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Virtual reality promotes greater improvements than video-stimulation screen on perceptual-cognitive skills in young soccer athletes

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(Article begins on next page)

Virtual reality promotes greater improvements than video on visual search behavior

Virtual reality promotes greater improvements than video on decision-making

Virtual reality promotes greater improvements than video on inhibitory control

- 1 Virtual reality promotes greater improvements than video-stimulation screen on perceptual-
- 2 cognitive skills in young soccer athletes

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### Abstract

**Background:** New studies are needed to provide more significant accurate conclusions about the effect of virtual reality (VR) on perceptual-cognitive skills in team sport athletes.

**Purpose:** This study aimed to analyze the chronic effect of VR and video-stimulation screen training on passing decision-making, visual search behavior, and inhibitory control performance in young soccer athletes. **Method:** A total of 26 young soccer players underwent an eight-week training protocol after being randomly assigned to the VR (n=13) or video-screen (VID, n=13) group. Passing decision-making, visual search behavior, and inhibitory control performance were measured before and after both interventions. **Results:** A group x time interaction was found for decision-making performance ( $p < 0.01$ ) and visual search behavior ( $p < 0.01$ ). Both groups improved both decision-making performance ( $p < 0.01$ ) and visual search behavior ( $p < 0.01$ ); however, greater improvements were verified in VR ( $p < 0.01$ ). Both VR and VID improved inhibitory control ( $p < 0.01$ ), but no group interaction effect was observed ( $p > 0.05$ ). **Conclusion:** Our results suggest that VR leads to greater improvements in decision-making and visual search behavior in young soccer athletes than VID.

*Keywords:* Sports psychology, team sports, visual search, brain; cognition.

21 Virtual reality promotes greater improvements than video-stimulation screen on perceptual-  
22 cognitive skills in young soccer athletes

23

24 Soccer demands frequent bouts of high-intensity activity distributed among prolonged  
25 low-intensity periods (Gantois et al., 2019; Smith et al., 2016). In addition, soccer is  
26 cognitively demanding as it requires sustained attention to make quick and accurate decisions  
27 based on retrieval and information processing from a dynamic environment (Fortes, Lima-  
28 Júnior et al., 2020; Smith et al., 2016). These demands suggest that soccer athletes have to  
29 improve their perceptual-cognitive skills to avoid the adverse effects of mental fatigue  
30 throughout training (i.e. during small-sided games) (Trecroci, Boccolini, Duca, Formenti, &  
31 Alberti, 2020) and matches (Gantois et al., 2019) to make winning possible (Vaeyens, Lenoir,  
32 Williams, Mazyn, & Philippaerts, 2007). It is commonly suggested that the better perceptual-  
33 cognitive skills such as decision making, visual search behavior, and inhibitory control are,  
34 the better the soccer players will perform in competitive matches (Gantois et al., 2019; Roca,  
35 Ford, & Memmert, 2019; Vaeyens et al., 2007).

36 Decision-making skill represents the human brain's ability to extract meaningful  
37 contextual information from the visual scene and is essential for high-level performance in  
38 sports (Gantois et al., 2019; Smith et al., 2016). Visual search behavior is part of the  
39 mechanisms underlying decision-making skill (Vaeyens et al., 2007). It is theoretically  
40 assumed that a more efficient visual search strategy is characterized by relatively fewer  
41 fixations of long duration (Vaeyens et al., 2007). Some scientific findings also support that  
42 team sport athletes with better decision-making skill present greater inhibitory control  
43 (Fortes, Lima-Junior et al., 2020; Gantois et al., 2020). Nevertheless, this hypothesis has not  
44 always been supported in the literature. It is important to identify interventions or training

45 programs which can improve visual search strategy and consequently potentialize decision-  
46 making skill in soccer athletes.

47 Previous studies have revealed decision-making performance improvements after an  
48 imagery training program in team sport athletes (Fortes, Freitas-Júnior et al., 2020; Slimani et  
49 al., 2016). Other studies have demonstrated the positive effects of small-sided games (SSG)  
50 on visual search behavior (Davids, Araújo, Correia, & Vilar, 2013; Vaeyens et al., 2007).  
51 Moreover, video-stimulus training has been shown to improve perceptual-cognitive skills in  
52 team sport athletes (Lorains, Ball, & MacMahon, 2013; Pagé, Bernier, & Trempe, 2019). It is  
53 essential to highlight that the Modified Perceptual Training Framework (Hadlow, Panchuk,  
54 Mann, Portus, & Abernethy, 2018) suggests that transfer gains obtained from perceptual-  
55 cognitive training might be predicted based on the similarity degree between the training  
56 modality and the targeted skill. While efforts can be made to increase the stimulus  
57 correspondence of video simulations compared to what is seen in “real life”, a difference in  
58 stimulus/visual correspondence between the two modalities (video vs real life) remains  
59 inevitable. This difference is probably one of the reasons why video simulations using a  
60 TV/computer screen lead to relatively modest levels of immersion in the action (Pagé,  
61 Bernier, & Trempe, 2019). According to the Modified Perceptual Training Framework  
62 (Hadlow et al. 2018), this dissimilarity would decrease the transferability of video simulation  
63 training programs. In this regard, it is noteworthy that “virtual reality” (VR), a visual-based  
64 computer simulation of a real or imaginary environment in which the viewer can interact with  
65 the simulation (Craig, 2013), can increase visual correspondence of the video simulation and  
66 may be able to improve perceptual-cognitive skills, such as passing decision-making, visual  
67 search behavior, and inhibitory control performance in team sport athletes.

