Immersive screens change attention width but not perception or decision-making performance in natural and basic tasks

Abstract

In the last decades, a number of studies have examined people's perceptual and attentional capabilities using flat screen displays. The completion of studies using curved displays/screens has been neglected so far, despite their advantage of creating a more immersive and life-like experience. In two studies, we analysed possible performance differences between subjects' perceptual and attentional capabilities during a decision-making task whilst viewing life-size stimuli on large flat and curved immersive screens. In Study 1, participants performed an attention-demanding shape discrimination task. In Study 2, participants performed a more naturalistic football-specific discrimination task. Results of both studies revealed no differences in perception and decision making between screen conditions, but that attention can be directed across greater visual angles on immersive screens compared to flat screens. The findings suggest that attention can be directed across a larger visual angle on curved screens compared to flat screens probably because curved screens distort the image less than flat screens. This study has implications for the use of flat screens in studies that examine perceptual and attentional capabilities in the visual periphery.

Keywords: attentional distortions; focus of attention; football discrimination task

1. Introduction

Advances in technology have led to the availability of various visual display and presentation forms. For presenting as much information as possible, convex curved displays are a suitable option. An example of such a display is an interactive advertising pillar. In contrast to conventional planar and rectangular displays, such a curved display encouraged users to investigate all sides of the display and explore all of the content covered by the construction. It also allows for interactions from all sides and for interactions by several users at the same time (Lin et al., 2009). Besides such convex curved displays, also concave curved displays exist, which can be used in a variety of situations, as for example, in driving simulators or in sport.

Over the last decade, there has been a shift in research designs towards a more ecological approach offering greater potential to generalize the result to the natural environment. Mostly, researchers using this approach have focused on employing realistic movements and behaviours in natural environments, while the investigation of different methods of displaying visual information to participants has largely been neglected so far. Consequently, the current study analysed differences in perceptual and attentional performance depending on different screen surfaces (flat vs. convexly bent to the observer) in two experiments.

In recent years, researchers, particularly in the work environment, have focused their attention on exploring optimal ergonomic conditions of a curved display based on the users' subjective judgments (e.g., Choi et al., 2015). Among others, Häkkinen, Pölönen, Salmimaa, and Hantanen (2008) investigated reading experiences on a curved paper-like display and measured the subjective reading experience depending on different curvature magnitudes and directions. Results revealed that reading a text on a curved surface is easier when the curvature direction is perpendicular to the text direction. The authors found that curvature along the horizontal axis (perpendicular to the direction of the text) was associated with better reading experience, than on displays with curvature along the vertical axis (along the text direction). This indicated that the adaptation to changes in depth is more difficult to implement along sentences than between the lines of a text. Shupp, Andrews, Dickey-Kurdziolek, Yost, and North (2009) evaluated the task efficiency that can be achieved using multiple monitor interfaces. Results showed an enhancement of the task performance for curved arrangements of multiple displays in comparison to flat interfaces. This result was explained by the fact that curved displays compensate for the image distortion caused by the difference between the distances from the viewer to the screen centre and to the screen edge.

Other than research into reading, no scientific investigation has been conducted regarding the differences between flat and curved surfaces of displays. The preservation of the visual image in different presentation surfaces could have implications for different research areas, particularly in perception and attention research. Flat screens are the most common type of screens, for example in the form of televisions. However, there are some benefits of curved screens (cf. Jeong, Han, Na, & Suk, 2017). Curved screens create a greater sense of immersion and reduce distracting reflections. In two studies, we investigated how a curved screen affects the visual attentional focus and the probability of perceiving stimuli in the visual periphery.

Previous research studies have investigated the differences between concave, convex, and flat displays only for small screen sizes, such as handheld displays or smaller screens used for desk-based working processes (Mustonen, Kimmel, Hakala, & Häkkinen, 2015). However, it is questionable to what extent these findings are transferable to greater domes that are used in different research areas to conduct studies closely resembling image sizes seen in reality. In research studies in sports, there is the requirement for ecological validity and representative designs of experimental paradigms (Dicks, Davids, & Button, 2009). Researchers are encouraged to increase the ecological validity of research designs to maximize the transferability of findings from laboratory settings to performance environments, such as in sports (Brunswik, 1956). The term representative design refers to the composition of experimental task constraints and controls, matching those in the behavioural setting to which the results are intended to be generalized to (Araujó, Davids, & Passos, 2007). Representative designs in sports should, in part, allow for adequate sampling of informational variables from the sport-specific environment (Pinder et al., 2011). Large immersive concave screens preserve the need for a broad attentional focus that is required for many decision-making tasks in sport (Hüttermann & Memmert, 2017).

