from a distance (i.e., outside the penalty box), we assumed that participants would have adequate time to recover from any lapses of alerting, as well as to overcome potential response conflict. Still, of interest was to determine whether alerting and conflict resolution would account for unique variance in the VR Goalkeeper task beyond that explained from orienting. In addition to ANT measures and given that the VR Goalkeeper task employed is essentially a Go/No-Go task (i.e., an inhibitory control task as the goalkeeper needs to make a motor response to the target ball and withhold a response to the non-target, distracting balls), we compared performance in the VR task with performance on a more traditional computerized Go/No-Go task, namely the Whack-a-Mole task, in which optimal performance requires efficient response inhibition. Although the two tasks exhibit some important differences (i.e., the VR Goalkeeper task provides the participant with time to stop a response that has been initiated while the Whack-a-Mole task does not to the same degree), we expected performance on the two tasks to correlate given that both tasks are believed to assess the same underlying construct. Finally, we asked participants to fill out two questionnaires related to the functioning of attention in everyday life to explore possible associations between performance in the computerized tasks, the VR Goalkeeper task, and attentional difficulties encountered in daily life. With the aforementioned tasks and scales, our overall aim was to determine the aspects of attention that a basic goalkeeping task relies on.

## 2. Materials and Methods

### *2.1. Participants*

One hundred volunteers (34 males and 66 females) from the student community of the University of Cyprus participated in the study in exchange for course credit. The number of participants exceeds the number obtained from a power analysis as well as from using Green's heuristic [33,34]. A power analysis using G*Power 3.1.9.7 indicated that for a hierarchical regression to achieve power of 0.80 to detect a medium effect size, with a significance level of $\alpha = 0.05$, and 4 predictors, a total of 85 participants would be needed. Based on Green's rule of thumb, 82 participants would be needed.

All participants were between 18 and 35 years of age, had normal or corrected-to-normal vision, and reported no health-related issues. Participants were recruited from introductory undergraduate Psychology classes using an online sign-up tool. No participant reported being part of a soccer team (professional or amateur).

### *2.2. Materials*

*The VR Goalkeeper task*. The VR Goalkeeper task is an immersive VR task in which users adopt the role of a goalkeeper in soccer whose task is to block with his/her hands a specified type of target balls and let go all others types of balls (Figure 1).

The task was selected from the set of drills included in the prototype version of the VkeepR app made available by MentisVR Ltd. (www.mentis-VR.com, (accessed on 4 October 2021)). By donning a VR head-mounted-display (HMD), users are immersed in a soccer pitch at a standing position between the goal posts. Body and hand movements are tracked with 6 degrees-of-freedom so that users can move in the virtual environment and block the balls by extending their arms. Handheld controllers that appear as goalkeeper gloves in the virtual environment serve to simulate arm movement. The task used involves 4 different types of balls—red and green footballs and red and green volleyballs—that are shot by a cannon positioned at some distance outside the penalty area, straight ahead from the goalkeeper. For each participant, one of the four types of balls is set as the target type that must be blocked while the other 3 types are distractors that should not be responded to. Thus, the task aligns with the Go/No-Go paradigm in which responses are made to certain stimuli but not to others. Following extensive pilot testing, the speed, frequency, and landing positions of the balls at the goalposts were set to levels that made the task physically comfortable for participants. Participants were instructed to carry out the task by moving only their arms and avoid moving their body away from the initial standing position between the goalposts.


**Figure 1.** Game play screenshot of the VR Goalkeeper task with the four types of balls used.

*The Attention Network Test (ANT)*. Participants completed the adult version of the Attention Network Test [13] on a desktop computer. Each trial in the ANT entails the presentation of a central arrow on the screen and requires participants to click the left or right mouse button to indicate the arrow's pointing direction (Figure 2). Four flanker arrows are also presented, two on each side of the central arrow, pointing to the same or different direction, creating thus trials that are congruent or incongruent. Neutral trials in which the central arrow is flanked by lines without an arrow cap are also included. Furthermore, in each trial, the array of arrows is presented either above or below the center of the screen that is marked with a fixation cross. Trials begin with the presentation of the fixation cross alone for a variable duration (100, 400, or 1700 ms) followed by a warning type display presented for 200 ms. Depending on the condition, a different type of warning cue is presented. In trials with spatial cues, an asterisk is displayed either above or below the fixation to orient attention to where the arrow array may appear. In the standard version of the ANT used here, spatial cues were always valid. In central cue trials, the asterisk is presented on top of the fixation to alert participants for the upcoming arrow array without moving attention away from fixation. In double cue trials, two asterisks are presented, one above and the other below the fixation. Like central cues, double cues provide alerting information. However, they divide attention to the two possible locations in which the arrow array could appear. Finally, trials in which no cue is presented were included. The combination of different warning cue conditions and flanker type conditions allows computing the distinct attentional networks (details on the network computations are presented in Section 2.5). For the present study, we adapted the ANT task to the OpenSesame software [35]. Stimuli, sizes, positioning, and timing were identical to the original task (the OpenSesame version of the task we developed is freely available on our OSF depository: DOI 10.17605/OSF.IO/FPMN3).

