Original Article

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Effects of a 6-week stroboscopic training program on specific blocking reaction speed in young volleyball players

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Abstract: Background: Although stroboscopic effects are recognized as an effective tool for enhancing information processing in general perceptual-cognitive tasks, research on their transfer to sport-specific skills is limited. This study aims to evaluate the impact of a 6-week stroboscopic intervention on volleyball-specific blocking reaction speed. Additionally, it analyzes the variation in explosive leg strength as a potential factor influencing the effectiveness of volleyball blocking. Material and Methods: This study included 50 young volleyball players (26 males, 24 females), divided into an experimental and a control group. Both groups performed the same volleyball-specific tasks, but the experimental group did so under stroboscopic conditions. Participants were evaluated three times using a volleyball-specific blocking reaction task: pre-training, post-6-week training, and four weeks later. Additionally, a countermovement jump with arm swing (CMJA) test assessed its impact on blocking reaction speed. Results: The ANOVA conducted on the blocking reaction speed test revealed a significant effect of time ($p<0.001$, $\eta p^2= 0.17$). In the stroboscopic group, significant differences were found between pre-test and post-test ($p=0.031$, $d=0.54$) and between post-test and retention test ($p=0.017$, $d=0.58$). The ANCOVA analysis revealed that variations in CMJA did not significantly affect the improvements in blocking reaction speed ($p=0.426$, $\eta p^2=0.01$). Conclusion: Over six weeks, stroboscopic training was more effective than regular training in improving volleyball-specific blocking reaction speed, though these effects were short-term and ultimately showed no lasting differences between the groups. Furthermore, the enhancements in reaction speed were more likely due to adaptations in perceptual-cognitive performance rather than motor factors.

Keywords: training intervention; stroboskopic glasses; skill transfer; volleyball blocking skills; reactive training

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INTRODUCTION

The speed of visuomotor reactions is commonly regarded as an essential aspect of goal-directed movements in team sports, especially those requiring agility maneuvers. Volleyball is a multifaceted sport that relies on a combination of technical, tactical, and physical skills. It involves various dynamic movements, including vertical jumps, shots, and quick changes of direction [1]. In volleyball, the effectiveness of movement in blocking is a crucial element of special agility, requiring quick, goal-directed movements in response to the opponent's actions in attack to prevent the opponent from scoring points. Effective volleyball blocking movement demands not only the synchronization of team actions and the recall of strategic patterns, but also a combination of anticipation and decision-making skills [2-5]. Additionally, it requires precise coordination of movements, optimal body positioning, and a thorough understanding of the biomechanical elements involved in the action [6].

In the dynamic and fast-paced environment of volleyball, players are required to quickly process a large amount of information to make accurate motor actions. Specifically, in blocking scenarios, players must swiftly assess the trajectory and timing of the incoming attack, and adjust their blocking strategy in real-time based on these dynamic factors. This need for quick assessment and adaptation places an emphasis on perceptual-cognitive skills, adding another layer to the comprehensive skill set required for effective blocking in volleyball. Perceptual-cognitive skills are crutial for achieving proficiency in this context, particularly under the pressure of time constraints [4, 7]. These volleyball-specific skills and perceptual-cognitive functions not only differentiate players at different competitive levels [8] and positions on the court [9], but also vary across age groups [4] and genders [10]. This variation underscores the importance of understanding how perceptual-cognitive training can be adapted and applied effectively in diverse contexts.

