Virtual Reality
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ORIGINAL ARTICLE

A preliminary investigation into the efficacy of training soccer heading in immersive virtual reality

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Abstract
Recent research has suggested a link between repetitive soccer heading and the increased incidence of neurodegenerative disease in retired players. In response, restrictions have been introduced to limit the amount of soccer heading in training and competitive matches. Therefore, while heading remains an integral part of the game, players are restricted in the amount of training that they can gain on this important skill without potentially harming their long-term wellbeing. The aim of this study was to provide a preliminary investigation into the efficacy of training soccer heading in immersive virtual reality (VR) which allows the practice of the skill without the risk of repetitive head impacts. Thirty-six recreational soccer players were divided into a VR group ($n=18$) who trained soccer heading on three occasions over a 7–10-day period in VR and a control group ($n=18$) who received no training in soccer heading. Measures of real-world heading performance (i.e. the number of goals scored and shot accuracy), perceived confidence and perceived self-efficacy were assessed pre- and post-training. The results showed that the VR group experienced significant improvements in the number of goals scored and increased their perceptions of confidence and self-efficacy. These results show preliminary support for the inclusion of VR-based training in soccer heading where players can hone their heading skills without exposure to repeated head impacts. Implications and practical applications are discussed.

Keywords Football · Concussion: sub-concussion · Intervention · Sport

1 Introduction

In soccer, short bouts of heading have been shown to immediately impair cognition, movement control and neurological function (see Snowden et al. 2021 for a review). Over the course of a typical playing career, soccer players head the ball thousands of times and this accumulation of subconcussive impacts has recently been related to a 3.5-fold increase in neurodegenerative disease in retired soccer players (Russell et al. 2021). Risks from repetitive heading may be particularly problematic for youth soccer players where poorer heading ability (Quintero et al. 2020) and weaker neck muscles (Caccese et al. 2018; Gutierrez et al. 2014) have the potential to magnify the linear and rotational forces induced by ball impact and thus increase the risk of subconcussive brain trauma. In response to this, governing bodies such as Union of European Football Associations (UEFA), the Football Association of England (F.A) and United States (US) Soccer have introduced guidelines and restrictions that limit the amount of soccer heading players are exposed to in training and competitive matches (The FA 2021; UEFA 2020; US Soccer 2019). For example, the F.A. currently advises that professional adult players perform only 10 higher force headers (e.g. headers from crosses, corners, free kicks and returning of goal kicks) per training week. For players aged 12–18 years, heading should be limited to a single session of no more than five headers (10 headers per session permitted for 14 years and above). For players aged 11 years and younger, it is advised that heading should not be introduced into training sessions at all. Despite these concerns and regulations, heading remains an integral part of the game and if players are skilled at heading, they are more likely to adopt a heading technique that minimises the head impact forces that are thought to underpin the detrimental effects on cognitive and neurological function (Quintero et al. 2020). This then

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creates a dilemma for coaches and governing bodies: skilful heading is important for soccer performance, and for the long-term wellbeing of players, but players are restricted on the amount of training that they can gain on this important skill. Therefore, the identification of innovative answers to this question is warranted.

One potential solution to this problem is training soccer heading in immersive virtual reality (VR), which enables players to train heading without the subconcussive ball impact. In VR, it is possible to accurately simulate the flight and trajectory of a soccer ball in a variety of specific heading training drills and match situations while negating the need to make physical contact with the ball. Furthermore, VR has become increasingly available to consumers as new cost-effective, user-friendly, stand-alone devices have been developed. VR has been demonstrated to be a valid and reliable training tool across different environments, particularly those where real-life practice is challenging such as surgery (Mao et al. 2021), aviation (Vine et al. 2015) and rehabilitation (Rose et al. 2018). There is also an emerging body of evidence for the positive impacts VR training intervention can have for improving real-world performance in sport (Le Noury et al., 2022), with positive transfer effects reported in table tennis technique and performance (Michalski et al. 2019), Olympic trap shooting accuracy (Rao et al. 2018) and baseball batting statistics (Gray 2017). At the heart of these performance-related improvements is the development of critical perceptual–cognitive skills, induced by the exposure to the real-world visual environment containing meaningful visual cues (Bird 2020). For example, perceptual skills critical to soccer heading such as anticipation (Witte et al. 2022), timing (Gray 2017), decision-making (Pagé et al. 2019) and even the ability to predict ball-spin trajectories (Dessing & Craig 2010) can be attuned in a virtual environment. Interestingly, the functional improvements induced by motor learning in VR training can also improve participants' self-confidence and self-efficacy (e.g. Long et al. 2020) which have been shown to be significant predictors of superior sports performance (Moritz et al. 2000; Woodman & Hardy 2003). Improvements in self-confidence and self-efficacy elicited through VR training can lead to greater motivation to engage and adhere to virtual interventions (Holden & Dyar 2002). Therefore, it seems that VR training can have both behavioural benefits and benefits for the affective and emotional states of athletes. Overall, the growing evidence supporting the efficacy of VR training for improving real-world performance in sport is encouraging, particularly for interceptive skills like soccer heading, where training in VR may alleviate growing concerns about the injury risks associated with repetitive physical practice. However, limitations such as a lack of haptic feedback and differences in perception–action processes between VR and real-world states (Harris et al. 2019) must still be considered.