68 VR is known as a visual-based computer which simulates a real or imaginary  
69 environment in which the viewer can interact with it (Dunkin, Holmberg, & Sperlich, 2018)

70 and increases the action immersion feeling (Pagé et al., 2019). It is essential to highlight that  
71 there are different VR types, like those regarding virtual environments (Gray, 2017), and 360  
72 video/360 VR/immersive video (i.e. Pagé et al., 2019, Kittel et al., 2019). In the virtual  
73 environment, the subject watches 3D video without any subject-environment interaction  
74 changes. There are an additional three other VR types (360 video/360VR/immersive video)  
75 allowing subject-environment interaction, in which the subject has control over their actions.  
76 Several studies have demonstrated the effectiveness of VR on perceptual-cognitive skill  
77 improvements (Gray, 2017; Miles Pop, Watt, Lawrence, & John, 2012; Pagé et al., 2019;  
78 Kittel, Larkin, Elsworthy, Lindsay & Spittle, 2020). The most recent studies verified  
79 improvements in perceptual-cognitive skills in basketball athletes post four VR experimental  
80 sessions (Pagé et al., 2019). Another recent study revealed improvement in decision-making  
81 skills in soccer athletes submitted to five experimental sessions with VR (Kittel, Larkin,  
82 Elsworthy, Lindsay & Spittle, 2020). Although the VR strategy seems to be promising to  
83 improve perceptual-cognitive skills in team sport athletes, the recent studies regarding this  
84 field have presented limitations such as: a) a reduced sample size in the experimental group  
85 (Pagé et al., 2019) and b) a short-term intervention (Kittel et al., 2020; Panchuk Klusemann,  
86 & Hadlow, 2018). These limitations mean that the findings cannot be generalized and new  
87 studies are needed to provide more significant accurate conclusions about the effect of VR on  
88 perceptual-cognitive skills in team sport athletes.

89         As a main practical point, this study might indicate if perceptual-cognitive skills (e.g.,  
90 passing decision-making, visual search behavior, and inhibitory control) are improved when  
91 team sport athletes are chronically submitted to a VR or video-stimulation just before the  
92 training sessions. Thus, this study aimed to analyze the short-term effect of VR and video-  
93 stimulation screen training on passing decision-making, visual search behavior, and  
94 inhibitory control performance in young soccer players. Based on previous studies (Dunkin et

95 al., 2018; Pagé et al., 2019), we hypothesize that VR would promote greater improvements in  
96 passing decision-making, visual search behavior, and inhibitory control than video-  
97 stimulation screen training in young soccer athletes.

98

99

## Materials and Methods

### 100 *Participants*

101 We estimated the sample size using the GPower v.3.1 with the power set at 0.80,  $\alpha =$   
102 0.05, and an effect size of 0.50 for passing decision-making performance in the experimental  
103 design of parallel groups (Pagé et al., 2019). The results indicated that twenty subjects were  
104 necessary for the study. By considering eventual losses and dropouts, 30% more volunteers  
105 were added to the first twenty volunteers, which resulted in a total of twenty-six volunteers  
106 needed for the study. The non-probabilistic method was adopted for sample recruitment. The  
107 recruited volunteers were about 15-16 years old ( $M = 15.4$ ,  $SD = 0.3$ ), at the national level,  
108 and had been playing soccer on average for 5.0 years ( $SD = 1.2$ ). They were randomly divided  
109 into two equal groups, hereafter named as the Virtual reality (VR) and Video screen (VID)  
110 groups. All experimental sessions were conducted in-season; therefore, the study was  
111 performed throughout the weekly training (i.e. three times per week). This study was  
112 approved by the local Ethics committee, the consent form was obtained from the volunteers,  
113 and the principles of the Helsinki Declaration were observed throughout the study.

114

### 115 *Experimental design*

116 This is an experimental and randomized study with parallel groups. The young male  
117 soccer athletes underwent an eight-week intervention (1<sup>st</sup> week - baseline assessment; 2<sup>nd</sup>-6<sup>th</sup>  
118 weeks - experimental sessions [three sessions per week]; and 7<sup>th</sup> week - post-experiment  
119 assessment) (Figure 1). Each volunteer performed 18 experimental sessions (VR or VID) plus



120 30 training sessions which involved physical, technical, and tactical skills. The athletes were  
121 pair-matched according to decision-making performance (pass) and randomized into two  
122 groups: VR (n = 13) and VID (n = 13).

123 Passing decision-making, visual search behavior (number of fixations and fixations  
124 duration time), and inhibitory control performance (accuracy and response time) were  
125 measured before (baseline) and after (post-experiment) the six-week intervention. An interval  
126 of 24-48 h was adopted between each test in both baseline and post-experiment  
127 measurements.

128 For the passing decision-making and visual search behavior analyses, the athletes  
129 were organized into two small-sided games (SSG) with different setups (5 vs. 5 and 3 vs. 3  
130 with goalkeeper), adopting the official rules of soccer. A CANON® camera (SX60 model,  
131 Yokohama, Japan) was used in the passing decision-making analysis, and a head-mounted  
132 eye-tracking device was used to analyze visual search behavior.

133 All experimental procedures are illustrated in Figure 1. The participants were asked to  
134 avoid any physical exercise or alcohol ingestion 24-h before testing during the whole eight-  
135 week experiment, as well as to refrain from consuming caffeine at least 3-h before each  
136 training session.

137

138 **\*\*\*Figure 1 here\*\*\***

139

#### 140 *Interventions*

141 *VR and VID.* Videos for the VR and VID training sessions were custom-made for this study  
142 and acquired using a GoPro Hero 3. The GoPro Hero 3 captured 123° horizontal and 94°  
143 vertical images. VR group videos were edited on Final Cut Pro (Apple Inc.), while iMovie  
144 (Appel Inc.) was used to edit VID group videos. Participants enrolled in the VR group

145 watched the VR videos in a Utopia 360 Head Mounted Display (HMD) equipped with an  
146 LG3 smartphone (LG Electronics), while an iMac desktop computer (iMac14.1, 21.5-inch)  
147 was used to present the videos from the VID group. The HMD presented the original scene  
148 110° horizontally and 100° vertically (with both components being adjusted in real-time  
149 based on the orientation in the participant's head), while the computer screen displayed the  
150 entire field of view recorded with the GoPro Hero 3.