Accordingly, in recent years, there has been extensive investigation into the impact of perceptual-cognitive training on volleyball skills using a variety of different approaches. For instance, the study conducted by Fleddermann et al. [11] focused on evaluating the impact of an eight-week, off-court, visually oriented perceptual-cognitive training program, which utilized a three-dimensional multiple-object tracking task, in elite volleyball players. Their research confirmed positive outcomes in task-specific assessments and two near-transfer tests directly related to the perceptual-cognitive intervention. However, it did not find significant improvements in far-transfer tests, particularly in the volleyball-specific blocking test. In turn, Fortes et al. [12] demonstrated an improvement in the passing decision-making performance of young volleyball athletes through an eight-week imagery training protocol. The experimental group engaged in training that involved observing images and videos of successful competitive volleyball actions, aimed at enhancing imaginative capacity. The assessment of passing decision-making was conducted using a simulation that replicated the conditions of an official volleyball game. In their 6-week study, Formenti et al. [13], evaluated the impact of sport vision training (with generic or volleyball-specific motor actions) in a non-sport-specific context, comparing it to traditional volleyball training in a sport-specific context among female volleyball players. The study found that traditional training improved the accuracy of volleyball-specific skills (accuracy of passing, setting, and serving skills) more than vision training, but the vision training groups showed greater improvement in cognitive performance (clinical reaction time, executive control, and perceptual speed). These results indicate that the training environment is crucial for enhancing sport-specific skills and cognitive performance, supporting an ecological approach to sports training.

One of the emerging trends in perceptual-cognitive training within sports scenarios involves integrating stroboscopic stimulation into on-field tasks. Stroboscopic training is a technique that intensifies the requirements on the visuomotor system by providing intermittent visual input during motor activities, leading to improved performance in standard visual situations [14]. Our recent study [15] demonstrated the positive impact of stroboscopic training, especially in terms of improvements in laboratory tasks measuring simple motor reaction time, complex reaction speed, and saccade velocity. In addition, we noted significant gains in reactive agility during field tests post-intervention in the stroboscopic group. However, the final training effects did not show a significant difference between the stroboscopic and control groups. While both groups exhibited improvements in reactive agility, the results clearly highlighted the beneficial effects of stroboscopic training on this skill. It is important to acknowledge that reactive agility is closely linked to motor and biomechanical factors, including running speed, technique, balance, and the strength and muscle power of the lower limbs [16-20]. Consequently, this study aimed to assess the efficacy of stroboscopic intervention in specific agility tasks. This included evaluating reaction speed in a volleyball-specific blocking task, while controlling for the motor factor, specifically the variation in explosive leg strength.

Current research into the effects of stroboscopic training on athletes' sport-specific skills, also known as far transfer, remains limited and has yielded mixed results. For example, an experimental study in badminton found that stroboscopic training appeared to enhance on-field performance [21], though these improvements weren't statistically significant when compared to a control group. In contrast, ice hockey research involving on-ice tests such as shooting accuracy, reaction time, and puck handling demonstrated that participants who underwent stroboscopic training improved their on-ice skills by an average of 18%, a significant contrast to the non-improving control group [22]. Despite this, the comprehensive effectiveness of far transfer through various perceptual and cognitive training methods, including stroboscopic training, remains underexplored [11, 23-26].

Therefore, this study aims to assess the impact of a 6-week stroboscopic intervention on specific volleyball skills, particularly in the speed of movement in responding to visual cues during blocking. Additionally, to understand post-training effects, we evaluated the variability in explosive leg strength as a potential influencing factor on the effectiveness of volleyball blocking [27, 28].

MATERIAL AND METHODS

Participants

The study involved a group of 50 athletes, comprising 26 males and 24 females, with an average age of 16.5 years (±0.6 years standard deviation). Participants were randomly assigned to either a stroboscopic or non-stroboscopic group, ensuring an equal gender distribution in both groups. The stroboscopic group had an average height of 180.2 cm (± 8.2 cm) and weight of 74.3 kg (± 10.4 kg), while the non-stroboscopic group had an average height of 181.9 cm (± 8.1 cm) and weight of 71.6 kg (± 8.9 kg). Both groups had similar sports experience, averaging around 6.6-6.7 years. Inclusion criteria required regular volleyball training and participation in official competitions. Exclusion criteria included specific health conditions, such as epilepsy, migraine, or injuries that would impede the completion of the designated tests. Written consent was obtained from all participants and their guardians.

Protocol

Volleyball-specific blocking reaction task

The Fitlight® system (FITLIGHT Corp., Ontario, Canada) was used to analyze the reaction speed in a specific blocking task in volleyball. This protocol, adapted from the one initially outlined by Piasecki et al. [29], was first implemented in a study with a group of young volleyball players (n=97). It demonstrated good reliability, evidenced by ICC of 0.81, CV of 2.53%, and TE of 0.89 seconds.

