

Article

The Effects of Cognitive Load on Pupil Dilation in Volleyball Players: An Eye-Tracking Study

Tuğba Nalçacıgil^{1*}, Gülçin Güler², Semra Bıdıllı², Nuran Küçük², Tuğçe Akkurt², Deniz Şimşek²

¹ Faculty of Sports Sciences, Eskisehir Technical University, Eskisehir, Turkey

² Faculty of Sports Sciences, Eskisehir Technical University

* Correspondence: (TN) tugbanalcacigil@gmail.com  ORCID ID n° 0000-0002-9306-0760

Received: 13/12/2024; Accepted: 24/03/2025; Published: 30/06/2025

Abstract: Volleyball is a sport that demands not only high levels of physical exertion but also significant cognitive engagement. Rapid decision-making, attentional control, and visuomotor coordination are essential for optimal performance. This study investigates the effects of cognitive load on pupil dilation and reaction time in competitive volleyball athletes. A within-subjects, controlled experimental design was employed, involving 26 female volleyball players (age 15.4 ± 1.2 years) who regularly train and compete at the regional level. Participants completed three cognitive load conditions in a randomized order: (P1) a motor task requiring the suppression of randomly illuminated lights as quickly as possible, (P2) a cue-based task in which the next light always appeared in the same color zone as the previous one, allowing for anticipatory responses, and (P3) a mixed cue task that introduced a more mixed cue structure, increasing task difficulty and necessitating greater motor control adaptation. Performance was assessed using the Fitlight system, which involved deactivating 25 lights under three distinct levels of cognitive load. To ensure the precise evaluation of cognitive load effects, pupil dilation was continuously measured using Tobii Pro Glasses 2. Results demonstrated that pupil dilation increased significantly under higher cognitive load conditions ($p < .001$) and that reaction times were faster when predictive cues were available ($p < .001$). These findings suggest that cognitive load plays a critical role in shaping athletes' visual and motor responses, with direct implications for sports training and decision-making processes. Enhancing cognitive training protocols in volleyball may improve athletes' ability to process visual information efficiently and execute rapid motor responses under high-pressure conditions.

Keywords: cognitive load; volleyball; vision, pupil, eye tracking

1. Introduction

Volleyball is a dynamic team sport that demands both physical and cognitive skills to maintain effective performance in a constantly evolving environment. Success in volleyball relies not only on motor skills such

as jumping, agility, passing, and spiking but also on cognitive and perceptual abilities, including visual scanning and movement anticipation (Formenti et al., 2022). Throughout the game, athletes must accurately perceive the positions of their teammates and opponents to make strategic



decisions (Pleša et al., 2021). In this context, the capacity to process information rapidly and respond appropriately under time pressure is a critical determinant of high-level performance. Core cognitive processes such as perception, attention, and decision-making empower athletes to perform swift and precise actions in high-pressure game scenarios (Memmert, 2009). Skilled players integrate both kinematic and contextual information derived from dynamic game conditions to anticipate the actions of opponents and teammates, which is particularly vital during high-paced phases of play (Müller & Abernethy, 2012).

In volleyball, athletes must simultaneously process multiple sources of information to make quick and accurate decisions under dynamic game conditions. The efficient management of cognitive resources during sports performance is largely dependent on attentional control mechanisms (Knudsen, 2007). Attention is a cognitive process that filters out distractions while selecting relevant stimuli and acts as a fundamental mechanism responsible for regulating the activation levels of both internal and external representations (Desimone & Duncan, 1995; Pashler et al., 2001). Research suggests a bidirectional relationship between working memory and attention. While attention facilitates the encoding of stimuli into working memory (Atkinson & Shiffrin, 1968), working memory, in turn, modulates attentional control by prioritizing task-relevant information (Gazzaley & Nobre, 2012; Soto et al., 2008; Soto & Humphreys, 2007). This interaction is particularly crucial in dynamic environments such as sports, where athletes must rapidly shift their attention between

environmental cues and predetermined tactical strategies to optimize decision-making processes (Furley & Memmert, 2013). However, during mixed tasks, the limited capacity of working memory and cognitive resources (Adams et al., 2018; Chai et al., 2018) may result in excessive cognitive load that exceeds this limited capacity, negatively impacting learning processes and task performance (Paas et al., 2003). Additionally, a cognitive load that surpasses an individual's capacity can lead to heightened arousal, increasing stress levels and potentially impairing performance depending on the ability to maintain focus. Consequently, while moderate arousal levels enhance performance, excessive cognitive load can contribute to mental fatigue and performance decline over time (Arent & Landers, 2003; Yerkes & Dodson, 1908). Therefore, effective management of cognitive load in athletes is critical for enhancing decision-making speed and accuracy, ultimately optimizing game performance. The literature indicates that athletes engaged in open-skill sports possess higher attentional capacity and utilize cognitive processes such as visuospatial attention and problem-solving more efficiently (Gu et al., 2019; Voss et al., 2013; C.-H. Wang et al., 2013). Moreover, elite athletes exhibit superior anticipation and decision-making skills compared to novices by detecting environmental cues earlier and processing information more efficiently (X. Wang et al., 2023; Williams, 2002; Xu et al., 2021). In sports with high cognitive demands, such as volleyball, cognitive load management should be a fundamental component of training programs. Targeted strategies should be developed to enable athletes to

process environmental information in the most efficient manner possible.