151 Before the training session the participants were asked to watch custom-made videos  
152 from a first-person perspective, including nine actors (four as teammates and five as  
153 opponents) performing pre-determined variations of two distinct offensive patterns related to  
154 a soccer game. Thus, from an observer's point of view, the perspective of the images  
155 captured by the camera was identical, and the same players were presented to the participants  
156 in both VR and VID groups. The video clips lasted an average of 10.2 seconds (SD = 0.4),  
157 and a total of 160 different video clips were recorded.

158 Participants of the VR and VID groups watched 20 video clips during each  
159 experimental session, which represents 60 video clips weekly. From the 160 video clips  
160 recorded, 100 were presented three times during the experiment, while 60 video clips were  
161 performed only once. The order of these video clips was randomized; however, once the  
162 video clip order was chosen, the same video clip was presented for all participants.  
163 Individuals from both experimental groups (VR and VID) were placed in different rooms  
164 while using the HMD or watching the video. The participants were instructed not to talk to  
165 each other during the intervention.

166

### 167 *Small-sided games*

168 Passing decision-making and visual search assessments were obtained during  
169 standardized SSGs before and after the intervention period. SSGs consisted of a standard 5

170 vs. 5 and 3 vs. 3 soccer matches on a 40 m x 30 m (for both SSG configurations) interior turf  
171 soccer field to avoid weather influence. The teams were composed of five (5vs5) or three  
172 (3vs3) players each, including a goalkeeper. Each player took part in four halves of 5 min in  
173 matches lasting 20 min; a 3-minute rest interval was adopted between each half in both SSG  
174 setups (5 vs 5 and 3 vs 3). Players who were waiting for the next game to start kept  
175 themselves warmed up by stretching or practicing with the ball. The SSG was recorded using  
176 two video cameras (Canon SX60, Japan). Cameras were positioned in the bleachers of the  
177 stadium, approximately 10 m above the playfield, to cover the entire playing area. Jerseys  
178 and numbers identified the players, and the video recordings were analyzed using Dartfish  
179 Connect v6.0.

180

#### 181 *Variable measurements*

182 *Passing decision making-performance.* The passing decision-making ability during SSG was  
183 coded using standardized coding criteria adapted from a previous study (Romeas, Guldner, &  
184 Faubert, 2016). The decision component involves skill selection (i.e. passing), as well as  
185 which teammate received the pass. The quality of each decision was coded as 1 for an  
186 appropriate decision and 0 for an inappropriate decision according to the following criteria:  
187 1) for the one-point decision, the player made the right decision when the pass went to a free  
188 (i.e. unmarked) teammate and: a) directly or indirectly created a shot attempt; or b) passed  
189 the ball to a teammate who was in a better position than himself; 2) for the zero-point  
190 decision, the player made a poor decision related to the pass because: a) he passed the ball to  
191 a player who was closely guarded or when there was a defensive player positioned in the  
192 passing lane; or b) the pass was intercepted or turned over; or c) the pass was directed to an  
193 area where no teammate was positioned; or d) he kicked the ball out of the playing field.  
194 Decisions which were not appropriate or inappropriate were not coded. Decision-making

195 coding was assessed by two experienced soccer coaches blinded to the experiment and  
196 trained to use the instrument for coding. Next, the total score of each player by session was  
197 converted to a percentage for analysis. Percentage accuracy values were established for each  
198 participant by dividing the number of points awarded by the total amount available and then  
199 multiplying by 100. The intraclass coefficient correlation (ICC) was used to determine the  
200 reliability of passing decision-making accuracy at baseline (ICC = 0.82, CI<sub>95%</sub> = 0.77 to 0.86)  
201 and post-experiment (ICC = 0.79, CI<sub>95%</sub> = 0.74 to 0.85).

202

203 *Visual search behavior.* The visual search behavior data was measured using a portable Eye  
204 Tracking-XG (Applied Science Laboratories, USA) device with a sampling frequency of 60  
205 Hz. A second camera with a frequency of 25 Hz attached to the eye-tracking-XG glasses  
206 worked as the footage of the game scenario. Data from both cameras were combined using  
207 the Gaze Tracker software program (Applied Science Laboratories, USA). Visual search data  
208 were analyzed frame-by-frame using video software (Kinovea open source project,  
209 [www.kinovea.org](http://www.kinovea.org)). The number and duration of the fixations were obtained to examine  
210 visual search behavior during SSGs (5 vs 5 and 3 vs 3). A total of 55,536 trials (28,690 trials  
211 for SSG 5 vs. 5 and 26,846 trials for SSG 3 vs. 3) were coded of the maximum 64,400  
212 possible. However, 8,084 trials were not included due to technical difficulties with the eye  
213 tracker and/or camera during data collection. Next, the recorded values were averaged across  
214 all trials for each participant. A fixation was defined as the time when the individual's gaze  
215 remained stationary at a specific location for a minimum of 100 ms or four video frames and  
216 within a 3° visual angle (or less). So, the number of fixations was the sum of all fixations  
217 during the experiment. In addition, the duration of the fixations was defined as the mean  
218 duration of all fixations higher than 100 ms observed during the experiment.

219

220 *Inhibitory control.* The Stroop task (Graf, Uttl, & Tuokko, 1995) was used to assess the  
221 inhibitory control and selective attention. Both are considered components of cognitive  
222 function. The task requires the participants to read the written color names of the words  
223 independently of the typed color (for example, they would have to read red even if the color  
224 in the font was blue). However, a mismatch between the name of the color and the printed  
225 color is commonly set up, which may cause a delay in the reaction time. A 50-words stimulus  
226 was applied, and 200ms-intervals were provided between the response and a new stimulus.