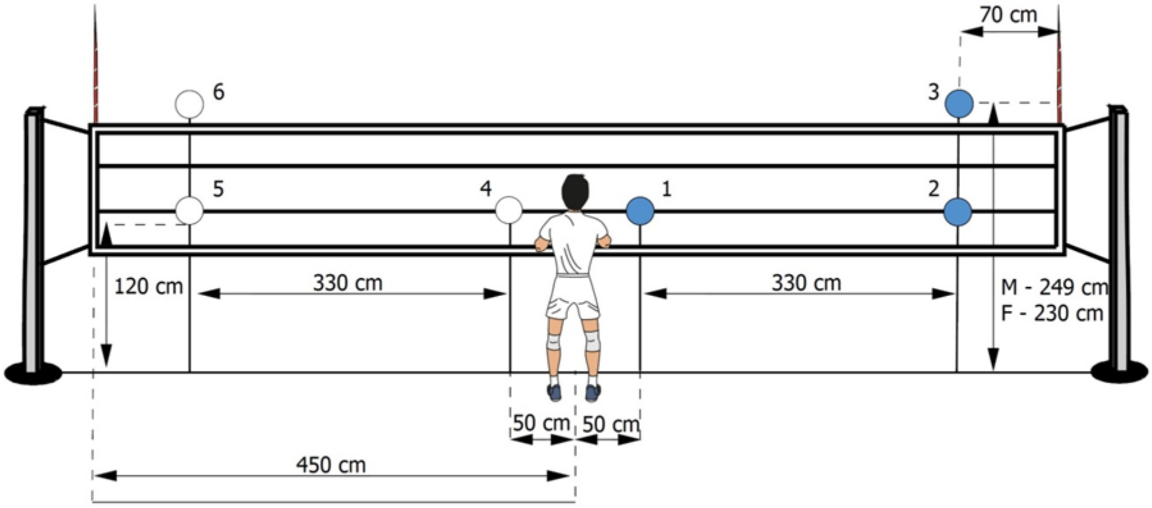

Figure 1. Volleyball-specific blocking reaction test protocol. The graphic illustrations were prepared using Easy Sports-Graphics software. Abbreviation: M - Male, F - Female.

In the study, participants assumed a ready position at the court's center, 450 cm from the sideline, as shown in Figure 1. The initial light discs (1 and 4) were positioned 50 cm from this starting point. Discs 1, 2, 4, and 5 were set at a height of 120 cm to mimic typical match conditions, ensuring the player's initial posture and reaction to visual stimuli were realistic. Considering FIVB net hight regulations for youth players (243 cm for males, 224 cm for females), the final light discs (3 and 6) were placed 6 cm above the upper net band (249 cm for males, 230 cm for females). A total of six light discs were used, arranged in sequence 3 for left side and 3 for right side in randomized order. The task required participants to quickly react to a blue light signal shown either on the right side (discs 1, 2, 3) or the left side (discs 4, 5, 6). Athletes were allowed to use any blocking technique of their choice. Deactivating the last light disc (3 or 6) had to be done following a jump with both hands, simulating a volleyball block. Deactivation of all light discs was configured in a "distance deactivation mode" of 60 cm. The delay in activating the next trial, varying from 3 to 5 seconds, occurred immediately after deactivating the last disc (3 or 6). The test began with a standard 15-minute warm-up, after which the participant received test instructions and performed one adaptation test module. All participants performed the test twice with a 5-minute break. The best overall time (s) taken to complete the trial was included in further analysis.

Explosive leg strength

A countermovement jump with an arm swing (CMJA) (ICC = 0.95; CV = 4.88%; TE = 1.79 cm) was performed to assess explosive leg strength, following the protocol by Bosquet et al. [30]. The jumps were measured using the Optojump Next system (Microgate Next, Bolzano, Italy). Participants performed three jumps, with no specific instructions given regarding the depth or speed of the countermovement or the arm swing. A minimum 30-second recovery period was allowed between jumps. The highest jump for CMJA was selected for further analysis. Jump height [cm] was the primary metric analyzed.