One of the most widely used methods in the field of sports to assess cognitive load is eye-tracking, a non-invasive physiological measurement technique (Cowley et al., 2016). Pupil diameter has long been recognized as a reliable indicator of cognitive load and was associated with task difficulty in early research (Hess & Polt, 1964). Kahneman and Beatty (1966) demonstrated that pupil dilation reflects cognitive effort during mental tasks. Subsequent studies have reinforced the use of pupil diameter as a robust indicator across various levels of cognitive load (Van Der Wel & Van Steenbergen, 2018). Jerčić et al. (2020) observed that players exhibited physiological responses such as increased heart rate and pupil dilation while performing cognitively demanding game tasks (Jerčić et al., 2020). These findings indicate that studies aiming to evaluate cognitive activity levels can rely solely on pupil diameter measurements and that pupillary responses effectively reflect physiological arousal levels, facilitating the detection of such activities (Jerčić et al., 2020). Given the effects of cognitive functions on motor performance, it is crucial to gain a deeper understanding of the motor performance and physiological responses exhibited by athletes under cognitive load conditions of varying difficulty.

There is a well-established relationship between cognitive functions and motor performance in volleyball players (Formenti et al., 2022; Trecroci et al., 2021). However, a comprehensive understanding of the impact of cognitive cues on attentional control and motor performance in volleyball players remains limited. One of the key

strengths of this study is its holistic approach, integrating objective measurement methods through a simultaneous reaction measurement system to provide both potential benefits and a deeper insight into the limitations of existing research. This study aims to provide a comprehensive evaluation of the effects of cognitive load on pupil diameter and reaction performance in volleyball athletes across three tasks with varying levels of cognitive cues in addition to a motor task: (1st Test: motor task (P1), 2nd Test: motor+cue task (P2), 3rd Test: motor+mixed cue task (P3)). The study hypotheses are: (i) Reaction times will be shorter in tasks involving cognitive cues (P2 and P3) compared to the test involving only the motor task (P1), (ii) Due to learning effects, the performance time in the mixed cognitive cue condition (P3) will remain the same as P2 despite increased cognitive load, (iii) Pupil diameter will increase as task difficulty increases, (iv) Greater cognitive load allocation in P3 compared to P2 will lead to a more pronounced increase in pupil diameter.

2. Materials and Methods

Participants -The sample size was determined based on data from previous studies (Alder et al., 2021; Yu et al., 2025) and was calculated using G*Power software (version 3.1) with an effect size of $f = 0.3$, an alpha level of 0.05, and a power of 0.80, resulting in a required sample size of 20 participants. The study includes 26 participants, which exceeds the minimum requirement and ensures valid statistical analysis.

The study sample comprised 26 female volleyball players from the same club,

ensuring a controlled and consistent training environment. Participants met specific inclusion criteria, including active participation in volleyball training five days a week and regular competition in regional leagues, thereby maintaining a standardized level of expertise. Additionally, only athletes who had not reported any upper or lower extremity injuries within the past six months were included. The exclusion criteria included chronic illnesses or physical injuries that could impair motor performance, as well as the use of medications or the presence of medical conditions that might affect pupil dilation or cognitive function. By implementing these selection criteria, the study ensured sample homogeneity, enhancing the generalizability of the findings to similar athletic populations while effectively controlling for potential confounding variables. The parents of all participants provided informed consent before their children participated in this study. All experimental procedures strictly adhered to the ethical principles outlined in the Declaration of Helsinki and received approval from the institutional ethics committee (Protocol No: E-87914409-050.03.04-2300016252).

Apparatus and Task - The study's data were collected using the FitLight Trainer™ system (FitLight Sports Corp., Canada), which consists of eight LED lights designed to measure participants' reaction times. The LED lights in this system, which are controlled by a tablet computer, can be set to different colors, and their flashing duration can be customized. Participants' pupil diameters were recorded using Tobii Pro Glasses 2 (Stockholm, Sweden), which feature 12 infrared projections reflecting off

the cornea. The glasses are equipped with four micro-cameras—two on the right and two on the left—positioned along the inner edges of the frame, as well as a main HD camera located at the front center of the glasses to capture the environment. Additionally, a microphone is situated beneath the main camera of the video recording glasses. The system operates at a frequency of 100 Hz with a deviation of 0.5 degrees. Raw data from the FitLight Trainer system (reaction times) and Tobii Pro Glasses 2 (pupil dilation) were stored on their respective software platforms. Reaction time data were automatically recorded and transferred to Excel for preprocessing. Pupil dilation data were processed using Tobii Pro Lab software, which established a baseline pupil size and extracted stimulus-related changes. Subsequently, the data were examined for missing values and artifacts, and statistical analyses were conducted using IBM SPSS Statistics (version 26.0). These methodological steps ensured high data reliability and accuracy, minimized measurement errors, and supported consistent and well-processed datasets for analysis.