227         Moreover, the stimulus did not fade out from the screen until any response was given.  
228 Stimuli vary between congruent (word and color have the same meaning), incongruent (word  
229 and color have a different meaning), and control (colored rectangle with one of the colors of  
230 the test: red, green, blue, and black). The keys D (red), F (green), J (blue), and K (black) were  
231 pressed to answer the questions. The stimulus disappeared when the answer was correct, and  
232 then a new one was set. An X showed up on the screen in case of incorrect answers, and a  
233 new stimulus showed up. These same procedures have been used in other studies (Diamond,  
234 2013; Gantois et al., 2019). Furthermore, the participants of the present study were familiar  
235 with these procedures of Stroop Task. The accuracy of the correct answers and response time  
236 were collected at the end of the test, and the evaluator was blind for the assessments and had  
237 previous training for the test. The tests were performed on a full-HD screen (1800 × 1260  
238 pixels) laptop (MacBook Pro, A1502 model, USA). The intra-class coefficient correlation  
239 (ICC) and coefficient of variation (CV) were used to determine the reliability of accuracy  
240 (ICC = 0.96, CV = 3.5%) and response time (ICC = 0.93, CV = 5.4%) at baseline and post-  
241 experiment [accuracy (ICC = 0.94, CV = 3.2%) and response time (ICC = 0.95, CV = 5.7%)].

242

243 *Statistical analysis*

244 The Shapiro Wilk test was conducted to evaluate data distribution. The Levene test  
245 assessed homoscedasticity. Two-way mixed ANOVA of repeated measures was used to  
246 analyze the group (VR vs. VID) vs. time (baseline-vs post-experiment) interaction for passing  
247 decision-making, visual search behavior (number of fixations, and fixation duration) and  
248 inhibitory control (accuracy and response time) performance. The effect size (ES) was  
249 indicated by the partial eta square ( $\eta p^2$ ). Based on Cohen (1992) criteria, the following  
250 classifications were adopted:  $\eta p^2 < 0.03$  = small;  $0.03 \leq \eta p^2 < 0.10$  = moderate;  $0.10 \leq \eta p^2 <$   
251  $0.20$  = large, and  $\eta p^2 \geq 0.20$  = very large effect size. Data were processed in the GraphPad  
252 Prism Software Version 8.0 program (California Corporation<sup>®</sup>, USA), and a significance  
253 level of 5% was adopted.

254

## 255 Results

### 256 *Passing decision-making performance*

257 A group x time interaction was found for passing decision-making performance in  
258 SSG 5vs5 (Figure 2A;  $F_{(1, 24)} = 5.04$ ;  $p = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.03];  $\eta p^2 = 0.05$  [CI<sub>95%</sub> = 0.03  
259 to 0.06]; ES moderate). The findings also presented group ( $F_{(1, 24)} = 26.68$ ;  $p = 0.001$  [CI<sub>95%</sub> =  
260 0.001 to 0.01];  $\eta p^2 = 0.03$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES moderate) and time ( $F_{(1, 24)} = 14.75$ ;  $p =$   
261 0.001 [CI<sub>95%</sub> = 0.001 to 0.02];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small) effects, where  
262 both groups improved the passing decision-making performance in SSG 5vs5 ( $p < 0.05$ ) with  
263 greater improvements observed in the VR group ( $p < 0.05$ ).

264 A group x time interaction for passing decision-making performance in SSG 3vs3  
265 (Figure 2B;  $F_{(1, 24)} = 7.07$ ;  $p = 0.01$  [CI<sub>95%</sub> = 0.003 to 0.02];  $\eta p^2 = 0.04$  [CI<sub>95%</sub> = 0.02 to 0.06];  
266 ES moderate). The findings also showed group ( $F_{(1, 24)} = 36.86$ ;  $p = 0.001$  [CI<sub>95%</sub> = 0.001 to  
267 0.02];  $\eta p^2 = 0.03$  [CI<sub>95%</sub> = 0.02 to 0.05]; ES moderate) and time ( $F_{(1, 24)} = 24.19$ ;  $p = 0.001$   
268 [CI<sub>95%</sub> = 0.001 to 0.03];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small) effects. Although

269 improvements were verified in both groups, the passing decision-making performance in SSG  
270 3vs3 ( $p < 0.05$ ) was greater in the VR group ( $p < 0.05$ ).

271

272 **\*\*\*Figure 2 here\*\*\***

273

274 *Visual search behavior*

275 *Number of fixations.* A group x time interaction was verified for the number of fixations in  
276 SSG 5vs5 (Figure 3A;  $F_{(1, 24)} = 4.26$ ;  $p = 0.04$  [CI<sub>95%</sub> = 0.02 to 0.05];  $\eta p^2 = 0.05$  [CI<sub>95%</sub> = 0.03  
277 to 0.07]; ES moderate). The findings also showed group ( $F_{(1, 24)} = 55.81$ ;  $p = 0.001$  [CI<sub>95%</sub> =  
278 0.001 to 0.03];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small) and time ( $F_{(1, 24)} = 17.76$ ;  $p =$   
279 0.001 [CI<sub>95%</sub> = 0.001 to 0.004];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.05]; ES small) effects for the  
280 number of fixations in SSG 5vs5. Both groups increased the number of fixations ( $p < 0.05$ )  
281 with a greater increase observed in the VR group ( $p < 0.05$ ).