Procedure

The study included a six-week training period with sessions conducted three times weekly, alongside regular training. Assessments were performed pre-, post-, and at retention stages, evaluating volleyball-specific blocking reaction speed test and countermovement jumps with arm swing (CMJA). Both stroboscopic and non-stroboscopic groups engaged in identical sport-specific exercises, differing only in visual conditions. Each group followed three volleyball-specific training protocols: 'wall passing drills' (three

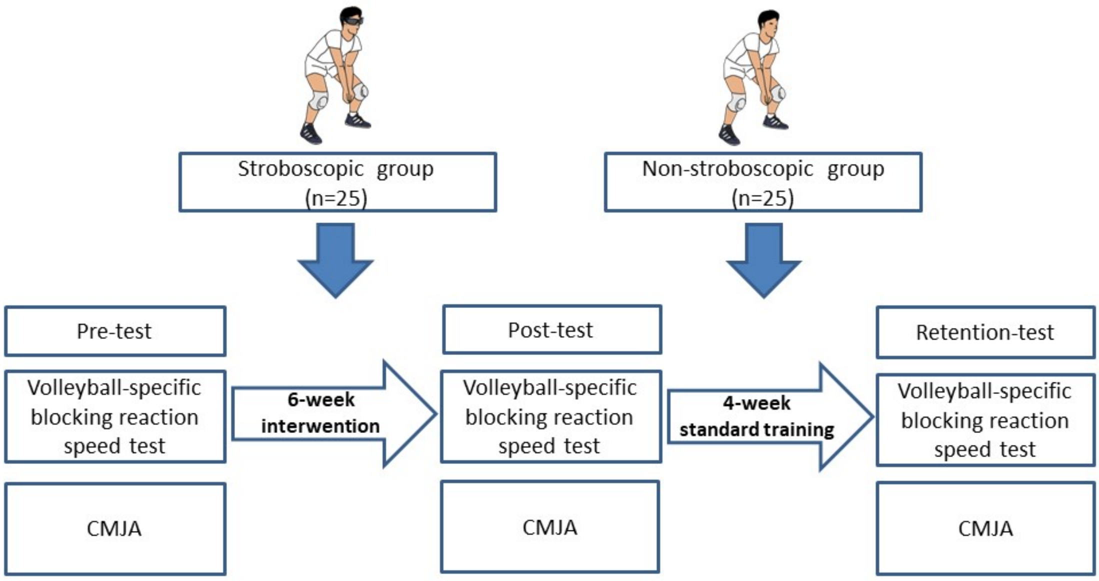

Figure 2. Overview of the experimental protocol for the study. Note: CMJA - countermovement jump with an arm swing.

tasks), 'partner passing drills' (five tasks), and 'passing rotation drill' (two forms of passing with directional changes) [15]. All protocols included reactive exercises based on various forms of reaction time training, lasting 25-30 minutes. The experimental group wore stroboscopic eyewear (Senaptec Strobe, Beaverton, USA) during training, controlled via Bluetooth and the Senaptec Strobe App. The stroboscopic sessions lasted 2.5 minutes each, followed by a 2.5-minute break. To progressively challenge visual processing, the flicker frequency and duty cycle were adjusted weekly: week 1 at 15 Hz, 50%; week 2 at 13 Hz, 50%; and so on, culminating in week 6 at 9 Hz, 70%. The weekly training duration averaged 45.0 ± 1.4 minutes for the stroboscopic group and 46.1 ± 2.0 minutes for the non-stroboscopic group. Figure 2 provides an overview of the experimental protocol.