Experimental Design - The data collection process was conducted by trained researchers with expertise in cognitive-motor performance assessment and eye-tracking technology. The researchers received specialized training in the operation and calibration of the FitLight Trainer system and Tobii Pro Glasses 2, ensuring adherence to standardized data collection procedures. The calibration of the eye-tracking system was performed before each session to maintain accuracy in pupil diameter measurements (Güler et al., 2024). Changes in pupil

diameter represented the average dilation recorded throughout the P1, P2, and P3 tests (25 lights). During data analysis, the baseline pupil diameter for each participant was set at 100%, and changes observed during the experiment were calculated as percentage increases relative to this baseline. The study implemented various methodological controls to reduce threats to internal validity. A within-subject design was employed, in which participants completed the three task protocols (P1, P2, P3) in a randomized order to minimize task order effects and learning biases (Hirsch et al., 2018). The pre-calibration of the FitLight Trainer system and Tobii Pro Glasses 2 ensured measurement accuracy. Single-blind procedures were used to prevent expectancy effects by keeping participants unaware of the study's hypotheses. Additionally, all tests were conducted in a controlled laboratory environment with consistent lighting to minimize environmental effects on pupil dilation. All measurements were completed within a single testing session. Variations in fatigue and motivation were controlled by scheduling test sessions at standardized times. Since the study aimed to evaluate sudden changes in reaction time and pupil dilation under different cognitive load conditions, a single-session measurement was sufficient to capture short-term effects. The FitLight Trainer system was used to determine reaction times during cognitive loading. The system comprises eight lights equipped with built-in sensors, positioned on platforms surrounding the participant from three sides. All lights were placed at heights corresponding to each participant's hip and shoulder levels. These lights were color-coded (red, blue, and green from left to right);

the red zone contained two lights, the blue zone had four lights, and the green zone included two lights (Figure 1). Each pair of lights was positioned at shoulder and waist height for the participants. The lights on the three platforms were placed 1.5 meters away from the center. During the experiment, participants performed a lunge step with their active foot to deactivate the active lights and extended toward each platform from the central position. Each trial consisted of 25 repetitions of a reaching task in which participants had to place their hand in front of one of the eight lights/sensors to turn it off. The lights illuminated one at a time, with a 0.5-second delay between the deactivation of one sensor and the activation of the next. Before each trial, participants were provided with instructions and asked to turn off five lights to familiarize themselves with the task procedure. For detailed information, see (Laessoe et al., 2016; Simsek et al., 2021).

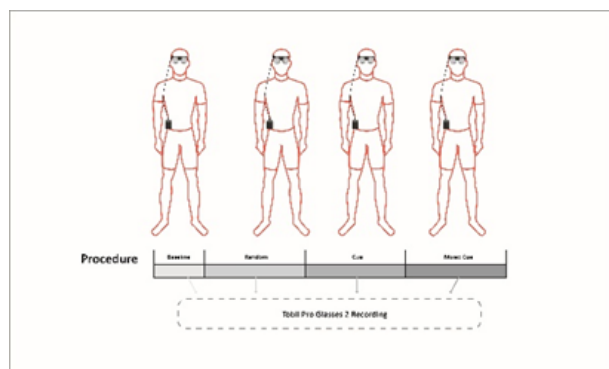


Figure 1. Test Environment and The Order of Lights: G: Green Zone, B: Blue Zone, R: Red Zone.

Procedure - As part of the study, four lights were positioned in the blue area on the wall directly in front of each participant, while two lights were placed in the red area to the left of the participant and another two lights in the green area to the right. These lights

were aligned at shoulder and hip levels, respectively. After participants completed a warm-up session, the eye-tracking system was fitted onto their faces, and the device was calibrated. Before starting the tests, participants were given a practice period to familiarize themselves with the procedure, and baseline measurements of their pupil diameters were recorded before the initiation of the dual-task protocol. Participants were instructed to approach the LED light setup and turn off the lights as quickly as possible by placing their hands over each light. All protocols were conducted twice, and the data from the second trial were used for statistical analyses (Figure 2). Once the dual-task protocol began, time markers were established for each protocol, and the devices recorded data simultaneously. Performance times for each protocol were automatically recorded by FitLight software and displayed on the system's controller. The average times were then recorded in Excel. The data stored on an SD card in the main unit were uploaded to the Tobii Pro Lab analysis software (Tobii Pro Glasses 2, Stockholm, Sweden) to calculate the baseline pupil size before the protocol and to analyze pupil diameter changes in response to stimuli during the protocol.