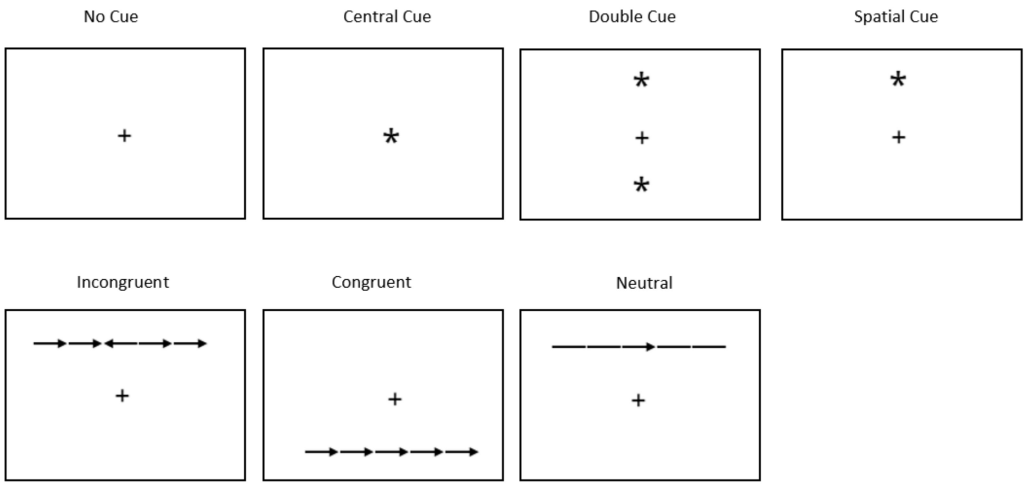


**Figure 2.** Example stimuli from the ANT. The top row shows the four warning cue types and the bottom row shows the three flanker type conditions.

*Whack-a-Mole task*. This is a computerized Go/No-Go task that evaluates response inhibition [36]. Each trial of the task involves the presentation of a mole or an eggplant on the computer screen. Participants are instructed to smash the mole (Go trials) by pressing the space bar on the keyboard as fast as possible, but to withhold response to the eggplant (No-Go trials). In order to induce a bias towards executing a response and test skills related to inhibitory control, 75% of all trials are Go trials. The version of the task used here was downloaded from the Essay and Tools page of the Sackler Institute for Developmental Psychobiology (stimuli courtesy of Sarah Getz and the Sackler Institute for Developmental Psychobiology) and was administered using E-Prime 2.

*Attentional Control Scale (ACS)*. The ACS [37,38] is a 20-item self-report questionnaire that assesses individual differences in the focusing and the shifting of attention. Focusing refers to a person's ability to focus attention on a stimulus or a task and ignore distractors while shifting is the ability to redirect attention from one task to another [39]. Out of 20 items, 9 items refer to focusing (e.g., "When I need to concentrate and solve a problem, I have trouble focusing my attention") and the remaining 11 to attentional shifting (e.g., "It is easy for me to alternate between two different tasks"). Responses are given on a 4-point Likert scale indicating how frequently a behavior takes place (1 = almost never; 2 = sometimes; 3 = often; 4 = always). The ACS scale has high internal consistency, Cronbach's alpha = 0.88 [37].

*Adult ADHD Self-Report Scale (ASRS).* The ASRS is an 18-item self-report questionnaire that is used for the diagnosis of attention-deficit/hyperactivity disorder (ADHD) in adults based on DSM-IV criteria (which match the DSM-5 criteria). The ASRS was developed by the World Health Organization and the Workgroup on Adult ADHD [40]. The questionnaire is divided into two parts. The first part includes items that assess inattentiveness (e.g., "How often do you make careless mistakes when you have to work on a boring or difficult project?") while the second part measures hyperactivity and impulsive behavior (e.g., "How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?"). Responses are given on a 5-point Likert scale (i.e., 0 = Never, 4 = Very often) and evaluate the presence of symptoms in the last 6 months. Total scores for each part range from 0 to 36, with scores greater than 17 indicating greater probability of ADHD in adulthood [41]. The ASRS has been shown to have high internal consistency, Cronbach's alpha = 0.88 for the patient version [41].