In two studies, we investigated the extent to which people's decision making is dependent on the presentation surface. Since previous research has shown that a curved monitor causes proportionally less image distortion at the edges than a flat monitor, we expected that participants would perceive stimuli in the visual periphery over a wider breadth of attention on a convexly curved screen, compared to a flat screen. We also assumed that the shape of an image would appear closer to its natural geometric structure towards the edge of the screen when displayed on a curved screen. In Study 1, this prediction was tested in a general attentional task (cf. Hüttermann, Memmert, Simons, & Bock, 2013) with neutral stimuli (triangles and circles). In Study 2, more natural stimuli were used (cf. Hüttermann, Smeeton, Ford, & Williams, 2019); here the attentional differences between presentations on flat and curved screens were examined for football game situations. Based on previous findings, we expected to find that attention can be deployed over greater visual angles when using curved screens compared to flat screens in both studies.

2. Study 1: Attention-Window Task

2.1. Method

2.1.1. Participants

To calculate sample size requirements G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) was used. Power analysis indicated that a sample size of at least 16 participants would result in a power of 0.8 (α-level = 0.05, f = 0.25). Therefore, sixteen students aged 19 to 31 years (M_{age} = 22.94, SD = 2.84 years) took part in the study. All participants reported normal or corrected-to-normal vision (with either glasses or contact lenses) and had not participated in any sensorimotor research within the preceding six months. Informed consent was obtained from each participant prior to testing according to the Declaration of Helsinki and the experimental protocol received approval from the local ethics committee.

2.1.2. Materials and Procedure

Participants were tested individually in a laboratory. They performed the attention-window task (cf. Hüttermann et al., 2013) projected onto a flat screen and onto a curved screen (IGLOO Vision ltd, Shropshire, UK) in randomized order. In the curved screen condition participants were asked to stand approximately 3m in front of a 210° curved projection screen (radius of 3m, height: 2.20m). In the flat screen condition, on the other hand, participants were placed approximately 3m in front of a non-curved screen (width of 3.10m, height of 2.20m). Before each task, instructions were presented on the screens, yet participants were also encouraged to ask questions prior to starting the experiment.

Attention-Window Task. The attention-window task—developed by Hüttermann and colleagues (2013)—was presented using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). By means of this task, the maximum attentional breadth was measured as the maximum visual angle between two correctly identified peripheral stimuli that were presented simultaneously for 300ms. Symmetrically around the screen centre along a horizontal meridian different stimulus pairs were displayed with stimulus distances ranging from 10° to 80° in 10° steps. Stimulus positions varied randomly in the total of 288 trials, which were divided into six blocks of 48 trials each and presented with a break after each block. Each of the eight angles was tested 36 times. Before commencing the main task, participants performed twelve practice trials.

At the beginning of each trial a central fixation cross was presented for 1000ms, after which two pre-cue circles indicated the future locations of the two groups of target stimuli for

200ms (see Figure 1). After a 200ms black interval, the target stimuli appeared for 300ms. Four different types of elements were used in the study: circles and triangles (each corresponding to a size of 3.97°) of either light or dark grey colour. Each stimulus group was comprised of four elements while the shape (circle, triangle) and shading (light grey, dark grey) of these elements varied randomly from trial to trial. The participants' task was to identify the number of light grey triangles presented within each stimulus group. Each stimulus group could contain zero, one, two, three, or four light grey triangles; each of those conditions was presented with the same probability of 20%. Therefore, by requiring participants to detect, not just the shape or the shading of elements, but rather, the conjunction of both (i.e. identifying the light grey triangles), the attention-window task is in its nature an attention-demanding task.