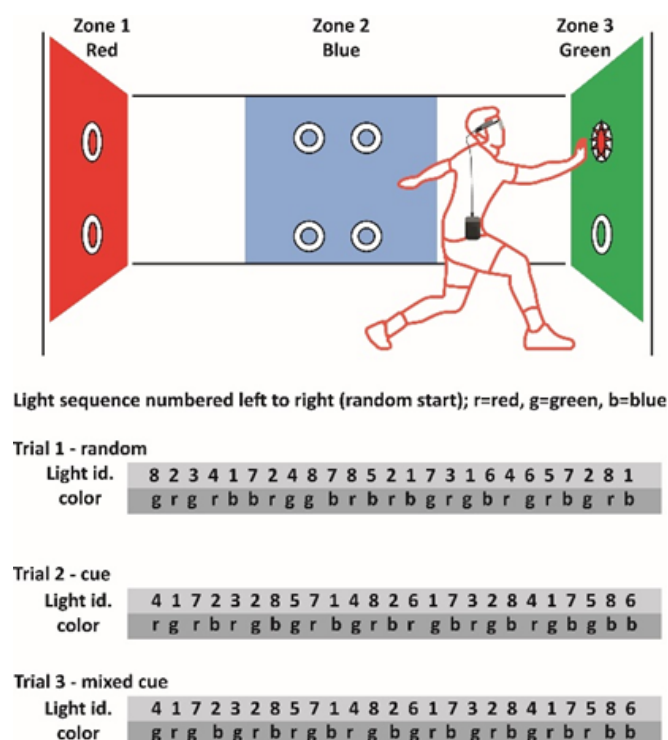


Figure 2. Representation of the experimental design.

Statistical Analysis - The data were described using the arithmetic mean (M) and standard deviation (SD). Before conducting the statistical analyses, the normality of the variables was assessed using the Shapiro-Wilk test. Based on the normality results, both non-parametric and parametric tests were applied accordingly. The Friedman test was employed to analyze the duration of the protocols. When the Friedman test indicated statistically significant differences, the Wilcoxon signed-rank test was subsequently used for post hoc comparisons. Repeated-measures analysis of variance (ANOVA) was utilized to examine differences in pupil dilation across the experimental conditions. All statistical analyses were performed using the IBM SPSS Statistics software (version 26.0, IBM Corp., Armonk, NY, U.S.A.). Unless otherwise stated, the level of statistical significance was set at $p < .05$.

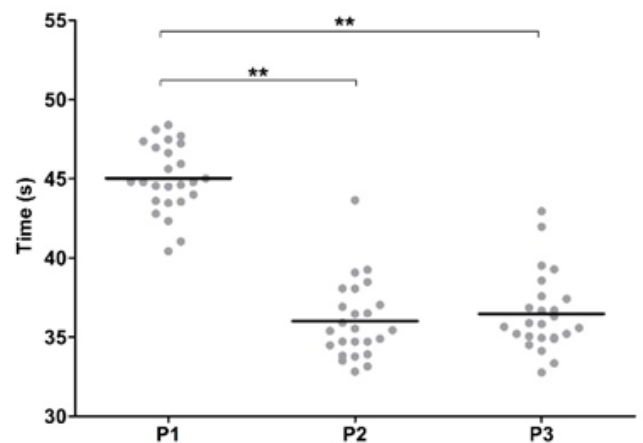
3.Results

Protocol Durations - A Friedman test was conducted to determine whether there were differences in performance times between different difficulty levels (P1, P2, and P3) of dual tasks. The results of repeated measures indicate a significant difference: $\chi^2(2) = 94.662$, $p < .001$. Following the Friedman test, a Wilcoxon signed-rank test was performed to discern differences between dual tasks. Athletes performed better in P2 (Mdn = 35.44) and P3 (Mdn = 35.85) than in P1 (Mdn = 44.79). The Wilcoxon signed-rank test showed significant differences between P1 and P2 ($Z = -4.372$, $p < .001$), and also between P1 and P3 ($Z = -4.373$, $p < .001$). However, there was no significant difference between P2 and P3 ($Z = -1.816$, $p = 0.069$). Figure 3 illustrates the performance duration of participants across the three difficulty levels, showing that the performance times in P2 and P3 are similar, both being significantly faster than in P1. Table 1 presents the descriptive values of participants, providing additional statistical details of the data.

Pupil Dilation - ANOVA revealed significant pupil dilations for protocols ($F(3,72) = 64.838$, $p < .001$, partial $\eta^2 = 0.730$). The post hoc tests confirmed that pupils dilated in P1, P2, and P3 ($p < .001$). Also, there was more dilation in P2 than in P1 ($p = .021$). There were no differences in the rest of the comparisons ($p > .05$). Figure 4 below

illustrates the pattern of pupil dilations across the different protocols. The data clearly show a marked dilation response in all protocols (P1, P2, and P3), with P2 showing significantly greater dilation compared to P1.

Figure 3. Performance Duration of the Participants During Dual Tasks of Different Difficulty



Values are given as mean $\pm$ SD. P1 = random protocol, P2 = protocol with cue, P3 = protocol with mixed cue. ** $p < .001$.