### 2.3. Experimental Design

All participants carried out the three computerized tasks and filled out the two paper-and-pencil scales. Performance on the VR Goalkeper task was the dependent variable while scores from the three attentional networks of ANT were used as predictor variables in a hierarchical regression along with the gender of participants. Performance on the Whack-a-Mole task, as well as scores on the ACS and ASRS, were used in correlational analyses. We expected the orienting score from the ANT to contribute to performance in the VR Goalkeeper task as assessed by the regression. We also expected the Whack-a-Mole scores to correlate with performance in the VR Goalkeeper task. All other variables were included as exploratory variables in the analyses.

### 2.4. Procedure

Participants were tested individually at a quiet laboratory at the University of Cyprus. Upon arriving at the lab, each participant read and signed an informed consent. First, participants carried out the two computerized tasks, i.e., the ANT and the Wack-a-Mole. The order in which the two tasks were administered was counterbalanced across participants. In between the two tasks, participants filled out the ACS and the ASRS questionnaires. The VR Goalkeeper task was administered last to preclude physical fatigue impacting negatively cognitive processing in the computerized tasks.

For the ANT, participants sat in front of a desktop computer at a comfortable distance from the screen and they were instructed to click the left or right button of a mouse to indicate the direction of the central arrow while keeping their gaze on the central fixation. They were also informed that whenever a spatial cue was presented above or below the fixation cross, the arrow array would always appear at that location. Each trial presented one of the 12 possible combinations of flanker types (congruent, incongruent, and neutral) and warning types (no cue, central cue, double cue and spatial cue). As with the original task of Fan et al. (2002), participants carried out a total of 192 trials, divided into 4 blocks of 48 trials. Before the experimental blocks, participants completed a practice block of 24 trials during which response feedback was provided by the computer. The experimenter was also present during the practice block to ensure that participants fully understood the task. No feedback was provided in the experimental trials.

Participants carried out the Whack-a-Mole task on the same computer. They were instructed to press the space bar as quickly as possible to smash the mole that appeared in the garden but refrain from any response when an eggplant appeared instead. The mole and the eggplant could appear in different disguises making perceptual discrimination more difficult. Participants completed a total of 220 trials, divided in 4 blocks. From these, 165 were Go trials that presented the mole and 55 were No-Go trials presenting the eggplant. The number of Go trials that preceded a No-Go trial was also varied so that about 82% of No-Go trials were preceded by 1, 3, or 5 Go trials, in equal probability across the 3 types. Foils in which a No-Go trial was preceded by 2 or 4 Go trials (about 18% of No-Go trials) were included to prevent participants from inferring the pattern. Participants were instructed to respond as fast as possible to targets but without sacrificing accuracy for speed. Response feedback was provided for each trial throughout the task.

Once participants completed the ANT or the Whack-a-Mole task, depending which one was administered first, they filled out the ACS and the ASRS questionnaires. Both questionnaires were completed anonymously and the participant number was used to associate the data with those from the other tasks.

Finally, participants were guided to a different room in the laboratory where they carried out the VR Goalkeeper task. For this task, they put on an Oculus Rift S VR HMD that immersed them into the soccer pitch. The Oculus Controllers were used to enable arm movement towards the balls. Each participant carried out the task for 2 min that entailed blocking the target balls with the hands (Go trials) and refraining from responding to all other types of balls (No-Go trials). The assignment of a ball type as the target amongst the 4 types possible was counterbalanced across participants. About 60 balls were shot within the 2 min time, 48 of which (80%) were Go and the 12 (12%) were No-Go. Before the actual task, participants performed a 1 min practice with only one target ball to familiarize themselves with the task.

### *2.5. Data Analysis*

Based on Signal Detection Theory, we computed d′ scores for each participant in the VR Goalkeeper task using the hit rate (i.e., % of targets responded to from target-present trials) and the false alarm rate (i.e., % of distractors responded to from target-absent trials). Similarly, hit rates and false alarm rates were used to compute a d′ score for each participant in the Whack-a-Mole task. Following the procedure reported in previous studies using the ANT (e.g., [7]), we computed three scores for each participant using their response time data. To compute the Alerting score, we subtracted the response time for double cue trials from that of no cue trials. For the Orienting score, we subtracted the median response time for spatial cue trials from that for central cue trials. Finally, to compute the Conflict score, we subtracted the response time for congruent trials from the response time for incongruent trials. We computed subscores for focusing and attentional shifting, as well as a total score, from participant responses to the ACS. Additionally, we computed scores for inattentiveness (Part A of the scale) and hyperactivity/impulsive behavior (Part B of the scale) for each participant from responses to the ASRS scale. Statiscial analyses were carried out using Jamovi 1.6 (www.jamovi.org, (accessed on 4 October 2021)).