The aim of this study was to test the efficacy of training soccer heading in VR in a group of recreational players. It was hypothesised that VR training would transfer to significant improvements in real-world heading performance (pre-test to post-test). It was also expected that training in VR would increase perception of confidence in general heading ability and perceptions of self-efficacy on a real-world heading task.

2 Methods

2.1 Participants

Thirty-six recreational-level soccer players were randomly split into a control group and an experimental (VR) group. The control group consisted of 16 males and 2 females (mean age = 28.67yrs, SD = 5.95yrs), and the VR group consisted of 14 males and 4 females (mean age = 24.17yrs, SD = 5.02yrs). Sample size estimates were calculated using G*POWER software (version 3.1; Heinrich Heine University Dusseldorf, Dusseldorf, Germany; Faul et al. 2009) and were based upon the large effect sizes previously reported for similar virtual reality training interventions undertaken in baseball (Gray 2017; $\eta p^2 = 0.34$) and table tennis (Michalski et al. 2019; $\eta p^2 = 0.30$). If assuming a large effect ($\eta p^2 = 0.30$) with 80% power and an alpha level of $p = 0.05$, a total sample size of at least 22 would have been required for a repeated measures ANOVA with a within-between interaction. However, we decided to increase our sample size to enable the detection of more subtle effects given the novelty of our study. Recreational-level players, rather than elite players, were used as they are likely to be more responsive to training over the short intervention period used in this experiment. Each participant was free from injury and had normal or corrected-to-normal vision. All participants gave their written informed consent to take part in the experiment, which had been granted ethical approval by the university ethics committee prior to testing.

2.2 Materials and apparatus

The Oculus Quest 2 head-mounted display (HMD) (Facebook Technologies, Menlo Park, USA) was used for VR training in this experiment. This hardware displays at a resolution of 1832 × 1920 pixels per eye at 120 Hz and has a field of view of 89°. The Rezzil Player 22 (Rezzil Europe, Manchester, UK) application was used to provide VR football heading training (Fig. 1). This application consists of 60 heading training drills with high scores for consistency and accuracy allowing progress to further drills.