282 A group x time interaction was found for number of fixations in SSG 3vs3 (Figure  
283 3B;  $F_{(1, 24)} = 7.26$ ;  $p = 0.01$  [CI<sub>95%</sub> = 0.002 to 0.03];  $\eta p^2 = 0.04$  [CI<sub>95%</sub> = 0.02 to 0.06]; ES  
284 moderate). The findings also revealed group ( $F_{(1, 24)} = 62.67$ ;  $p = 0.001$  [CI<sub>95%</sub> = 0.001 to  
285 0.01];  $\eta p^2 = 0.03$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES moderate) and time ( $F_{(1, 24)} = 29.04$ ;  $p = 0.001$   
286 [CI<sub>95%</sub> = 0.001 to 0.004];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.03]; ES small) effects, where both  
287 groups increased the number of fixations ( $p < 0.05$ ) with a greater increase in the VR group  
288 ( $p < 0.05$ ).

289

290 *Fixations duration.* A group x time interaction was observed for fixation duration in SSG  
291 5vs5 (Figure 3C;  $F_{(1, 24)} = 4.13$ ;  $p = 0.04$  [CI<sub>95%</sub> = 0.03 to 0.06];  $\eta p^2 = 0.03$  [CI<sub>95%</sub> = 0.01 to  
292 0.05]; ES moderate). Furthermore, group ( $F_{(1, 24)} = 15.10$ ;  $p = 0.01$  [CI<sub>95%</sub> = 0.003 to 0.02];  
293  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small) and time ( $F_{(1, 24)} = 13.38$ ;  $p = 0.01$  [CI<sub>95%</sub> = 0.004

294 to 0.03];  $\eta p^2 = 0.03$  [CI<sub>95%</sub> = 0.02 to 0.06]; ES moderate) effects were observed for fixation  
295 duration in SSG 5vs5. Both groups attenuated the fixation duration in SSG 5vs5 ( $p < 0.05$ ),  
296 with a greater reduction in the VR group ( $p < 0.05$ ).

297 A group x time interaction was found for fixation duration in SSG 3vs3 (Figure 3D;  
298  $F_{(1, 24)} = 7.26$ ;  $p = 0.01$  [CI<sub>95%</sub> = 0.003 to 0.04];  $\eta p^2 = 0.05$  [CI<sub>95%</sub> = 0.02 to 0.07]; ES  
299 moderate), followed by group ( $F_{(1, 24)} = 67.09$ ;  $p = 0.001$  [CI<sub>95%</sub> = 0.001 to 0.003];  $\eta p^2 = 0.03$   
300 [CI<sub>95%</sub> = 0.01 to 0.04]; ES moderate) and time ( $F_{(1, 24)} = 29.04$ ;  $p = 0.001$  [CI<sub>95%</sub> = 0.001 to  
301 0.01];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small) effects for fixation duration in SSG 3vs3.  
302 Both groups attenuated the fixation duration in SSG 3vs3 ( $p < 0.05$ ), however, the VR group  
303 presented a greater reduction ( $p < 0.05$ ).

304

305 **\*\*\*Figure 3 here\*\*\***

306

307 *Inhibitory control*

308 No group x time interaction for accuracy was observed (Figure 4A;  $F_{(1, 24)} = 0.23$ ;  $p =$   
309 0.63 [CI<sub>95%</sub> = 0.50 to 0.72];  $\eta p^2 = 0.04$  [CI<sub>95%</sub> = 0.02 to 0.05]; ES moderate). Although the  
310 findings presented no group effect ( $F_{(1, 24)} = 0.05$ ;  $p = 0.80$  [CI<sub>95%</sub> = 0.61 to 0.84];  $\eta p^2 = 0.01$   
311 [CI<sub>95%</sub> = 0.004 to 0.03]; ES small), a time effect was verified for accuracy ( $F_{(1, 24)} = 5.76$ ;  $p =$   
312 0.02 [CI<sub>95%</sub> = 0.01 to 0.04];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small). Both groups  
313 improved the accuracy ( $p < 0.05$ ) with no difference between them ( $p > 0.05$ ).

314 A group x time interaction was not found for response time (Figure 4B;  $F_{(1, 24)} = 2.46$ ;  
315  $p = 0.12$  [CI<sub>95%</sub> = 0.07 to 0.18];  $\eta p^2 = 0.03$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES moderate). The findings  
316 did not present a group effect ( $F_{(1, 24)} = 0.83$ ;  $p = 0.86$  [CI<sub>95%</sub> = 0.71 to 0.95];  $\eta p^2 = 0.01$   
317 [CI<sub>95%</sub> = 0.003 to 0.02]; ES small), despite indicating a time effect ( $F_{(1, 24)} = 16.87$ ;  $p = 0.01$   
318 [CI<sub>95%</sub> = 0.003 to 0.04];  $\eta p^2 = 0.02$  [CI<sub>95%</sub> = 0.01 to 0.04]; ES small) for response time.



319 Additionally, both groups improved the response time ( $p < 0.05$ ) with no difference between  
320 them ( $p > 0.05$ ).

321

322 **\*\*\*Figure 4 here\*\*\***

323

### 324 **Discussion**

325 This study aimed to analyze the short-term effects of VR and video-stimulation screen  
326 training on passing decision-making, visual search behavior, and inhibitory control  
327 performance in young soccer players. The main findings revealed greater improvements in  
328 passing decision-making skill and visual search behavior for athletes submitted to VR than  
329 VID, however, no group interaction effect was observed for inhibition control. Our  
330 hypothesis was partially confirmed.