## 3. Results

We examined whether participants' performance in the VR Goalkeeper task is captured by the efficiency of the three attentional networks and inhibitory control. To do so, we (1) computed scores on the ANT and examined whether they could explain part of the variance in the performance of the VR Goalkeeper task, and (2) correlated performance on the VR Goalkeeper task with that on the Whack-a-Mole task. We also explored relations between accuracy performance in the VR Goalkeeper task and other variables within the same task such as the speed of movement. Finally, we assessed whether self-reported attentional abilities/difficulties as assessed in the two questionnaires were related to performance in the computerized and VR tasks.

### *3.1. VR Goalkeeper Performance and Efficiency of the Attentional Networks (ANT)*

To confirm that the various types of warning cues and the flanker types influenced the pattern of performance on the ANT task as expected and to verify that we replicated past findings from studies that have used this task, we first carried out a repeated-measures Analysis of Variance (ANOVA) with terms for Flanker type and Warning type on the median response times for correct responses. An $\alpha = 0.05$ criterion for significance was set across all analyses. Post-hoc comparisons from the ANOVA were Bonferroni-corrected to reduce the risk of type I error arising from multiple statistical tests.

The analysis revealed significant main effects for both the Flanker type and the Warning Type, $F(2,198) = 557.2$, $p < 0.001$, $\eta^2 = 0.35$ and $F(2,297) = 297.6$, $p < 0.001$, $\eta^2 = 0.09$, respectively. As seen in Table 1, response times were longer for the incongruent flankers than for either the congruent or neutral flankers ($p$'s $< 0.001$).

Furthermore, response times were faster for trials with spatial cues and slower for trials with no cues, compared to either center cue or double cue trials ($p$'s $< 0.001$). A significant Flanker type x Warning type interaction was also found, $F(6,594) = 20.6$, $p < 0.001$, $\eta^2 = 0.01$. The interaction was driven by performance in double cue trials being faster than performance in center cue trials in the incongruent flanker condition but not in the other two flanker conditions (congruent and neutral). Despite this interaction, the observed pattern of response times replicates closely the pattern reported by previous studies with the ANT (e.g., [12,13]) and verifies that both warning cues and flankers induce the expected influence on response times. Therefore, we proceeded to compute network scores for each participant. As seen in Table 2, a significant negative correlation between alerting and conflict was obtained, suggesting that the networks are not completely independent.

**Table 1.** Mean of median RT in ms for combinations of Warning type and Flanker type in the ANT task.

| | | | 95% Confidence Interval | |
|---|---|---|---|---|
| **Flanker Type** | **Warning Type** | **Mean** | **Lower** | **Upper** |
| Congruent | No cue | 513 | 499 | 528 |
| | Center cue | 463 | 449 | 478 |
| | Double cue | 466 | 452 | 480 |
| | Spatial cue | 432 | 418 | 447 |
| Incongruent | No cue | 625 | 611 | 640 |
| | Center cue | 597 | 583 | 612 |
| | Double cue | 579 | 564 | 593 |
| | Spatial cue | 526 | 512 | 541 |
| Neutral | No cue | 491 | 477 | 506 |
| | Center cue | 448 | 433 | 462 |
| | Double cue | 451 | 436 | 465 |
| | Spatial cue | 423 | 409 | 438 |

**Table 2.** Correlations among the three networks of attention, the d′ for the VR Goalkeeper task, and the d′ for the Whack-a-Mole task.

| | | **Orienting (C-S)** | **Alerting (N-D)** | **Conflict (C-I)** | **GK d′** |
|---|---|---|---|---|---|
| Orienting (C-S) | Pearson's r | — | | | |
| | *p*-value | — | | | |
| Alerting (N-D) | Pearson's r | 0.057 | — | | |
| | *p*-value | 0.575 | — | | |
| Conflict (C-I) | Pearson's r | 0.038 | −0.264 ** | — | |
| GK d′ | Pearson's r | 0.227 * | 0.146 | 0.299 ** | — |
| | *p*-value | 0.023 | 0.148 | 0.003 | — |
| WTM d′ | Pearson's r | 0.278 ** | −0.222 * | 0.138 | 0.207 * |
| | *p*-value | 0.005 | 0.026 | 0.171 | 0.039 |

Note. * $p < 0.05$, ** $p < 0.01$.