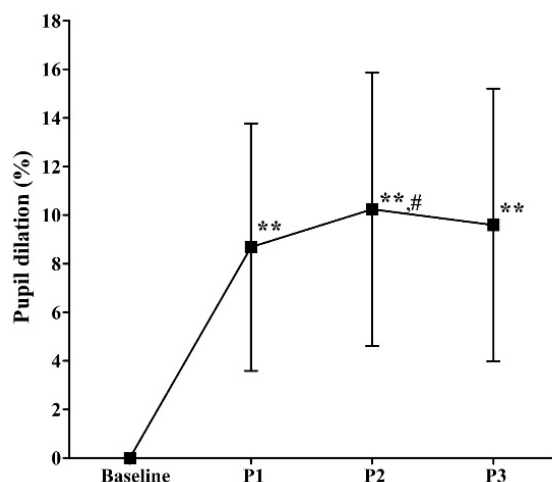
4.Discussion

This study aimed to comprehensively evaluate the effects of cognitive load on pupil diameter and reaction performance in volleyball athletes across three tasks with varying levels of cognitive cues in addition to a motor task: (1st Test: motor task (P1), 2nd Test: motor+cue task (P2), 3rd Test: motor+mixed cue task (P3)). The study hypothesized that

Table 1. Descriptive Values of Participants' Protocol Durations and Pupil Dilation

Variables	P1 (s)	P2 (s)	P3 (s)	P1(%)	P2 (%)	P3 (%)
First trial	45.91 $\pm$ 1.88	37.04 $\pm$ 3.06	37.98 $\pm$ 3.36	9.44 $\pm$ 4.97	10.48 $\pm$ 5.11	9.47 $\pm$ 5.17
Second trial	45.02 $\pm$ 2.14	36.00 $\pm$ 2.44	36.47 $\pm$ 2.44	8.68 $\pm$ 5.09	10.24 $\pm$ 5.63	9.59 $\pm$ 5.61

Values are given as mean $\pm$ sd. P1 = random protocol, P2 = protocol with cue, P3 = protocol with mixed cue. P1 (%) = Pupil dilation in P1, P2 (%) = Pupil dilation in P2, P3 (%) = Pupil dilation in P3.

Figure 4. Dilations of Pupils in Protocols

Values are given as mean $\pm$ SD. P1 = random protocol, P2 = protocol with cue, P3 = protocol with mixed cue. ** shows significance between baseline $p < 0.001$; # shows significance between P1 ($p < .05$).

adding cognitive cues to the motor task would increase cognitive load but lead to shorter performance times due to relevant cues, and that pupil diameter would expand as task difficulty increased. In this context, participants were expected to maintain task performance by interpreting cognitive cues. Consistent with our hypothesis, participants demonstrated significantly shorter performance times in the P2 and P3 tasks compared to P1. However, no significant performance difference was observed between the P2 and P3 tasks. The findings support our hypothesis that, despite the increased cognitive load in the P3 condition, performance time would remain similar to P2 due to learning effects. The results revealed that the cues presented in the P2 and P3 conditions significantly shortened reaction times by accelerating the athletes' information processing. These findings indicate that, instead of actively scanning the visual field, volleyball players accelerate their response process by quickly selecting

and processing specific cues. The athletes appeared to allocate attentional resources more efficiently under cognitive load and regulate their motor responses with greater precision. This finding offers valuable insights for developing training strategies aimed at improving decision-making speed and reaction time, particularly in high-paced sports. Such strategies could enhance athletes' ability to make quick decisions and respond effectively in dynamic and high-pressure game scenarios.

The findings of our study are consistent with previous research conducted with male and female badminton players (Şimşek et al., 2023) and non-athlete individuals (Laessoe et al., 2016). These studies demonstrate that task performance time in the presence of anticipatory cues is shorter compared to the time required to complete the task without cues. Additionally, the literature suggests that integrating cognitive processes into motor tasks supports enhanced decision-making mechanisms by optimizing attentional focus on task-relevant cues (Fleddermann et al., 2019; Romeas et al., 2019). However, the nature of the relationship between motor-cognitive cues and task performance, visual search behavior, and attentional control remains unclear in the existing studies. There are inconsistent findings in the literature regarding how pupil diameter changes under cognitive load. Some studies have reported different outcomes, such as increases, decreases, or no change in pupil diameter depending on the complexity of the task (Campbell et al., 2019; Chai et al., 2018). In this context, our study provides a significant contribution to understanding how athletes direct their attentional focus

(e.g., pupil behavior) in situations requiring cognitive interference. The findings obtained may shed light on both the development of theoretical models and the establishment of practical strategies in the fields of sports psychology and performance science.