Statistical analysis

Descriptive statistics were utilized to present means and standard deviations. The normality of data was assessed using the Shapiro-Wilk test, while the homogeneity of variances was verified using the Levene test ($p > 0.05$). To examine the impact of stroboscopic training on volleyball-specific blocking reaction speed, ANOVAs were conducted with 'GROUP' as the between-subjects factor and 'TIME' as the within-subjects factor. Additional analyses of covariance (ANCOVA) were performed to analyze changes in volleyball-specific blocking reaction speed, with post-training changes as the dependent variable. In this analysis, 'group' was treated as a categorical factor, and the explosive leg strength (CMJA) post-training changes were considered as a covariate. The Holm-Bonferroni procedure was applied for post-hoc comparisons, setting the significance level at $p < 0.05$. Effect sizes were reported using Cohen's d [31] for t-tests and partial eta squared (ηp^2) for F-tests. According to Cohen's criteria, effect size values of 0.2, 0.5, and 0.8 were interpreted as small, medium, and large, respectively, for Cohen's d. For partial eta squared, values of 0.01, 0.06, and 0.14 represented small, medium, and large effects, respectively. Pearson product moment correlation analysis determined whether training-induced changes in explosive leg strength were related to changes in volleyball-specific blocking reaction speed performance. All statistical analyses were performed using JASP software (version 16.1).

Ethics committee

The investigations were conducted in accordance with the principles of the Declaration of Helsinki. The study adhered to ethical standards and received approval from the Research Ethics Committee of the University School of Physical Education in Wrocław, under protocol number 8/2021.

RESULTS

The descriptive statistics of the sample in pre-, post-, and retention conditions for stroboscopic and non-stroboscopic groups are presented in Table 1.

Table 1. Descriptive statistics of the volleyball-specific blocking reaction speed and explosive leg strength in the stroboscopic and non-stroboscopic groups in pre-tests, post-tests, and retention tests.

Variable	Group	Pre-test mean±SD (min-max)	Post-test mean±SD (min-max)	Retention-test mean±SD (min-max)
Volleyball-specific blocking reaction speed [s]	stroboscopic	33.96±1.82 (30.27-36.86)	32.84±1.48 (29.93-35.01)	34.03±1.19 (31.00-35.45)
	non-stroboscopic	34.21±2.51 (29.28-39.13)	33.50±2.83 (29.45-39.43)	34.35±2.17 (29.85-38.16)
Explosive leg strength [cm]	stroboscopic	38.71±10.13 (25.10-66.80)	39.39±11.51 (21.20-65.70)	38.64±11.29 (24.80-63.80)
	non-stroboscopic	36.41±7.69 (25.90-53.40)	37.02±7.44 (24.20-50.50)	35.98±7.23 (25.10-49.50)

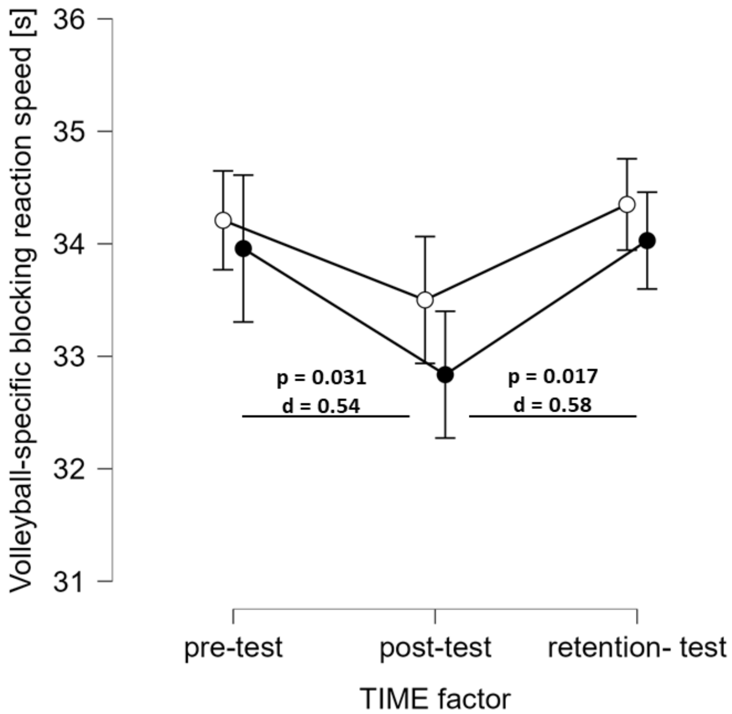

Figure 3. Interaction plots of volleyball-specific blocking reaction speed by TIME and GROUP: stroboscopic (black dots) vs non-stroboscopic (white dots) groups in a pre-post-retention design. Pre-, post-, and retention test values are presented as means and 95% CIs. Significant changes ($p < 0.05$) are observed for the stroboscopic group.