2.2. Results

In the attention-window task, responses were only counted as correct for trials in which participants reported the right number of light grey triangles in both, the left and the right, stimuli locations. We analysed accuracy rate as the dependent variable, conducting a repeated measures analysis of variance (ANOVA) with presentation screen (flat, curved) and angle (10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°) as the within-subjects factors. For analyses in which the sphericity assumption was violated, we reported the value of ε from the Greenhouse-Geisser correction. Participants correctly identified 65.03% (*SD* = 3.34%) of the stimuli across both conditions (flat screen, curved screen). The ANOVA revealed a main effect of visual angle, $F(7,105) = 489.632$, $p < .001$, $\eta^2 = .970$, meaning that participants' accuracy rate fell with increasing visual angles between stimuli. Furthermore, higher accuracy rates were found for the stimuli presented on the curved screen than for those displayed on the flat screen, $F(1,15) = 43.884$, $p < .001$, $\eta^2 = .745$; thus, accuracy rate differed as a function of screen type. Another interesting finding was the significant interaction between visual angle and screen type, $F(3.662,54.927) = 24.754$, $p < .001$, $\eta_p^2 = .623$, $\varepsilon = .523$ (Mauchly's test of sphericity: $\chi^2(27) = 47.083$, $p = .012$). All descriptive data are presented in Table 1. After collapsing the data into two groups of smaller (10°, 20°, 30°, 40°) and larger angles (50°, 60°, 70°, 80°), we analysed both angle groups for potential differences (for a similar procedure, see Hüttermann, Noël, & Memmert, 2017). T-tests revealed that participants showed a comparable performance for small angles (10°, 20°, 30°, 40°) when stimuli were presented on a curved screen or a flat screen, $t(15) = -1.036$, $p = .317$. Whereas, accuracy rates were higher for larger angles (50°, 60°, 70°, 80°) when stimuli were presented on a curved screen, as opposed to a flat screen, $t(15) = 9.119$, $p < .001$, $d = 2.28$.

2.3. Discussion

In Study 1, we investigated possible attentional differences depending on the stimulus presentation on a flat and on a curved screen. For identifying stimuli up to a visual angle of 40° there was no difference regarding the use of either type of screen. For visual angles going beyond (>40°), participants reached higher accuracy rates when the stimuli were presented on a curved instead of a flat screen. Previous studies have shown that people are usually able to perceive stimuli in the attention-window task on a flat screen up to a visual angle of 30-40° with a 75% accuracy rate (e.g., Hüttermann, Memmert, & Simons, 2014; Hüttermann & Memmert, 2014). The results of Study 1 confirm these findings for the use of a flat screen. On this screen type, participants achieved an accuracy rate of 81% for stimuli presented at visual angles of 40° and an accuracy rate of 56% for stimuli presented at visual angles of 50°. When the curved screen was used, participants were still able to perceive stimuli at visual angles of 50° with 78% accuracy. Overall, the results show that the identification of peripheral stimuli at larger visual angles can be improved through the use of curved screens. This result raises an important question about whether curved screens, rather than flat screens, should be used in the future to examine the limits of visual attentional skills.

It may be the case that the smaller eccentricity of the curved screen compared to the flat screen explains why stimuli are perceived more accurately in the periphery on curved screens. To illustrate this difference, Figure 2 shows the difference between required eccentricities when a subject has to perceive stimuli with a visual angle of 60° on a curved and on a flat screen. Previous studies have also pointed out that one key advantage of curved screens is the reduction of the slant of the picture surface near the edges of the screen (e.g., Zannoli & Banks, 2015). It may be the case that the preserved natural geometry of the shapes in the larger visual angle conditions on the curved screen may preserve more of the quality of the perceived visual information for the purpose of identifying stimuli in the periphery. There is evidence that shape detection thresholds are lower in the visual periphery compared to foveal vision (Gurnsey, Poirier, Bluett, & Leibov, 2006). Therefore, preservation of the shape structure in the periphery may aid performance at the greater visual angles in the curved but not in the flat screen condition.

Overall, our research shows that objects are perceived more accurately at greater visual angles on a curved screen compared to a flat screen. However, the ecological validity of this conclusion may not hold true for a more ecologically valid task. This was tested in Study 2.