An expansion in pupil diameter was observed in the P1, P2, and P3 tasks with varying difficulty levels of cognitive cues compared to the baseline condition. It was found that this dilation was greater in the P2 task condition, where cognitive load increased, compared to P1. However, no statistically significant difference was found between the P1-P3 and P2-P3 tasks. In our study, while reaction time performance decreased in tasks with increased cognitive load, it is considered that pupil diameter may have expanded due to the increased cognitive load during motor tasks combined with cognitive cues. Overall, our results align with previous studies reporting that pupil dilation is associated with higher cognitive load and greater visual attention (Appel et al., 2018; Duchowski et al., 2018; Parikh et al., 2018). However, the prediction that pupil dilation would be greater in the P3 task, where the cognitive cue was more complex, compared to the P2 task, was not confirmed. This finding may be explained by various mediating factors that could influence how athletes process cognitive cues and execute motor responses. One possible mediating factor is attentional control. The extent to which athletes can focus on relevant cues may influence performance outcomes by determining how cognitive resources are allocated (Furley & Wood, 2016). The mixed cues in the P3 task may not have generated additional cognitive load if athletes optimized their attentional resources due to

the learning effects from the P2 task. Additionally, physiological arousal levels could also be a significant factor shaping the effects observed in this study. The mixed cue in the P3 task may have led to high arousal by increasing stress levels, which, depending on the ability to maintain focus, could impair performance (Arent & Landers, 2003; Yerkes & Dodson, 1908). This heightened arousal might have caused mental fatigue, preventing further pupil dilation. These factors provide an important indicator for understanding how working memory may be linked to physiological responses in the P3 task.

In conclusion, this study evaluated how volleyball athletes respond to cognitive cues presented during motor tasks and examined the effects of these cues on cognitive load by assessing cognitive indicators such as reaction time and pupil diameter. Our findings demonstrate that athletes accelerate their information processing and significantly shorten their reaction times by utilizing cognitive cues. Additionally, it was observed that pupil diameter expanded as cognitive load increased, but this effect could be balanced when the complexity of the cue increased. This finding suggests that mediating mechanisms such as cognitive resource allocation, attentional control, and physiological arousal levels play a critical role in sports performance. Therefore, our findings and research methodology provide valuable insights that could inform future research in this field.

Future studies should explore the effects of cognitive cues on sports performance in more depth by considering individual differences, particularly working

memory capacity and attentional control mechanisms. Moreover, applying similar experimental protocols across different sports and with a broader athlete population could enhance the generalizability of the findings. Longitudinal studies should investigate how training programs incorporating cognitive cues affect long-term skill acquisition and game performance. Additionally, combining eye-tracking technologies with neuroimaging methods could contribute to a better understanding of the neural processes occurring under cognitive load. In this direction, developing strategies for the effective use of cognitive cues during training processes could lead to the creation of applications that optimize athletes' decision-making speed and attentional management.

5. Practical Applications

The findings of this study provide valuable insights into the interaction between cognitive load, reaction performance, and pupil dilation in volleyball athletes. The practical implications of these results can be evaluated from both sports performance optimization and cognitive training perspectives. The study revealed that volleyball players exhibited faster reaction times in cognitively demanding tasks (P2 and P3) compared to the motor-only task (P1). This finding indicates that integrating cognitive cues into training could enhance athletes' decision-making and reaction efficiency in real-game scenarios. Additionally, pupil dilation increased with cognitive load, demonstrating its potential as a physiological marker for monitoring cognitive effort during training. Structured cognitive-motor training and dual-task

conditions could facilitate athletes' adaptation to cognitive demands while maintaining motor performance. These findings may also apply to other open-skill sports such as football, basketball, and tennis, where quick decision-making and visual processing are critical. Furthermore, incorporating wearable eye-tracking technology into sports training could provide valuable insights into attentional distribution and cognitive workload, enabling the development of personalized training programs that reduce cognitive overload. This study suggests that the task protocol with increased cognitive load may affect pupil diameter; however, further research is needed to fully validate the effects of cognitive load on pupil dilation.

6. Conclusion

The results indicated that volleyball players demonstrated significantly faster reaction times when performing tasks with cognitive cues. This study highlights the importance of attentional control toward relevant cues and cognitive load in shaping motor performance in volleyball athletes. The findings indicate that integrating cognitive demands into training can enhance reaction times, improve attentional efficiency, and ultimately boost real-game performance under pressure. Sports scientists and coaches can optimize training protocols to maximize cognitive and motor efficiency by using pupil dilation as an indicator of cognitive effort. By doing so, they can ensure that athletes perform at their best in high-stakes environments.

Funding: This research received no external funding.

Acknowledgments: The authors wish to thank all the study participants for their collaboration.

Conflict of interest: The authors declare no conflicts of interest.