The ANOVA on the volleyball-specific blocking reaction speed test revealed a significant main effect for TIME ($F_{2,96} = 10.03$, $p < 0.001$, $\eta p^2 = 0.17$) and no effect for GROUP ($F_{1,48} = 0.65$, $p = 0.424$, $\eta p^2 = 0.01$). Further, the interaction between TIME and GROUP factors also had no significant effect ($F_{2,96} = 0.39$, $p = 0.679$, $\eta p^2 = 0.01$). In the stroboscopic group, post-hoc tests showed significant differences between the pre-test and post-test ($p = 0.031$, $d = 0.54$) as well as between the post-test and retention test ($p = 0.017$, $d = 0.58$), indicating a significantly faster volleyball-specific blocking reaction speed dependent on the stroboscopic training (Figure 3).

The ANCOVA, regardless of the group ($F_{1,47} = 0.36$, $p = 0.551$, $\eta p^2 = 0.01$), did not reveal the impact of post-test explosive leg strength changes on post-test volleyball-specific blocking reaction speed changes ($F_{1,47} = 0.64$, $p = 0.426$, $\eta p^2 = 0.01$). Pearson product moment correlation analyses revealed a lack of relationship between training-induced changes in volleyball-specific blocking reaction speed and the explosive leg strength changes ($r = 0.188$, $p = 0.414$).

DISCUSSION

This study evaluated the effects of stroboscopic intervention on volleyball-specific blocking reaction speed in young volleyball players. The results indicated that stroboscopic training was more effective than regular training, with participants in the stroboscopic group demonstrating significant improvement in volleyball-specific blocking reaction tasks after 6 weeks of intervention. However, it was noted that this effect was short-term, and ultimately, no lasting difference in performance achievements between the stroboscopic and control groups could be confirmed. Furthermore, it was determined that volleyball-specific blocking reaction speed improvements were independent of any changes in the athletes' explosive leg strength levels, suggesting that the observed enhancement was not influenced by analyzed motor factor.

Our findings lend additional support to the notion that stroboscopic training can effectively enhance visuomotor abilities in sports training [14, 32]. Specifically, the study results corroborated our earlier observations [15] where stroboscopic intervention improved reactive agility, with more pronounced performance gains observed in the short-term as opposed to long-term changes. Furthermore, our findings suggest that the enhanced performance in the stroboscopic group was not determined by motor aspects. The results show that variability in explosive leg strength during the intervention did not influence the variability in outcomes for volleyball-specific blocking reaction speed. This leads to the assumption that the stroboscopic intervention positively affected the perceptual-cognitive factor, which plays a key role in movements requiring directional changes in response to a signal. Recent studies highlight the importance of perceptual-cognitive expertise in the context of agility movements [10, 33]. This involves an athlete's ability to scan and process the environment, integrating relevant information into their actions and coordinating this with the execution of adequate motor responses

Furthermore, our research results can be related to the findings from the studies by Hülsdünker et al. [34], which revealed that in young elite badminton players, the improvements in visuomotor reaction times post-stroboscopic training were predominantly linked to advancements in visual processing, rather than to motor process enhancements. Other studies conducted among elite handball players [35] also indicated that the stroboscopic training program significantly impacts early visual processing. This is evidenced by a decrease in the P100 implicit time for both the dominant eye and binocular vision, especially in extra-foveal vision. Contrary to this, our previous study [15] demonstrated that stroboscopic training led to significant improvements in the majority of measures (three out of five) related to visual and visuomotor functions in laboratory tasks, with a more noticeable enhancement in visuomotor as opposed to sensory processing. It seems that the impact of the intervention, which disrupted the visual process during exercises, can affect various levels of information processing and largely depends on the specifics of the exercises performed. A recent study in this field by Kroll et al. [36] showcased the efficacy of stroboscopic training in improving jumping performance, highlighting its potential as a supplementary method to plyometric training for volleyball. In our exercise protocols, we concentrated on reactive exercises incorporating various forms of reaction time training. These exercises demanded enhanced alertness, heightened attention, faster eye movements, and more rapid body movements. In our view, the results suggest a significant utility of the training method involving stroboscopic glasses for both near and far transfer, as evidenced in both previous [15] and current studies.