3. Study 2: Football-specific decision-making task

The findings of Study 1 demonstrate that distortions of perceived shapes can be reduced by means of curved screens. Subjects were able to perceive stimuli—geometric shapes, i.e. circles and triangles—at a greater visual angle on a curved compared to a flat screen. In Study 2, we tested whether the findings of Study 1 could be reproduced in a more natural task, which involved athletes' perception of sport specific stimuli. We, furthermore, investigated whether the presentation surface has an influence on, not only the athletes' attentional performance, but also, their perceptual capability and sport-specific decision-making. Previous studies have found that team sports athletes playing on large courts, such as football or handball players, for example, require greater attentional capabilities along the horizontal attentional field (e.g., Hüttermann et al., 2014, 2017; Hüttermann, Helsen, Put, &

Memmert, 2018); thus, we chose a football-specific decision-making task (cf. Hüttermann, Smeeton et al., 2019; Hüttermann, Ford, Williams, Varga, & Smeeton, 2019) including measures of both perceptual and attentional performance for Study 2. Similar to the attention-window task used in Study 1, participants were required to make judgements based on two stimuli equidistant to the centre of their visual field on their left and right side, with varying degrees of separation between the stimuli. The attentional requirements used in Study 1 were replicated in Study 2. Participants were required to differentiate between both the colour and the shape of stimuli (recognition of players wearing black jerseys and assessment of their running direction), therefore, demanding visual attention (cf. Treisman & Gelade, 1980). Participants' accurate perception of jersey colours (recognition of players wearing white jerseys) was used as measure of the perceptual performance. In counterbalanced order, participants performed the football task once on a curved screen and once on a flat screen. Based on the results of Study 1, our assumption was that participants would show better attentional performances, i.e. being able to correctly judge playing situations over wider visual angles, when a curved screen was used for presentation, compared to a flat screen. Based on the attentional effect found in Study 1, we expected to not observe any differences in the perceptual task between both screen type conditions, because colour perception should be possible despite any deformation in shape geometry. Because information extraction from both the perceptual and the attentional processes impact an athletes' decision-making, and because we expected the screen surface to impact attentional processes, we surmised that also the athletes' decision-making performance should depend on the screen type. Due to the fact that several questions had to be answered during the processing of every trial in the football task, a working memory task was included in Study 2 to rule out working memory capacity differences as an explanation of performance differences observed in the perceptual, attentional, and football decision-making tasks.

3.1. Method

3.1.2. Participants

Seventeen subjects (4 female) aged 21 to 28 years (M_{age} = 24.12 years, *SD* = 1.83 years) participated under the same ethical constraints as in Study 1. Subjects were competitive athletes who trained 6.76 hours (*SD* = 1.39 hours) per week, plus competitions on the weekends; they played sports with primarily horizontal attentional requirements (cf. Hüttermann et al., 2014); football (*n* = 9), or lacrosse (*n* = 8).

3.1.3. Materials

Football-specific decision-making task. This task (originally developed by Hüttermann, Smeeton et al., 2019) was presented using Delphi XE 3. All participants completed this task twice, using each screen type once (flat screen versus curved screen). Participants completed the football task once on a flat screen and once on a curved screen in randomized order. In each of the two conditions (flat screen, curved screen), participants performed 24 trials preceded by 2 additional practice trials. After the display of a central fixation cross (1000ms) signalling the beginning of each trial, followed the presentation of two stimuli for 300ms equidistant from and on opposite sides of the fixation cross (see Figure 3). Stimuli were randomly presented at one of four horizontal distances from the centre of the screen (20°, 40°, 60°, 80°) and were equally likely to appear at each visual angle. The stimuli comprised different player configurations (the players' height was approximately 30cm), with one teammate on each side of the centre surrounded by zero, one, two, or three opposing players. The teammate could move towards either the centre of the screen or towards the sideline (the outer end of the screen) while the opposing players always moved towards the respective teammate on each of the subject's sides. This task was classified as attention-demanding because participants had to identify the conjunction of both the shape (indicating the direction of the teammates' movements: towards the centre versus towards the sideline) and the colouring (different coloured jerseys of teammates and opponents) of the stimuli (cf. Treisman & Gelade, 1980).