References

- Adams, E. J., Nguyen, A. T., & Cowan, N. (2018). Theories of Working Memory: Differences in Definition, Degree of Modularity, Role of Attention, and Purpose. *Language, Speech, and Hearing Services in Schools*, 49(3), 340–355. https://doi.org/10.1044/2018_LSHSS-17-0114
- Alder, D., Broadbent, D. P., & Poolton, J. (2021). The combination of physical and mental load exacerbates the negative effect of each on the capability of skilled soccer players to anticipate action. *Journal of Sports Sciences*, 39(9), 1030–1038. <https://doi.org/10.1080/02640414.2020.1855747>
- Appel, T., Scharinger, C., Gerjets, P., & Kasneci, E. (2018). Cross-subject workload classification using pupil-related measures. *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications*, 1–8. <https://doi.org/10.1145/3204493.3204531>
- Arent, S. M., & Landers, D. M. (2003). Arousal, anxiety, and performance: A reexamination of the inverted-U hypothesis. *Research Quarterly for Exercise and Sport*, 74(4), 436–444.
- Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In *Psychology of learning and motivation* (Vol. 2, pp. 89–195). Elsevier. <https://www.sciencedirect.com/science/article/pii/S0079742108604223>
- Campbell, M. J., Moran, A. P., Bargary, N., Surmon, S., Bressan, L., & Kenny, I. C. (2019). Pupillometry during golf putting: A new window on the cognitive mechanisms underlying quiet eye. *Sport, Exercise, and Performance Psychology*, 8(1), 53.
- Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working memory from the psychological and neurosciences perspectives: A review. *Frontiers in Psychology*, 9, 401.
- Cowley, B., Filetti, M., Lukander, K., Tornainen, J., Henelius, A., Ahonen, L., Barral, O., Kosunen, I., Valtonen, T., & Huottilainen, M. (2016). The psychophysiology primer: A guide to methods and a broad review with a focus on human–computer interaction. *Foundations and Trends® in Human–Computer Interaction*, 9(3–4), 151–308.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18(1), 193–222.
- Duchowski, A. T., Krejtz, K., Krejtz, I., Biele, C., Niedzielska, A., Kiefer, P., Raubal, M., & Giannopoulos, I. (2018). The Index of Pupillary Activity: Measuring Cognitive Load vis-à-vis Task Difficulty with Pupil Oscillation. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–13. <https://doi.org/10.1145/3173574.3173856>
- Fleddermann, M.-T., Heppel, H., & Zentgraf, K. (2019). Off-court generic perceptual-cognitive training in elite volleyball athletes: Task-specific effects and levels of transfer. *Frontiers in Psychology*, 10, 1599.
- Formenti, D., Trecroci, A., Duca, M., Vanoni, M., Ciovati, M., Rossi, A., & Alberti, G. (2022). Volleyball-specific skills and cognitive functions can discriminate players of different competitive levels. *The Journal of Strength & Conditioning Research*, 36(3), 813–819.
- Furley, P., & Memmert, D. (2013). “Whom should I pass to?” The more options the more attentional guidance from working memory. *Plos One*, 8(5), e62278.
- Furley, P., & Wood, G. (2016). Working memory, attentional control, and expertise in sports: A review of current literature and directions for future research. *Journal of Applied Research in Memory and Cognition*, 5(4), 415–425.
- Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends in Cognitive Sciences*, 16(2), 129–135.
- Gu, Q., Zou, L., Loprinzi, P. D., Quan, M., & Huang, T. (2019). Effects of open versus closed skill exercise on cognitive function: A systematic review. *Frontiers in Psychology*, 10, 467457.
- Güler, G., Şimşek, D., Tuncer, S., & Mon-López, D.