331 Decision-making skill improvements as a result of the video-stimulation training  
332 observed in the present study can take place in a real-life context and adds relevant content to  
333 previous studies (Broadbent, Causer, Williams, & Ford, 2015; Gray, 2019). The VR group  
334 led to greater improvement in passing decision-making performance than the video-  
335 stimulation intervention, even watching similar training videos; these findings corroborate a  
336 previous study conducted by Kittel et al. (2020) assessing soccer athletes. Interestingly, a  
337 recent study assessed basketball players and also verified greater decision-making skills  
338 improvements after VR intervention compared to VID stimulation (Pagé et al., 2019);  
339 however, it appears that the number of offensive and defensive players may equally affect  
340 passing decision-making performance post-VR or post-VID intervention, since the results  
341 were similar for 5vs5 and 3vs3 SSG.

342 The better performance in passing decision-making observed in the VR group  
343 compared to VID stimulus is aligned with the Modified Perceptual Training Framework

344 (Hadlow et al., 2018), which suggests that transfer gains resulting from a perceptual-  
345 cognitive training can be predicted based on similarity degree between the training modality  
346 and the targeted skill. Both the VID and VR modalities targeted the same perceptual  
347 functions (e.g., anticipation and decision-making skills) and involved the same response  
348 correspondence in order to compare them. However, the videos presented in the VR headset  
349 looked closer to what would be perceived on a real soccer field and were thus more  
350 immersive. It seems that the immersion level can be a key factor leading to transferable gains  
351 of perceptual-cognitive skills (Brault, Kulpa, Duliscouët, Marin, & Bideau, 2015; Gokeler et  
352 al., 2016). It is also noteworthy that videos in the VR group were presented using a head-  
353 mounted display which was responsive to the head movements. This adjustment enabled  
354 more coupling between the participant's actions and acquiring visual information compared  
355 to the VID intervention, which provides the visual flow perception (Gray, 2019). When  
356 together, these two elements increased the sport-specificity of the stimulus correspondence  
357 (Hadlow et al., 2018).

358         Regarding visual search behavior, the results revealed an increased fixation number  
359 and a reduced fixation duration in both experimental groups. However, the VR group  
360 presented a more significant increase and reduced fixation number and duration, respectively,  
361 than the VID group. The VR group participants employed a different search strategy  
362 comprising a higher number of fixations of shorter duration and directed towards more  
363 suitable locations in the environment. The scientific literature has been indicating that more  
364 skilled soccer players usually show a higher number of fixations and lower fixation duration  
365 (i.e., fixation duration higher 100 ms) when compared to less skilled ones (Roca et al., 2018;  
366 Vaeyens et al., 2007). Therefore, although the video-stimulation screen can potentialize  
367 visual search behavior in young soccer athletes, it is essential to highlight that the VR showed  
368 greater efficiency. Our results suggest that VR can develop attentional focus, which has been

369 shown to facilitate the emergence of skilled decision-making (Roca et al., 2018). Also, the  
370 results for visual search behavior data showed that players in the VR group could detect a  
371 greater number of teammates in positions which might lead to a goal-scoring opportunity if  
372 they received the ball.

373         In considering inhibitory control, the findings showed improvement in accuracy and  
374 response time for both VR and VID groups, without in-between differences. Our results  
375 suggest that both training strategies (i.e. video-stimulation screen and VR) were efficient in  
376 improving inhibitory control performance in young soccer athletes. Inhibitory control is an  
377 executive function which inhibits consistently irrelevant stimulation attention focus  
378 (Diamond, 2013). Thus, soccer players with higher inhibitory control performance employ a  
379 broader attention focus on more relevant stimuli, which facilitates the emergence of skilled  
380 creative behavior (Roca et al., 2018). According to Friedman, Fishbach, Forster, and Werth  
381 (2003), cognitive inhibition limits the stimuli number and relevant information which can be  
382 acquired and processed, providing game-relevant details to the players.

383         The present data presents relevant implications for coaches and those involved in  
384 developing perceptual training programs. The strengths of the study are the ecological  
385 validity (i.e. experimental design close to what happens in sport training centers) and  
386 originality (i.e. it is the first study to analyze the chronic effect of VR on visual search  
387 behavior in athletes). Although the present study revealed impressive results which might add  
388 information to the scientific literature, it presents some limitations such as the impossibility  
389 of blinding group allocation and treatment. Also, it was not possible to use an  
390 electroencephalogram to analyze brainwaves (i.e. alpha and theta) during VR and VID  
391 interventions. Therefore, the results should be interpreted cautiously, and future research  
392 should investigate the chronic effects of VR strategy on perceptual-cognitive skills in team  
393 sport athletes and measure brain waves.

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**Conclusion**

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In conclusion, our results support the effectiveness of using video simulations to improve decision-making skills, visual search behavior, and inhibitory control in athletes and confirm the value of this training modality. In addition, the greater gains obtained post-VR simulation is a very appealing strategy to further optimize the development of percept-cognitive skills in young soccer athletes.