Participants were asked to imagine they were the player in possession of the ball while standing in front of the flat screen or the curved screen (IGLOO, see Figure 4) and to decide whether it would be best to pass the ball to one of the teammates or to stop/control the ball. They were only supposed to decide on a pass to the left or right side when they perceived their teammate to be running towards them (in the direction of the centre) while, at the same time, not being surrounded by any opponent players. Whenever a teammate was running towards the side line and/or was being surrounded by at least one opponent player, it was expected of participants to choose to control the ball instead and not pass it. Participants were asked to verbally report their decision (pass to the left, pass to the right, no pass) as fast as possible, but at least within a time limit of 3sec.

Automated operation span (Aospan) task. The working memory task (Aospan task) was run in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). This task required participants to memorize lists of letters (e.g., SLK; FLKST) while simultaneously solving simple mathematical problems (e.g., 2*3=?; 10-4=?) (Unsworth, Heitz, Schrock, & Engle, 2005). The Aospan task included a total of 15 trials (3 trials for memorizing each 3, 4, 5, 6, and 7 letters). It was pointed out to the participants that they needed to, at all times, maintain their math accuracy at or above a level of 85%, as the operation span score was only valid if participants reached a score above this threshold at the end of the task. The dual-task (math/memory) was designed to put a strain on the limited-capacity executive attentional resources (Conway et al., 2005). We used the total number of letters recalled across all error-free trials as a measure of participants' working memory, in line with the standard procedure concerning data evaluation (cf. Unsworth et al., 2005).

3.1.4. Procedure

Participants were tested individually in a laboratory room standing in front of the presentation screens. In random order, they performed the Aospan task and the football-specific decision-making task on a flat screen and on a curved screen (cf. Unsworth et al., 2005). The same displays as in Study 1 were used for the flat screen and the curved screen conditions and participants again were placed at a distance of 3m to the screens. Participants carried out the Aospan task sitting in front of a 50 13-inch display (resolution: 1366 x 768 pixels) at a distance of approximately 50cm. Although the instructions were delivered on the screen, participants were encouraged to ask questions prior to starting.

3.2. Results

Separate analyses of the performances in the football decision-making task were conducted for the different involved tasks (decision-making task, attentional task, perceptual task). All descriptive data are presented in Table 2.

Decision-making in the football task. We conducted a repeated-measures ANOVA with participants' accuracy rate in decision making (pass to the left, to the right, or no pass) as dependent variable and visual angle (20°, 40°, 60°, 80°) and screen type (flat, curved) as the within-subject factors. Since Mauchly's test revealed violations of the sphericity assumption for visual angle, $\chi^2(5) = 27.182$, $p < .001$, we used adjusted degrees of freedom based on the Greenhouse-Geisser correction and reported the value of ε from the correction. The ANOVA revealed a main effect of visual angle, $F(1.672,26.760) = 4.999$, $p = .019$, $\eta^2 = .238$, showing that participants' decisional performance worsened with increasing visual angles between stimuli. Neither an effect of screen type, $F(1,16) = 0.239$, $p = .632$, nor an interaction effect between visual angle and screen type, $F(3,48) = 0.059$, $p = .981$, was found.

Moreover, we examined participants' certainty rates (i.e., how convinced they were of their decisions) via evaluations on a ten-point Likert scale. On average, participants reported a certainty value of 7.66 (*SD* = 0.79). Conducting a repeated measures ANOVA with the within-subject factors angle and screen type we found a difference between the confidence ratings dependent on angle, $F(3,48) = 7.441$, $p < .001$, $\eta^2 = .317$, but not dependent on screen type, $F(1,16) = 1.948$, $p = .182$. There was no interaction between angle and screen type, $F(3,48) = 0.588$, $p = .626$.

Attention in the football task. To analyse the identification rate of the teammates' running directions (attentional task) we performed a further ANOVA with the same within-participant factors. The ANOVA showed a significant main effect of angle, $F(3,48) = 27.038$, $p < .001$, $\eta^2 = .628$, indicating that participants performed better at solving the attentional task when stimuli were presented with smaller angles between them, as opposed to greater angles. We, furthermore, found a significant effect of screen type, $F(1,16) = 7.448$, $p = .015$, $\eta^2 = .318$: Participants showed better performances when the task was presented on the curved screen compared to the flat screen. In addition, a significant interaction between screen type and visual angle became visible, $F(3,48) = 3.287$, $p = .028$, $\eta^2 = .170$. Figure 5 shows an overview of the post-hoc analyses. At the 60° and 80° visual angles, attentional performance in the curved screen condition was significantly better than attentional performance in the flat screen condition.