- (2024). Evaluation of physiological parameters and gaze behaviour of air pistol shooters related to performance outcomes. *International Journal of Performance Analysis in Sport*, 24(3), 218–229. <https://doi.org/10.1080/24748668.2023.2280348>
- Hess, E. H., & Polt, J. M. (1964). Pupil Size in Relation to Mental Activity during Simple Problem-Solving. *Science*, 143(3611), 1190–1192. <https://doi.org/10.1126/science.143.3611.1190>
- Hirsch, P., Nolden, S., Declerck, M., & Koch, I. (2018). Common cognitive control processes underlying performance in task-switching and dual-task contexts. *Advances in Cognitive Psychology*, 14(3), 62.
- Jerčić, P., Sennersten, C., & Lindley, C. (2020). Modeling cognitive load and physiological arousal through pupil diameter and heart rate. *Multimedia Tools and Applications*, 79(5–6), 3145–3159. <https://doi.org/10.1007/s11042-018-6518-z>
- Kahneman, D., & Beatty, J. (1966). Pupil Diameter and Load on Memory. *Science*, 154(3756), 1583–1585. <https://doi.org/10.1126/science.154.3756.1583>
- Knudsen, E. I. (2007). Fundamental Components of Attention. *Annual Review of Neuroscience*, 30(1), 57–78. <https://doi.org/10.1146/annurev.neuro.30.051606.094256>
- Laessoe, U., Grarup, B., & Bangshaab, J. (2016). The use of cognitive cues for anticipatory strategies in a dynamic postural control task-validation of a novel approach to dual-task testing. *PloS One*, 11(8), e0157421.
- Memmert, D. (2009). Pay attention! A review of visual attentional expertise in sport. *International Review of Sport and Exercise Psychology*, 2(2), 119–138. <https://doi.org/10.1080/17509840802641372>
- Müller, S., & Abernethy, B. (2012). Expert Anticipatory Skill in Striking Sports: A Review and a Model. *Research Quarterly for Exercise and Sport*, 83(2), 175–187. <https://doi.org/10.1080/02701367.2012.10599848>
- Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive Load Theory and Instructional Design: Recent Developments. *Educational Psychologist*, 38(1), 1–4. https://doi.org/10.1207/S15326985EP3801_1
- Parikh, K., Zhuang, J., Pallister, K., Jiang, J., & Smith, M. (2018). 40-1: Invited Paper: Next Generation Virtual Reality Displays: Challenges and Opportunities. *SID Symposium Digest of Technical Papers*, 49(1), 502–505. <https://doi.org/10.1002/sdtp.12611>
- Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and Performance. *Annual Review of Psychology*, 52(1), 629–651. <https://doi.org/10.1146/annurev.psych.52.1.629>
- Pleša, J., Kozinc, Ž., & Šarabon, N. (2021). The association between force-velocity relationship in countermovement jump and sprint with approach jump, linear acceleration and change of direction ability in volleyball players. *Frontiers in Physiology*, 12, 763711.
- Romeas, T., Chaumillon, R., Labbé, D., & Faubert, J. (2019). Combining 3D-MOT With Sport Decision-Making for Perceptual-Cognitive Training in Virtual Reality. *Perceptual and Motor Skills*, 126(5), 922–948. <https://doi.org/10.1177/0031512519860286>
- Şimşek, D., Bıdıl, S., & Özböke, C. (2023). Cognitive-Motor Dual-Task Ability of Elite Badminton Athletes. *Spor Bilimleri Dergisi*, 34(1), 32–41.
- Simsek, D., Ozboke, C., & Gultekin, E. A. (2021). Evaluation of the use of postural control strategies during dual-tasks of hearing-impaired athletes. *Montenegrin Journal of Sports Science and Medicine*, 10(1), 11.
- Soto, D., Hodsoll, J., Rotshtein, P., & Humphreys, G. W. (2008). Automatic guidance of attention from working memory. *Trends in Cognitive Sciences*, 12(9), 342–348.
- Soto, D., & Humphreys, G. W. (2007). Automatic guidance of visual attention from verbal working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 33(3), 730.
- Trecroci, A., Duca, M., Cavaggioni, L., Rossi, A., Scurati, R., Longo, S., Merati, G., Alberti, G., & Formenti, D. (2021). Relationship between Cognitive Functions and Sport-Specific Physical Performance in Youth Volleyball Players. *Brain Sciences*, 11(2), Article 2. <https://doi.org/10.3390/brainsci11020227>
- Van Der Wel, P., & Van Steenbergen, H. (2018).

- Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychonomic Bulletin & Review*, 25(6), 2005–2015. <https://doi.org/10.3758/s13423-018-1432-y>
- Voss, M. W., Heo, S., Prakash, R. S., Erickson, K. I., Alves, H., Chaddock, L., Szabo, A. N., Mailey, E. L., Wójcicki, T. R., White, S. M., Gothe, N., McAuley, E., Sutton, B. P., & Kramer, A. F. (2013). The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: Results of a one-year exercise intervention. *Human Brain Mapping*, 34(11), 2972–2985. <https://doi.org/10.1002/hbm.22119>
- Wang, C.-H., Chang, C.-C., Liang, Y.-M., Shih, C.-M., Chiu, W.-S., Tseng, P., Hung, D. L., Tzeng, O. J., Muggleton, N. G., & Juan, C.-H. (2013). Open vs. Closed skill sports and the modulation of inhibitory control. *PloS One*, 8(2), e55773.
- Wang, X., Soh, K. G., Samsudin, S., Deng, N., Liu, X., Zhao, Y., & Akbar, S. (2023). Effects of high-intensity functional training on physical fitness and sport-specific performance among the athletes: A systematic review with meta-analysis. *Plos One*, 18(12), e0295531.
- Williams, M. (2002). Perceptual and cognitive expertise in sport. *The Psychologist*, 15(8), 416–417.
- Xu, X., Ding, X., Chen, L., Chen, T., Su, H., Li, X., Ye, Y., Shi, W., Ji, J., & Zhao, M. (2021). The transcranial direct current stimulation over prefrontal cortex combined with the cognitive training reduced the cue-induced craving in female individuals with methamphetamine use disorder: A randomized controlled trial. *Journal of Psychiatric Research*, 134, 102–110.
- Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. <http://psychclassics.yorku.ca/Yerkes/Law/>
- Yu, Y., Zhang, L., Cheng, M.-Y., Liang, Z., Zhang, M., & Qi, F. (2025). The effects of different fatigue types on action anticipation and physical performance in high-level volleyball players. *Journal of Sports Sciences*, 1–13. <https://doi.org/10.1080/02640414.2025.2456399>