We then proceeded to examine whether the three attentional network scores predicted performance on the VR Goalkeeper task. Based on Signal Detection Theory, we computed d′ scores for each participant in the VR Goalkeeper task using the hit rate (i.e., % of targets responded to from target-present trials) and the false alarm rate (i.e., % of distractors responded to from target-absent trials). We then carried out a hierarchical multiple regression with the d′ score on the VR Goalkeeper task as the dependent variable.

Given that the VR Goalkeeper task is one that men are more likely to be familiar with than women, gender was entered as a factor at step 1 of the analysis. Orienting was entered at step 2 as we deemed this sub-component of attention to be the most relevant to the VR Goalkeeper task used. Finally, Alerting and Conflict were entered at step 3 as we had no a priori hypothesis on whether they would predict performance in the VR Goalkeeper task. Hierarchical Regression statistics are reported in Table 3.

The regression analysis revealed that at step 1, gender contributed significantly to the regression model, [F (1.98) = 8.98, $p = 0.003$] and accounted for 8.4% of the variation in VR goalkeeper performance. As the analysis showed, men had higher d′ scores (M = 3.38, SE = 0.15) than women (2.84, SE = 0.11), $p = 0.004$. Introducing Orienting in step 2 explained an additional 4.2% of variation in goalkeeper d′ and this change in $R^2$ was significant, F (1.97) = 4.62, $p = 0.034$. Adding Alerting and Conflict in step 3 accounted for an additional 12.63% of the variation of VR goalkeeper d′ with the change in $R^2$ being again significant, F(2.95) = 8.02, $p < 0.001$. As seen in Table 3, when the three attentional networks and gender were included in step 3, they were all significant predictors of VR goalkeeper d′. The final model explained 25.20% of the variation in VR goalkeeper d′. A model that included the interaction terms of the three network scores with gender accounted for 26.20% of the variation. However, none of the interaction coefficients were significant in this model.

**Table 3.** Hierarhical regression analysis on gender and attentional network scores predicting d′ prime in the VR Goalkeeper task.

| | | Step 1 coefficients | | |
|---|---|---|---|---|
| **Predictor** | **Estimate** | **SE** | **t** | ***p*** |
| Intercept [a] | 2.82 | 0.114 | 24.67 | <0.001 |
| Gender: | | | | |
| M − F | 0.587 | 0.196 | 3 | 0.003 |
| | | Step 2 coefficients | | |
| **Predictor** | **Estimate** | **SE** | **t** | ***p*** |
| Intercept [a] | 2.53227 | 0.17469 | 14.5 | <0.001 |
| Gender: | | | | |
| M − F | 0.55362 | 0.19314 | 2.87 | 0.005 |
| orienting (c-s) | 0.0071 | 0.0033 | 2.15 | 0.034 |
| | | Step 3 coefficient | | |
| **Predictor** | **Estimate** | **SE** | **t** | ***p*** |
| Intercept [a] | 2.93392 | 0.27527 | 10.66 | <0.001 |
| Gender: | | | | |
| M − F | 0.5401 | 0.18358 | 2.94 | 0.004 |
| orienting (c-s) | 0.00619 | 0.0031 | 2 | 0.049 |
| conflict (C-I) | 0.00649 | 0.00186 | 3.48 | <0.001 |
| alerting (n-d) | 0.00786 | 0.00282 | 2.79 | 0.006 |

[a] Represents reference level.

The final model met the assumptions of the regression analysis. Specifically, VIF values were close to 1 for all predictors (1.01–1.1) documenting the absence of collinearity and the Durbin–Watson test was not significant, indicating that the residuals of the model were independent. A non-significant Shapiro–Wilk test indicated no deviations from normality while residual plots verified homoscedacity for predictor variables.

### 3.2. VR Goalkeeper Performance and Inhibitory Control (Whack-a-Mole)

As with the VR Goalkeeper task, we used the hit rates and false alarm rates to compute a d′ score for each participant in the Whack-a-Mole task. An initial analysis indicated that the number of Go trials that preceded a No-Go trial (1, 3, or 5) did not influence performance; therefore, we aggregated data across the three types of No-Go trials before computing d′. Notably, the resulting d′ in the Whack-a-Mole task correlated significantly with the d′ from the VR Goalkeeper task, r(100) = 0.21, $p = 0.039$. As seen in Table 2, the Whack-a-Mole d′ also correlated positively with the Orienting score and negatively with the Alerting score from the ANT.