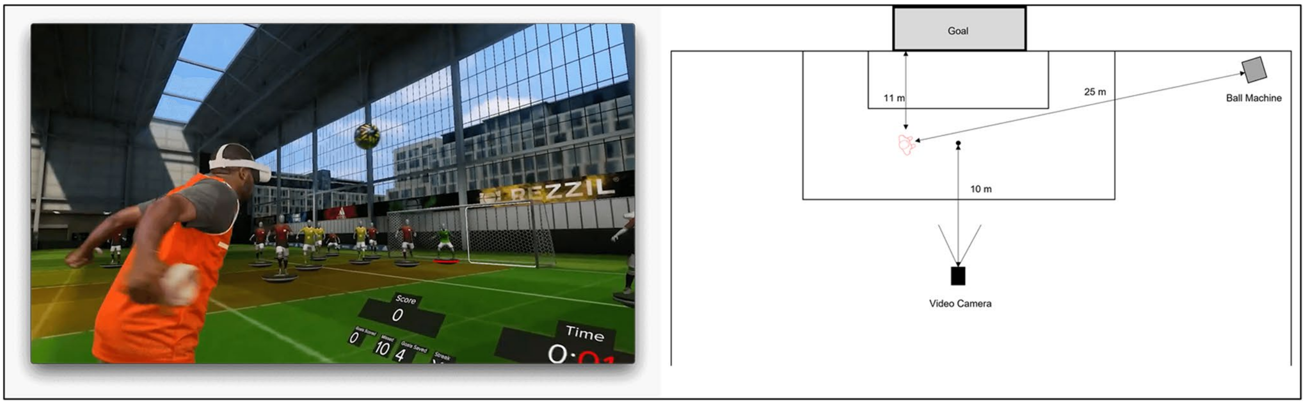

Fig. 1 The Player 22 VR environment (left) and the experimental set-up for the real-world heading task (right)

3 Procedure

3.1 Pre-test

Participants attended individual sessions at an indoor 3G football pitch and had the task explained to them. After providing written informed consent, they then performed three practice headed shots on goal. Balls were served to the participants using a ball launcher that was set to deliver balls to head height at the back post at 30 mph. These conditions were selected to replicate those provided in the Rezzil Player 22 software as closely as possible. After completing their practice attempts, participants then completed 15 recorded headed shots on goal. The number of goals scored was recorded and captured on video for post hoc analysis of shot accuracy. Each participant was asked to try to score as many goals as possible and to try to get the ball as close to the post as possible, in recognition of the fact that shots closer to the post are considered to be more accurate and less likely to be saved by the goalkeeper (Wood et al. 2017a, b). Each pre-test session lasted approximately 20 min.

3.2 Training

The control group were asked to refrain from heading practice for 7–10 days before returning for their post-test assessment. Participants in the VR training group completed a minimum of three sessions of 30 min of training using the Rezzil Player 22 application and Oculus Quest 2 over a period of 10 days. Training in VR consisted of players heading virtual balls projected from ball machines from different distances in a simulated indoor soccer facility (Fig. 1). This training took place in the participants own home as this has been previously shown to be an effective delivery method for improving the perceptual–cognitive skills of soccer players (Murgia et al. 2014). Adherence to training was recorded via self-report. Prior to training, each participant was shown how to operate the VR system and connect it to WiFi, and they were taken through the platform's tutorial process which involved instructions on how to navigate the interface and select levels of difficulty. They were permitted to practise on any level of the game providing they completed at least 30 min of practice on three separate occasions throughout the duration of the training period. Some higher difficulty levels of the VR training application included scenarios where defenders and goalkeepers were present but did not interfere with the heading action. All participants reported to have adhered to these training recommendations.

3.3 Post-test

Participants again attended individual sessions at an indoor 3G football pitch and rated their perceived level of heading ability and their confidence in completing the task of performing 15 headed shots on goal. Participants then performed three practice attempts and 15 recorded headed shots on goal as per the pre-test procedure. For each session, the number of goals scored was recorded and shot accuracy was analysed using post hoc video analysis.

3.4 Measures

3.4.1 Shot success and shot accuracy

The number of goals scored was recorded and compared for each participant at pre- and post-test. Headers that missed the goal completely or that struck either post or crossbar were not counted. Shooting accuracy was measured using Kinovea video analysis software (http://www.kinovea.org). Each half of the goal was divided into 3 × 81 cm scoring zones. Balls landing in the zone closest to the post were awarded three points and then two points and one point, respectively, for the scoring zones closest to the centre of the goal.

3.4.2 Perceptions of confidence and self-efficacy

Participants were asked two questions: (1) “how would you rate your general heading ability?” and (2) “how confident are you in consistently scoring in the next 15 heading attempts?”. Responses were recorded using a 10-point Likert-type scale ranging between 1 = very poor and 10 = extremely good, and 1 = not at all and 10 = extremely, respectively.