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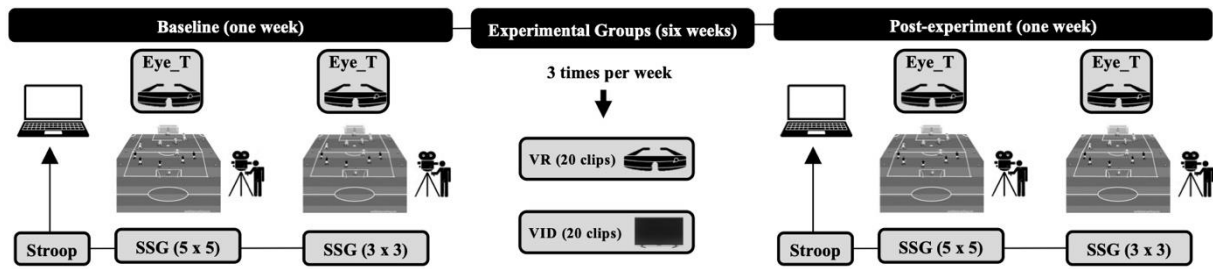
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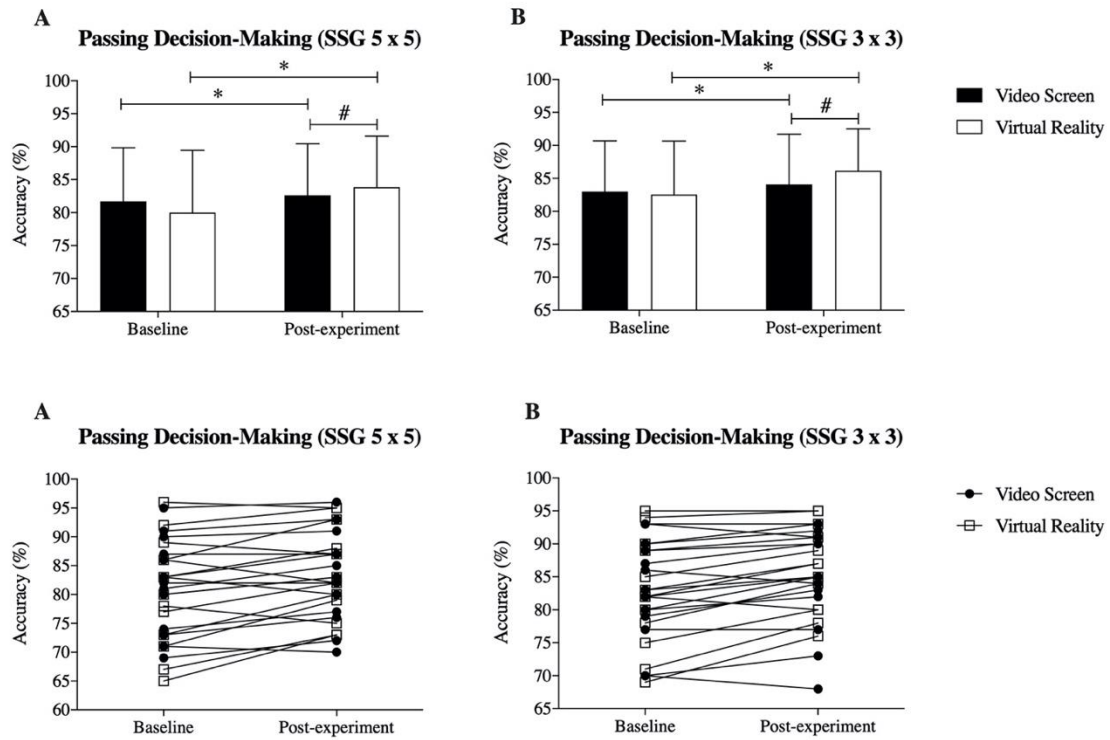


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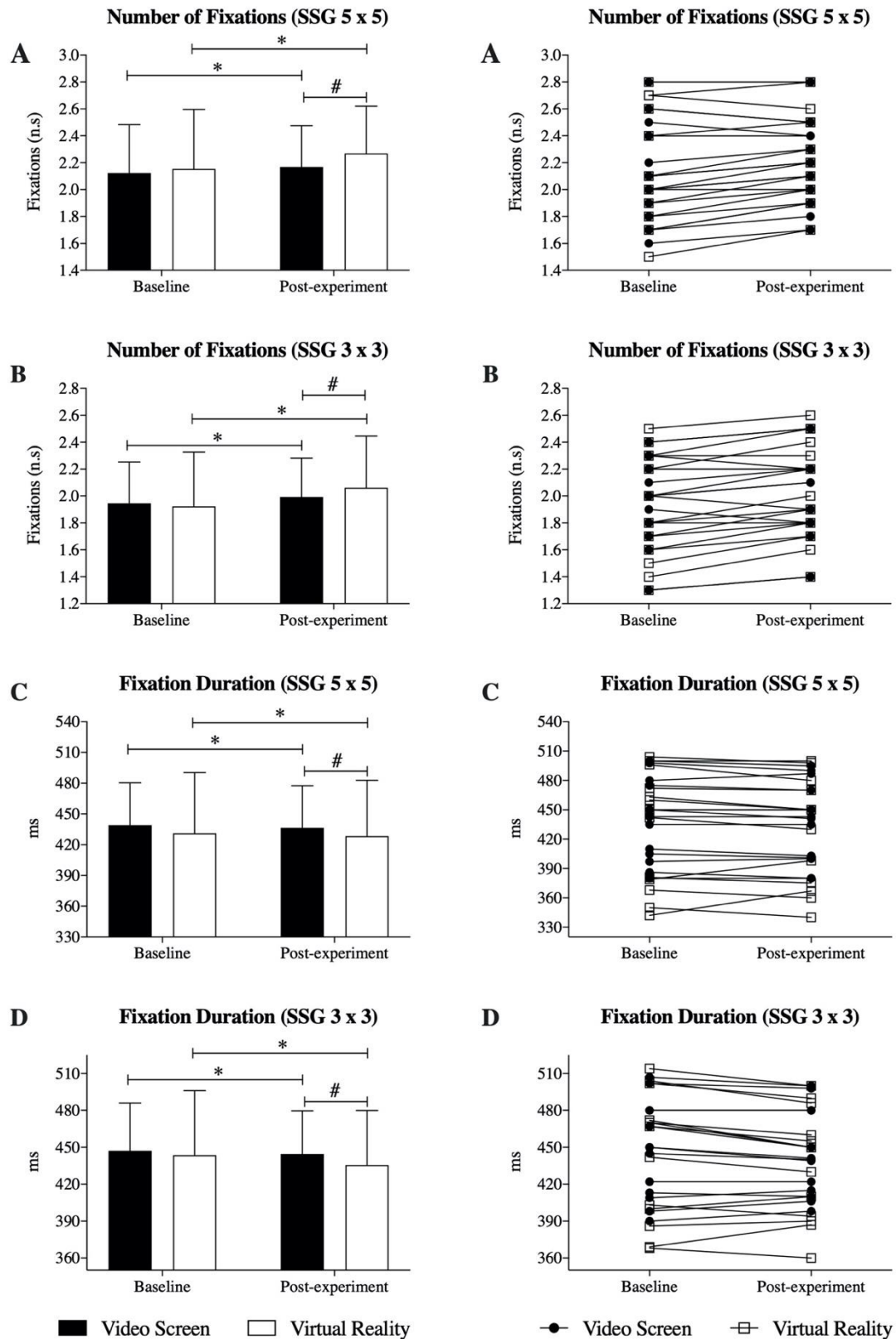
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Figure 1  
*Experimental design of the study*  
Note. SSG = small-sided game; Eye\_T = Eye-tracker; VR = virtual reality; VID = video screen.