### 3.3. VR Goalkeeper Accuracy Performance and Speed of Movement

To further investigate the characteristics of the VR Goalkeeper task, we analyzed the acceleration data that were recorded from the hand controllers. For each trial, the maximum change in movement velocity was recorded. That is, large values indicated abrupt movement from the user while smaller values indicated smoother movement. We correlated these data with the d′ on the same task. As shown in Table 4, acceleration across all types of trials (target-present or target-absent) correlated negatively with d′. Thus, users who executed smoother than abrupt movements tended to do better overall at the VR Goalkeeper task. Notably, this was the case in both present trials in which participants had to respond and distractor trials in which they had to inhibit (i.e., to withhold) a prepotend response. Given that for target-absent trials this correlation could arise by false alarm alone, we repeated the analysis using the acceleration data from correct rejections only. As shown in Table 4, even for these responses, the negative correlation between acceleration and d′ was significant. Notably, as corroborated by the presence of a significant negative correlation between acceleration for hits and d′, even for trials with correct responses to targets, participants who carried out sudden movements did overall worse in the task. No gender differences were present in the acceleration data.

**Table 4.** Correlations among measures of the VR Goalkeeper task.

| | | Acceleration Overall | Acceleration Target Present | Acceleration Target Absent | Acceleration Hits | Acceleration Correct Rejections |
|---|---|---|---|---|---|---|
| Acceleration overall | Pearson's r | — | | | | |
| | *p*-value | — | | | | |
| Acceleration Target Present | Pearson's r | 0.995 *** | — | | | |
| | *p*-value | <0.001 | — | | | |
| Acceleration Target Absent | Pearson's r | 0.962 *** | 0.931 *** | — | | |
| | *p*-value | <0.001 | <0.001 | — | | |
| Acceleration Hits | Pearson's r | 0.988 *** | 0.994 *** | 0.924 *** | — | |
| | *p*-value | <0.001 | <0.001 | <0.001 | — | |
| Acceleration Correct Rejections | Pearson's r | 0.954 *** | 0.923 *** | 0.995 *** | 0.911 *** | — |
| | *p*-value | <0.001 | <0.001 | <0.001 | <0.001 | — |
| d′ | Pearson's r | −0.337 *** | −0.320 ** | −0.247 * | −0.321 ** | −0.372 *** |
| | *p*-value | <0.001 | 0.001 | 0.013 | 0.001 | <0.001 |

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

### 3.4. Questionnaire Data

Attentional Control Scale (ACS). For each participant, we computed a total score for the ACS as well as subscores for focusing and attentional shifting. None of the three measures correlated significantly with the VR goalkeeper d′. However, the ACS total score correlated significantly with the accuracy for Go Trials in the VR Goalkeeper task, r(99) = 0.24, $p = 0.014$. The focusing score was marginally correlated with the accuracy of Go trials but the shifting score was not, r(99) = 0.20, $p = 0.05$ and r(99) = 0.06, $p = 0.53$, respectively.

Adult ADHD Self-Report Scale (ASRS). We used the data from the ASRS scale to compute scores for inattentiveness (Part A of the scale) and hyperactivity/impulsive behavior (Part B of the scale) for each participant. The inattentiveness score correlated with both the focusing and the shifting scores from the ACS, r(99) = −0.54, $p < 0.001$ and r(99) = 0.39, $p < 0.001$. The hyperactivity/impulsive behavior score correlated significantly only with the focusing score from the ACS, r(99) = −0.23, $p = 0.02$. More importantly for the scope of the present research, no significant correlations were found among the ASRS measures and any of the variables of the VR Goalkeeper task.

## 4. Discussion

The main aim of the present study was to examine the involvement of different attentional processes in a simple VR Goalkeeper task, that of blocking fast-approaching balls. To do so, we asked participants to carry out two established psychological measures, each assessing different attentional processes and correlated their performance to that in the VR Goalkeeper task.

We expected that the orienting network as assessed by the ANT would contribute to successful performance in the VR Goalkeeper task while we made no predictions about alerting and executive control/conflict. Indeed, the results supported our prediction about the orienting network. However, they showed that all three networks of attention contributed to accurate performance in the VR Goalkeeper task. This result is in line with the broader past research documenting the importance of cognitive skills in sports [42–44], and soccer in particular [1,3,45,46], by showing here that responding to fast-approaching balls employs specific aspects of attention. Specifically, as our results show, to carry out the task efficiently participants needed to be alert throughout the task in order to detect as early as possible that the ball is shot, to spatially orient attention quickly towards the ball that was shot from a particular direction, and to decide quickly whether to initiate a move towards the ball or not while exerting cognitive inhibition, that is, while ignoring other distracting information. Moreover, the importance of inhibitory control (i.e., deciding quickly and correctly whether to respond or not) for this goalkeeping task was supported by the significant correlation in accuracy in the VR Goalkeeper task and the more traditional Go/No-Go task (Whack-a-Mole) that we used in the study and which is thought to measure the ability to inhibit a prepotent response.