We additionally analysed participants' certainty rates, regarding the running direction of teammates. On average, they reported a confidence value of 5.72 ($SD = 1.00$). As we conducted a repeated measures ANOVA with the within-participant factors angle and screen type we found a difference between the confidence ratings dependent on angle, $F(3,48) = 7.380$, $p < .001$, $\eta^2 = .316$, and dependent on screen type, $F(1,16) = 9.425$, $p = .007$, $\eta^2 = .371$. Yet no interaction between angle and screen type, $F(3,48) = 1.153$, $p = .337$, $\varepsilon = .652$, became visible (Mauchly's test of sphericity: $\chi^2(5) = 12.773$, $p = .026$).

Perception in the football task. To examine the identification rate of the number of opponent players (perceptual task), we conducted a further ANOVA with the same factors as before. The ANOVA revealed a significant main effect of visual angle, $F(3,48) = 4.235$, $p = .010$, $\eta^2 = .209$. However, no significant effect for screen type, $F(1,16) = 0.742$, $p = .402$, and no significant interaction effect between screen type and angle, $F(3,48) = 0.500$, $p = .6.84$, was found. Furthermore, we analysed participants' certainty rates. In total, they reported a confidence value of 6.93 ($SD = 0.99$). A repeated-measures ANOVA with the within-subject factors angle and screen type showed no difference between the confidence ratings dependent on screen type, $F(1,16) = 0.434$, $p = .519$, but dependent on angle, $F(3,48) = 3.757$, $p = .017$, $\eta^2 = .190$. There was no interaction between angle and screen type, $F(3,48) = 1.153$, $p = .337$, $\varepsilon = .477$ (Mauchly's test of sphericity: $\chi^2(5) = 27.733$, $p < .001$).

Additional analyses. As the largest subgroup within the team sport athletes consisted of football players (*n* = 9) and we used a football-specific decision-making task, we checked for intragroup differences in the decision-making, attentional, and perceptual tasks. Mann-Whitney U Tests for paired comparisons were applied to examine between-group differences. The results are presented in Table 3. There was no significant difference between football players and lacrosse players in any of the subtasks of the football-specific decision-making task dependent on screen type.

Aospan task. Participants achieved an average score of 62.76 (*SD* = 7.11) out of a possible total value of 75 in the Aospan task. No correlation between performance in the Aospan task and accuracy in the decision-making task, *r* = .-0.155, *p* = .553, nor accuracy in the attentional task, *r* = 0.227, *p* = .381, nor accuracy in the perceptual task, *r* = .-0.063, *p* = .811 was found.

3.3. Discussion

In accordance with the findings of Study 1, team sport athletes in Study 2 showed greater attentional capabilities (i.e. they identified stimuli more accurately for greater visual angles) when using a curved screen compared to a flat screen. Moreover, we analysed whether the use of a curved screen improves athletes' decision-making in the football task as well as their perceptual capabilities, but we did not find any differences compared to the use of a flat screen. Thus, it can be concluded that curved screens enable the identification of stimuli along greater visual angles in the periphery in contrast to flat screens, but, in total, these differences do not affect decision-making and visual perception. This finding can be explained by the fact that the visual field is much greater than the attentional window (e.g., Hüttermann & Memmert, 2017) and that the stimuli presented in this study were all located within the total visual field, so that the screens did not have any impact. We replicated our findings from Study 1 suggesting that the visual attentional window is larger for the use of curved screens than that of flat screens. The results from the football task can be attributed to attentional and perceptual capabilities rather than working memory capacity because we did not find a positive correlation between athletes' performances in the football task and in the working memory task (Aospan task; cf. Unsworth et al., 2005),

4. General Discussion

In recent years, a few studies have dealt with individuals' perceptual and attentional capabilities depending on curved and flat displays (e.g., Jeong et al., 2017; Lee & Kim, 2016), but most often they focused on handheld displays or standard computer screens (Mustonen et al., 2015). However, especially in sport science where the importance of the ecological approach is constantly growing (Araújo et al., 2007), athletes' performances should be analysed in representative designs of experimental paradigms. In general, representative designs preserve the information sources available to athletes when they are making decisions in their natural environment (e.g., real size of teammates and opponent players). In two studies, we found increases in attentional width by use of a curved screen as compared to use of a flat screen, indicated by the measure of visual angles. The question as to why this effect was observed can be answered by the differences in peripheral eccentricities between flat and curved screens (Zannoli & Banks, 2017). When the large screen is curved, the slant angle is reduced (see Figure 2).