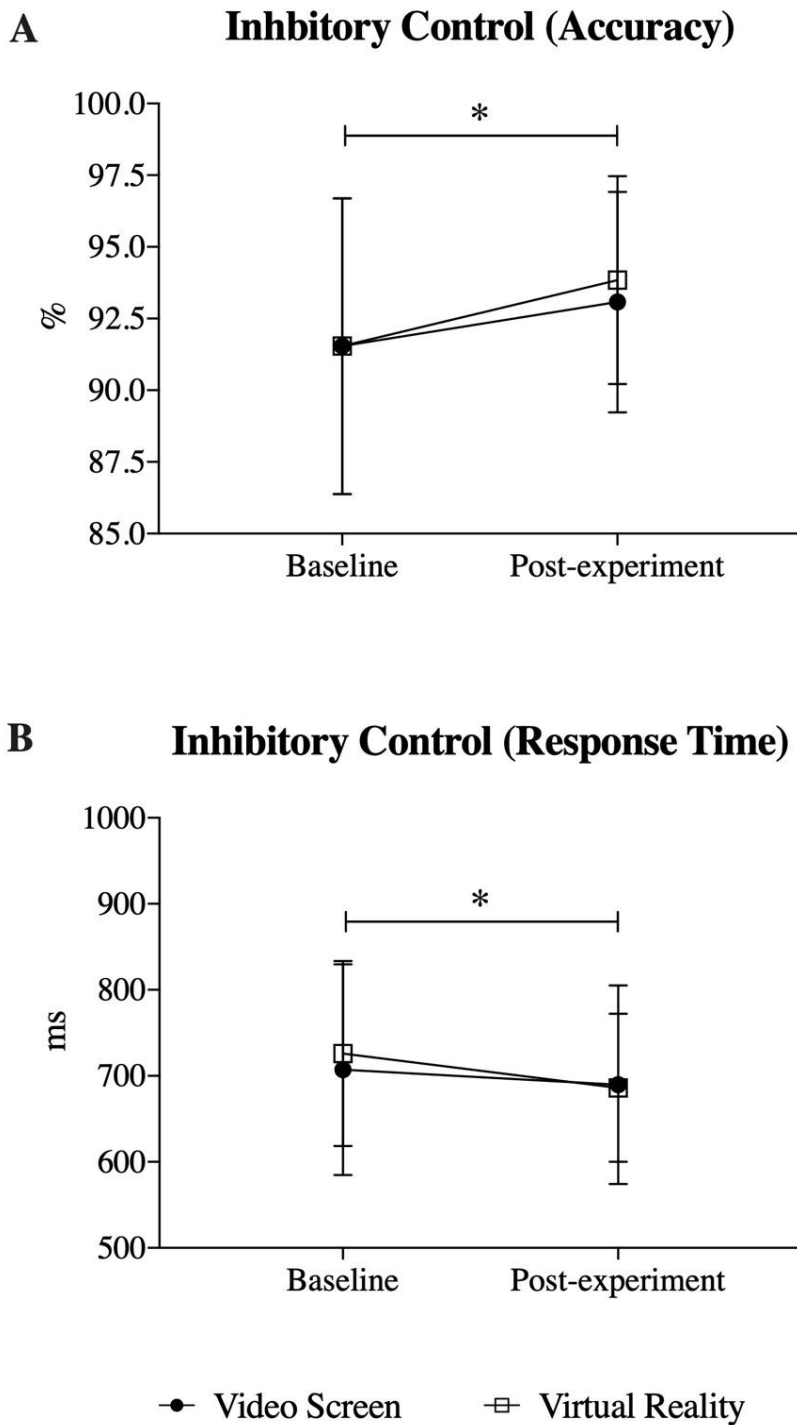
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Figure 2  
 Passing decision-making performance in small-sided game 5vs5 (A) and 3vs3 (B) according to the experimental group (VR and VID) in young soccer athletes.  
 Note. \*difference pre-vs post-experiment intra-group ( $p < 0.05$ ); #difference between groups in post-experiment ( $p < 0.05$ ).



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Figure 3  
 Number of fixations in small-sided game 5vs5 (A) and 3vs3 (B) and fixation duration in small-sided game 5vs5 (C) and 3vs3 (D) according to the experimental group (VR and VID) in young soccer athletes.  
 Note. \*difference pre-vs post-experiment intra-group ( $p < 0.05$ ); #difference between groups in post-experiment ( $p < 0.05$ ).



507 Figure 4  
 508 Accuracy (A) and response time (B) of inhibitory control according to the experimental group (VR and VID) in  
 509 young soccer athletes.  
 510 Note. \*difference pre-vs post-experiment intra-group ( $p < 0.05$ ).  
 511

1 Virtual reality promotes greater improvements than video-stimulation screen on perceptual-  
2 cognitive skills in young soccer athletes

3

4 **Conflicts of interest:** none