The contribution of the alerting network to the VR goalkeeping task we used is in line with the findings of [2], who showed that talented soccer players between 8 and 16 years of age outperformed age-matched controls in this measure. Our findings, taken together with those of [2], suggest that alerting might be a fundamental cognitive skill that may contribute to developing elite-level skills in soccer, at least for goalkeepers. Notably, however, the authors of [2] found no differences between the two groups of participants in orienting and conflict scores. Using the same task here (i.e., the ANT task), we found that orienting and executive control/conflict are significant predictors of performance in the VR goalkeeping task. It is, therefore, possible that these two networks of attention (i.e., orienting and executive control) are more relevant to goalkeeping tasks than the tasks carried out by soccer players at other positions. This discrepancy corroborates our conjecture that research should focus on uncovering and disentangling the cognitive skills implicated in each role that is undertaken on the pitch during a soccer game.

Furthermore, the relation between inhibitory control (Whack-a-Mole, a Go/No-Go task) and goalkeeping performance we obtained is also in line with the results of [2], who found that the juvenile talented soccer players had better motor inhibition, measured with a Stop Signal task, than the amateur soccer players. Inhibitory control has been shown to be implicated in other sports (e.g., basketball, baseball, volleyball, and tennis) that require decision making based on stimulus–response relations [47–50]. Thus, here, we demonstrate that inhibitory control is implicated in a blocking-ball task that is essential for goalkeepers in soccer and other sports. Taken together, our results from the ANT and the Whack-a-Mole signify that efficient goalkeeping relies on inhibition at different system levels: cognitive inhibition of interference from other distracting stimuli and motor inhibition of a prepotent response. The VR Goalkeeper task used here made demands at both levels by requiring participants to process the target ball amongst distractor balls of different color or type that caused interference and subsequently to withhold a motor response at non-target balls.

Another notable result from our study is the finding of a negative correlation between acceleration data (measured with speed of movement) and accuracy performance in the VR Goalkeeper task. Intuitively, one would think that a participant (assuming goalkeeping duties) who is capable of carrying out fast movement would be more efficient at blocking a ball that is shot towards his/her goal, but our result suggests that the opposite is the case. Our conjecture for this result is that participants with more advanced cognitive abilities can decide faster on whether to respond or not and as a result are able to react to an approaching ball without needing to carry out sudden movements. In line with this is the finding that the negative correlation between acceleration and accuracy in the VR Goalkeeper task pertained even for correct rejections. That is, even for trials that participants correctly decided not to respond to a distractor (i.e., to a non-target ball), those who made sudden movements did worse in the VR Goalkeeper task. In other words, the participants with efficient goalkeeping skills in our study were able to decide early that they should not respond and therefore refrained from executing any movement. Importantly, this was also corroborated by the correlation findings with the Whack-a-Mole task, as detailed above. On the pitch, a goalkeeper deciding early not to respond unnecessarily to a ball would save physical energy, thus allowing him/her to maintain good performance for the rest of the game. The smooth movements observed for participants with good performance in the VR Goalkeeper task are in fact in line with findings from the motor control literature documenting that hand movements for intercepting objects tend to be minimally jerky [51–53].

Overall, our findings demonstrate the important role of key attentional processes in a goalkeeping task, suggesting that efforts should be placed in training such abilities to potentially improve performance on the pitch. Of course, in a real soccer match other contextual and physiological factors may influence performance further even in the VR task we used here (e.g., reduced visibility due to other players on the pitch, heightened arousal due to the presence of spectators, etc.) and future research should also examine factors others than those studied here.

In the current study, we tested participants that were not expert goalkeepers. As explained in Section 1, we chose to do this as our main interest was to understand the rudimentary attentional mechanisms involved in the given task, without any influences from strategies and other skills that experienced goalkeepers may have developed to carry it out. Of course, a logical next step for future research is to extend this study by including goalkeepers with different levels of experience to determine whether the attentional processes identified here contribute markedly to their efficient performance when experts carry out the task. Yet, our current findings highlight the significance of distinct attentional abilities for intercepting fast-approaching balls efficiently. This suggests that aspiring new goalkeepers may be either evaluated on the level of their attentional skills or focus on improving them through mental training.