3.5 Data analysis

A 2 (Group: control vs. VR training) × 2 (Time: pre-test vs. post-test) ANOVA was conducted to assess the effect of training on the number of goals scored and shot accuracy. Post hoc Bonferroni -corrected pairwise comparisons were conducted to explore statistically significant effects. Effect sizes are reported as partial eta squared where 0.01 indicates a small effect, 0.06 indicates a medium effect and 0.14 indicates a large effect (Field 2013). A series of Wilcoxon signed-rank tests were used to analyse the participant’s self-reported scores of perceived confidence and perceived self-efficacy between groups at pre- and post-test and within groups across pre- and post-test. Due to the number of comparisons for each variable, Bonferroni corrections were applied to adjust p-values relative to the number of tests (i.e. multiplied by 4). All data and analyses can be downloaded from the Open Science Framework (https://osf.io/e6spw/?view_only=47622050dda6483c97733708fe3c9c65).

4 Results

4.1 Goals scored

No statistically significant difference was evident for Group, $F(1,34) = 0.23$, $p = 0.443$, $\eta p^2 = 0.017$, or Time, $F(1,34) = 0.60$, $p = 0.638$, $\eta p^2 = 0.007$, but the interaction between Group and Time was statistically significant, $F(1,34) = 5.42$, $p = 0.026$, $\eta p^2 = 0.137$, and showed that the VR group scored significantly more goals after training ($p = 0.042$), whereas the control group had no significant increase ($p = 0.558$) in the number of goals scored (Fig. 2). No group differences were evident at pre-test ($p = 0.290$) or post-test ($p = 0.203$).

4.2 Shot accuracy

No statistically significant difference was evident for Group, $F(1,33) = 0.86$, $p = 0.361$, $\eta p^2 = 0.025$, or Time, $F(1,33) = 1.41$, $p = 0.244$, $\eta p^2 = 0.041$, and no statistically significant interaction between Group and Time was evident, $F(1,33) = 2.78$, $p = 0.105$, $\eta p^2 = 0.078$ (Fig. 2).

4.3 Perceived confidence

The VR group demonstrated a significant increase in perceptions of self-reported confidence from pre- to post-test ($Z = 3.39$, $p < 0.001$), whereas the control group displayed no statistically significant changes in perceived confidence ($Z = 0.73$, $p = 0.467$). No statistically significant differences were evident between groups at either pre-test ($Z = 0.10$, $p = 0.932$) or post-test ($Z = 1.37$, $p = 0.172$; Fig. 3).

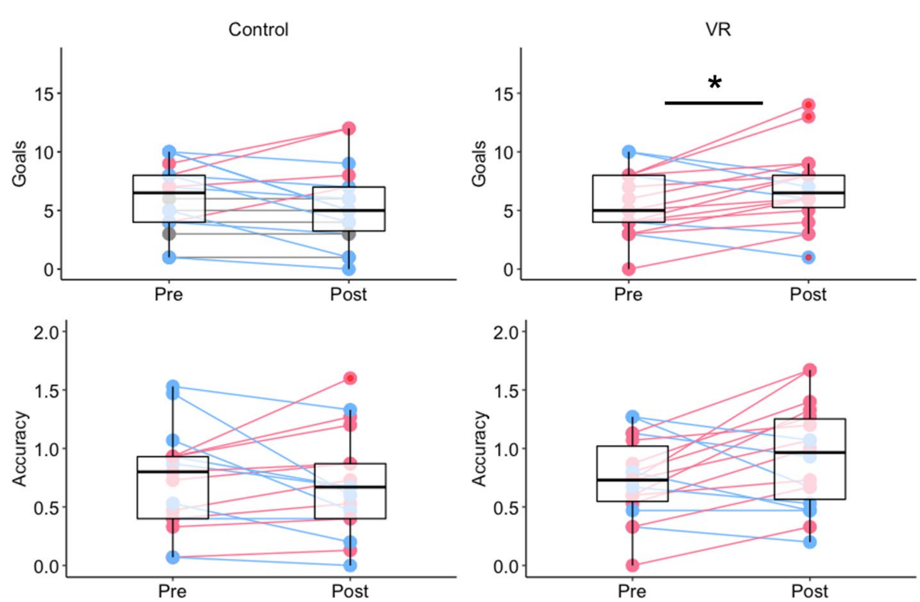

Fig. 2 Boxplots displaying the group median, quartiles and each individual’s mean for goals scored and accuracy across pre- and post-tests for both experimental groups (*$p < .05$)