Stimuli presented with the same visual angle require smaller eccentricities when using curved as opposed flat screens. This difference in eccentricity in the screen shapes may have an effect on the perception of the information (Zannoli & Banks, 2017). Compared to curved screens, flat screens increasingly distort shapes as the lateral distance from the screen centre increases. Moreover, due to the curved display the stimuli are closer to the observer's eyes.

These differences would make the information more salient to the observer using a curved screen. Some researchers have addressed differences between flat and curved screens, especially with regard to television screens. They found, among others, that curved screens create a greater sense of immersion, reduce distracting reflections, and minimize perceptual distortions that are commonplace with large televisions (e.g., Jeong et al., 2017). Curved screens seem to be important when the stimulus array span peripheral and foveal vision, thus preserving each stimulus element orientation and their relative orientation between stimuli. For example, team athletes, such as in basketball, handball, and football, are confronted with situations in which the observation of teammates and opponents are directly in front of them as well as next to them can be important for their decision-making process. This also applies for situations in road traffic, where relevant situations do not only happen in front of the driver, but also next to him/her. In order to better represent the ecologically valid environment through laboratory tasks within intervention studies, curved screens offer advantages over flat screens to display game or road traffic situations even more realistically.

One possible limitation of our study is that flat and curve screens lead to different informational properties of the stimuli being picked up. This different information pickup could have led to different performances in the attentional task. But, because the effect here is limited to attentional task performance, it is likely that the changes to the image, which have been suggested to result from the differences in eccentricity of the flat and curved screens, are the most likely the cause of these performance differences. Future experimental studies should distort potential informational properties, whilst keeping the screen surfaces the same, to provide direct evidence for this hypothesis. Additionally, it may be the case that participants may need to have familiarity with the stimuli in order for these attentional effects to be observed. Nearly half of the team sport athletes in the current study were football players. Consequently, the familiarity with the football specific stimuli present in the football players may have led to these participants processing the stimuli in a different way to the other participants. However, to examine familiarities effect, we examined differences in task performance between football players and lacrosse players. Football players did not show better attentional or perceptual performances, nor did they make better decisions compared to lacrosse players. These findings suggest that this heterogeneity in our sample did not influence our results. However, experience of directing attention broadly, which is typically seen in team sport environments may be important prerequisite for observing the effects found in this study.

In summary, we have shown that curved screens can influence human performance. Specifically, we have shown for the first time that attentional, but not perceptual and decision-making performance is enhanced when observing stimuli on curved compared to flat screens. This effect is present when observing basic and more naturalistic stimuli. Future research should identify the changes to the informational properties of stimuli at the edges of large flat screens.

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Tables

Table 1. Mean Percentage and 95% Confidence Interval of participants' total accuracy rate in the attention-window task for visual angles as a function of screen type (curved, flat).

Visual angle	**Flat screen**	**Curved screen**	**Average**
10°	98.44 [97.12, 99.76]	97.40 [94.67, 100.12]	97.92 [96.36, 99.47]
20°	96.53 [95.26, 97.79]	94.10 [90.56, 97.64]	95.31 [93.44, 97.18]
30°	89.58 [85.18, 93.99]	86.98 [83.33, 90.63]	88.28 [82.29, 91.28]
40°	81.08 [75.97, 86.18]	81.42 [79.22, 83.63]	81.25 [78.08, 84.43]
50°	55.73 [49.21, 62.25]	78.30 [76.66, 79.94]	67.01 [63.41, 70.62]
60°	39.77 [36.33, 43.22]	71.84 [62.65, 81.04]	55.81 [50.75, 60.86]
70°	16.49 [11.80, 21.19]	35.62 [28.26, 42.99]	26.06 [21.66, 30.45]
80°	5.21 [1.06, 9.36]	11.98 [7.31, 16.65]	8.59 [4.98, 12.21]
Average	60.35 [57.97, 62.74]	69.71 [67.43, 71.98]	65.03 [63.25, 66.81]

Table 2. Mean Percentage and 95% Confidence Interval of participants' accuracy rate in the decision-making task, the identification rate of the teammates' running direction, and the identification rate of the number of opponents in the football decision-making task, in degrees of visual angle as a function of screen type (flat, curved).