That said, new training studies should also examine whether potential benefits from the training of cognitive skills in the lab transfer to the real world (i.e., to goalkeeping performance in the field), by documenting gains in actual player performance. Immersive VR technology may provide the means for designing novel training protocols that simulate more closely the tasks soccer players execute during an actual soccer match (e.g., [10]). For example, the VR environment we used in the current study immersed participants in a realistic soccer pitch in which they could move and act with 6 degrees-of-freedom. Although training basic cognitive skills such as different aspects of attention may not require that the environment and the task used resembles visually the one of interest (i.e., a non-soccer task that taps on alerting may be just as efficient as one that does), immersing participants in a virtual environment has important advantages (see [54] for an overview of benefits and considerations for designing VR tasks).

First, it allows participants to process information in egocentric (self-to-object) coordinates as in the real world, unlike the screen-based tasks that can only be carried out based on allocentric (i.e., object-to-object information) coordinates. That is, in the VR Goalkeeper task we used, a goalkeeper may process information relating to the direction of the ball relative to his/her own body position in space and update that information during the approach of the ball before executing a response. A screen-based version of such task would pose quite different demands. The participant would act as an external observer and rely on the processing of object-to-object relations, e.g., compute and update the spatial relation between two objects in space: the ball and the goalkeeper. Therefore, compared to screen-based tasks, the demands of the immersive VR task are closer to those of actual goalkeeping on the pitch. As a result, using VR, one could reproduce realistic settings in the laboratory to study variables that are difficult to examine on the pitch. For example, the authors of [9] used immersive VR to obtain a detailed analysis of goalkeeper hand movements when responding to curved balls.

Second, unlike screen-based tasks, immersive VR tasks allow the execution of natural movements for responding. In our task, for example, participants blocked the balls by moving their arms towards the ball just like a goalkeeper does in an actual soccer game. The closer correspondence of the response mediums in the laboratory and the real-world tasks reduces the possibility of different cognitive mechanisms recruited by different motor demands (see [55] for a discussion).

Indeed, findings suggesting that the lack of immersion and natural motor responses may alter the nature of a goalkeeping task are provided by an eye-tracking study from [56]. In this study, goalkeepers faced penalty kicks under different conditions that manipulated whether the task was carried out in situ or as a video simulation and whether responding was by interception (i.e., by carrying out dives onto a mat) or other means (by moving a joystick or providing verbal responses). Results showed that, compared to all other combinations, in the in situ interoception condition goalkeepers fixated earlier and for longer on the ball location. This finding suggests that screen-based tasks that entail processing information from an external perspective and responding with button presses may not be ideal for training cognitive skills that underlie performance in fast-paced sports. Instead, immersive VR may represent a more efficient means to that end.

In closing, it should be noted that various details of the experimental procedure could have influenced the results. For example, in the VR Goalkeeper task launchers were placed outside the penalty box but the box itself was not visible. Although we did this to minimize the visual clutter in the scene, the lines of the penalty box could function as a depth cue that could help performance. Past studies in spatial cognition have documented distortions in the perception of distances in VR (e.g., [57]) so perhaps providing an additional depth cue via the penalty box may help participants judge more accurately the egocentric location of the launchers and update more efficiently the locations of the balls that were shot. It is thus possible that performance in the VR Goalkeeper task is better with the addition of further visual information such as the penalty box.

Another potential limitation of the study is that, in addition to soccer balls, the VR Goalkeeper task included volleyballs as distractors. As these types of balls are not encountered by soccer goalkeepers in actual games, this could have compromised the stimulus correspondence of the task [58]. Although we consider it rather unlikely that this threat to stimulus correspondence influenced the performance of our non-goalkeeper participants, whether it makes a difference for professional goalkeepers is an important issue that needs to be clarified in future research.

Finally, another potential limitation of the study is that the tasks were presented in a fixed order for all participants. Although this was done to prevent asymmetric carry-over effects (e.g., fatigue from the physically demanding VR Goalkeeper task to subsequent tasks), the fixed order could have yielded systematic effects of practice and/or fatigue with unknown consequences.

## 5. Conclusions

As a first step, the current findings provide clear evidence that soccer-related VR tasks providing immersion and entailing natural motor responses can indeed capture individual differences in cognitive skills, as assessed by traditional computer-based tasks. The next step is to examine whether such a VR task can be efficiently used to train these skills and benefit performance on the pitch.

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