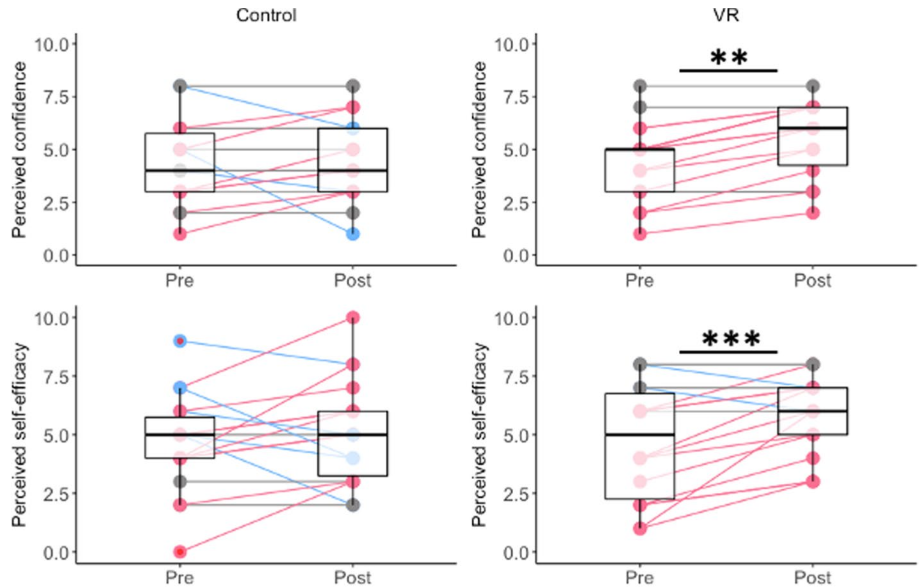

Fig. 3 Boxplots displaying the group median, quartiles and each individual's mean for perceived confidence and perceived self-efficacy across pre- and post-tests for both experimental groups (***$p<.001$; **$p<.01$)

4.4 Perceived self-efficacy

The VR group demonstrated a significant increase in perceptions of self-efficacy from pre- to post-test ($Z=2.85$, $p=0.004$), whereas the control group reported no statistically significant changes in perceived confidence ($Z=1.17$, $p=0.243$). No statistically significant differences were evident between groups at either pre-test ($Z=0.21$, $p=0.836$) or post-test ($Z=1.38$, $p=0.168$; Fig. 3).

5 Discussion

The aim of this study was to provide a preliminary investigation into the efficacy of training soccer heading in immersive virtual reality. The results suggest that the VR group significantly improved heading performance, whereas the control group displayed no significant improvement from pre- to post-test. Training in VR also had significant benefits for improving perceptions of confidence in general heading ability and increased perceptions of self-efficacy.

There are a few potential reasons why the VR training may have produced these benefits. The first may be related to the representative nature of the heading task in VR. The major perceptual motor skill needed when intercepting an approaching ball is the ability to quickly locate and track the ball as it approaches and then the ability to execute a timely motor response to intercept it (Słowiński et al. 2019; Wood et al. 2017a, b). Fundamentally, this coupling between perception and action processes was maintained to a high degree of ecological validity creating a representative VR simulation of this task. Therefore, it is possible that the VR group saw improvements in their heading performance due to their improved ability to track the ball and execute a timely header to direct it to the goal. While the use of eye-tracking to confirm this is problematic for obvious reasons, exploring the movement profiles of performers after VR training might uncover training-induced prospective, online regulatory processes used by performers to ensure their head will end up in the right place at the right time to intercept the ball (e.g. Peper et al. 1994).

An alternative explanation for the benefits of VR may be related to improvements in perceived confidence and self-efficacy. As players will have experienced heading success in VR, this likely influenced the improvement in their perception of confidence and self-efficacy. These improved perceptions have been shown to be related to improvements in perceived control, which has also been associated with improved performance in soccer skills (Wood and Wilson 2012). These more optimal affective states might also help alleviate any fear an individual might experience when facing soccer headers, inducing a more approach-oriented motivation towards our real-world heading task. The effectiveness of VR for reducing fear in real-world situations is well documented (Freitas et al. 2021), so it is also possible that the improvements shown in this study may be related to increased perceived competence and reduced fear of heading. Future work should explore these benefits more directly and attempt to disentangle training-induced improvements to perceptual-cognitive skills from those elicited via improved perceived confidence or self-efficacy.