	Visual angle				
	20°	**40°**	**60°**	**80°**	**Average**
Decision-making					
Flat screen	98.04 [93.88, 102.20]	96.08 [90.39, 101.77]	94.12 [87.38, 100.85]	82.35 [68.65, 96.06]	92.65 [88.97, 96.32]
Curved screen	98.04 [93.88, 102.20]	96.08 [90.39, 101.77]	92.16 [84.67, 99.65]	80.39 [66.76, 94.02]	91.67 [87.38, 95.95]
Average	98.04 [95.19, 100.89]	96.08 [92.33, 99.83]	93.14 [87.04, 99.24]	81.37 [69.69, 93.06]	92.16 [88.78, 95.53]
Teammates					
Flat screen	82.36 [73.54, 91.17]	70.59 [62.28, 78.90]	43.14 [29.91, 56.37]	35.29 [25.77, 44.82]	57.84 [52.49, 63.19]
Curved screen	76.47 [68.42, 84.52]	74.51 [63.13, 85.90]	60.79 [46.92, 74.65]	54.90 [42.87, 66.93]	66.67 [58.51, 74.83]
Average	79.41 [72.97, 85.86]	72.55 [66.54, 78.57]	51.96 [40.27, 63.65]	45.10 [37.22, 52.98]	62.26 [56.27, 68.24]
Opponents					
Flat screen	88.24 [79.80, 96.68]	88.24 [79.80, 96.68]	80.39 [68.19, 92.60]	70.59 [58.65, 82.53]	81.86 [75.05, 88.68]
Curved screen	88.24 [79.80, 96.68]	88.24 [79.80, 96.68]	86.28 [75.68, 96.87]	78.43 [66.40, 90.46]	85.30 [78.95, 91.64]
Average	88.24 [83.20, 93.27]	88.24 [81.62, 94.85]	83.33 [73.29, 93.38]	74.51 [66.43, 82.59]	83.58 [78.53, 88.63]

Table 3. Mann-Whitney U test results indicating the comparison of football players and lacrosse players in the three subtasks (decision making, perception, attention) as a function of screen type (flat, curved).

	Football players (n=9)		**Lacrosse players (n=8)**		**U**	**Z**	**p**
	Mean Rank	**Sum of Ranks**	**Mean Rank**	**Sum of Ranks**			
Flat screen							
Decision-making task	9.72	87.50	8.19	65.50	29.50	-.784	.433
Perceptual task	9.56	86.00	8.38	67.00	31.00	-.504	.615
Attentional task	10.00	90.00	7.88	63.00	27.00	-.881	.378
Curved screen							
Decision-making task	9.33	84.00	8.63	69.00	33.00	-.388	.698
Perceptual task	7.39	66.50	10.81	86.50	21.50	-1.436	.151
Attentional task	9.28	83.50	8.69	69.50	33.50	-.244	.808

Figure legends

Figure 1. Sequence of events in a trial with stimuli along the horizontal meridian in the attention-window task (from Hüttermann et al., 2013).

Figure 2. Illustration of the different eccentricities (highlighted in red) when an observer is required to identify objects on a flat and on a curved screen with the same visual angle.

Figure 3. Sequence of events in one exemplary trial showing a game situation with the left teammate (black jersey) running to the middle of the screen and the right teammate (black jersey) running to the side-line, both surrounded by two opponent players (white jerseys). Participants should decide not to pass the ball at all in this situation as both teammates are surrounded by opponent players (modified from Hüttermann, Smeeton et al., 2019).

Figure 4. The figure shows the experimental setup with a subject standing in front of the IGLOO dome and completing the test condition showing three opponent players on the left side while the teammate is running towards the middle of the screen and two opponent players on the right side while the teammate is running towards the middle as well (modified from Hüttermann, Smeeton et al., 2019).

Figure 5. Effect of representation screen on accuracy rate in the attentional task for visual angles of 20°-80°. Symbols represent across-subject means and error bars represent standard deviations. (Notes: *$p<.05$, **$p<.001$)