While these preliminary results are encouraging, there are several limitations that should encourage caution when interpreting these data. First, the short training period (i.e. $\geq 3 \times 30$-min session across 7–10 days) may have been insufficient to induce robust effects in terms of skill learning and consolidation. However, the training period is similar or greater than previous VR training interventions that improved performance in juggling (1 × 30-min session; Borglund et al. 2021), basketball tactics (1 × 20-min session; Tsai et al. 2020), darts (3 × 50 throws over 7 days; Tirp et al. 2015) and firearms training (2 × 20-min sessions; Harris et al. 2022, 2019). Indeed, the effects of long-term practice in this VR environment remain unclear and could even lead to negative transfer effects if the heading platform lacks representativeness (Le Noury et al. 2022) and evokes different perception–action processes (Harris et al. 2019) compared to the real-world heading. These issues warrant systematic evaluation in future work (cf. Wood et al. 2021).

Second, as the intervention relied upon home-based unsupervised practice, adherence could have been low (despite players reports to the contrary) and incorrect heading techniques could have been adopted. However, previous research has demonstrated that home-based training interventions are effective for training the perceptual-cognitive skills of soccer players (Murgia et al. 2014) and we envisage that in the context of heading, VR will be used outside the typical training environment as an adjunct to physical training. Third, the absence of any afferent feedback from ball-head impact may have impaired the learning of this skill. During interceptive sports actions, like heading, afferent feedback from ball contact is likely to be important for skill acquisition. Support for the importance of this information for motor learning can be taken from the work of Gray (2009) who showed that in virtual baseball batting the addition of tactile feedback congruent with location of bat–ball contact improved performance. Integrating similar technology within this soccer heading VR system may offer additional benefits to training. Finally, there was also no physical practice group, which is often a limitation of work in VR training for sport (Le Noury et al. 2022). However, while the addition of a physical practice group would reveal the magnitude of any learning effect in VR compared to real-world practice, in the context of soccer heading this has been limited in professional soccer and banned in youth soccer. Therefore, a comparison with a condition that had no heading exposure is probably more representative of the restrictions that many governing bodies are imposing. There was also an ethical consideration of including a physical practice group who were exposed to the same number of headers over the intervention period. In the VR system, players are likely to have headed hundreds of virtual soccer balls over the 7–10 days of training. We feel it would have been unethical to expose players to a similar number of real-world headers considering the FA regulations that propose players are exposed to less than ten headers in training per week. While this is a limitation of the research design, it nicely illustrates the strengths of VR as an intervention tool in this specific context—it allows repetitive practice that is potentially unsafe in the real world.

While these limitations of training heading in VR are acknowledged, it is also worth recognising the applied implications of practising this skill using this technology. For example, it allows heading practice without the need for any other players or coaches, and it provides competition with other virtual players, both of which are likely to increase the opportunity and motivation to train this important skill. There is also an argument that training this skill in VR offers a more representative practice than a coach throwing a lightweight sponge ball to players. In the virtual world, balls can travel further distances with varying trajectories and spin, offensive or defensive players can also move to provide obstruction or emerging heading affordances and game contexts can be added such as corners, free kicks, or defensive headers. In reality, however, this need not be an either/or choice between training methods. It is likely that a complimentary approach integrating the regular use of VR training in conjunction with neck strength training and physical practice within the currently advised limits on forceful heading practice would be an optimal solution. This may provide an opportunity for players to develop the perceptual–cognitive skills and technique associated with skilled heading performance while also increasing the requisite confidence and strength required to lessen the potential health risks associated with physical practice.

In conclusion, here we show some benefits of training soccer heading in immersive VR. While these initial findings appear promising, further work is needed to extend the intervention duration, incorporate a delayed retention test and provide more objective, mechanistic explanations for any improvements in performance and learning. With increasing restrictions of heading exposure to professional and youth soccer, it is evident that alternative methods for training heading confidence and technique will be required, while it remains an integral part of the game. The work presented here provides some initial evidence suggesting that immersive VR may have a place in any new approach to training this important skill.

Data availability All data can be downloaded from the Open Science Framework https://osf.io/e6spw/?view_only=47622050dda6483c97733708fe3c9c65

Declarations

Conflict of interest The authors declare they have no conflict of interest.

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