The findings of our study indicate that stroboscopic training enhances the effectiveness of a task that simulates volleyball blocking, thereby emphasizing the importance of the perceptual-cognitive factor. Fleddermann and Zentgraf [37] demonstrated that elite athletes experience disruptions between their motor skills and cognitive functions in a dual-task scenario, as observed through a simulated blocking task in a lab setting designed to replicate a game situation. Specifically, they observed that athletes achieved greater jumping height in self-initiated block jumps without any additional cognitive load, as opposed to when they were faced with a perceptual-cognitive task (dual-task). This suggests that cognitive demands can significantly affect motor performance, as evidenced by the decreased jumping height when athletes engaged in a perceptual-cognitive task simultaneously. In this context, our research requires further continuation.

Exploring the effectiveness of stroboscopic training, our study offers new insights on its utility concerning specific volleyball skills. However, our research is not without limitations. Since we have tested only a single specific far-transfer task, we cannot dismiss the possibility of other benefits from stroboscopic intervention, such as improved reactions during practice and games. Additionally, our task did not require players to differentiate their reactions, a crucial aspect for effective blocking. Decision-making in a sports context is a complex process. It relies on athletes' abilities to identify the correct information in their environment, plan future actions, and choose the most suitable response tailored to the specific play situation [38]. It should also be considered that sports situations are highly variable, and it's difficult to precisely determine which variables might be affected [39]. Consequently, the perceptual-cognitive factor is one of many influencing the effectiveness of actions, in this case, the reaction speed associated with movement in blocking. Future research should focus on examining perceptual-cognitive strategies and evaluating an athlete's ability to effectively integrate perception and action under dynamic and ecologically valid conditions. Finally, in our studies, we did not analyze the influence of players' positions as a variable that could affect the study results. From previous research, it is known that anthropometric characteristics, muscular strength and power test scores, and perceptual-cognitive skills of players vary in relation to their playing positions on the field [9, 40,41].

CONCLUSION

In conclusion, our study's findings reveal that a 6-week volleyball-specific training program using stroboscopic eyewear significantly outperformed traditional training methods. The athletes in the stroboscopic group exhibited considerable improvement in volleyball-specific blocking reaction tasks following the intervention, which may be associated with adaptations in the perceptual-cognitive gains of performance. However, it's important to note that these enhancements were observed in the short term. Therefore, the continuation of exercises that enhance visuomotor efficiency appears to be justified in the context of training young volleyball players.

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REFERENCES

1. Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. Am J Sports Med 2005;33(10):1513-9. doi: 10.1177/0363546505274935
2. Araújo R, Mesquita I, Marcelino R. Relationship between block constraints and set outcome in elite male volleyball. Int J Perform Anal Sport 2009; 9(3): 306-13. doi: 10.2202/1559-0410.1216
3. Nuri L, Shadmehr A, Ghotbi N, Attarbashi Moghadam B. Reaction time and anticipatory skill of athletes in open and closed skill-dominated sport. Eur J Sport Sci 2013; 13(5): 431-6. doi: 10.1080/17461391.2012.738712
4. De Waelle S, Warlop G, Lenoir M, Bennett SJ, Deconinck FJA. The development of perceptual-cognitive skills in youth volleyball players. J Sports Sci 2021; 39(17): 1911-25. doi: 10.1080/02640414.2021.1907903
5. Cieśluk K, Sadowska D, Krzepota J. The use of modern measuring devices in the evaluation of movement in the block in volleyball depending on the difficulty of the task determined by light signals. Appl Sci 2023; 13(20): 11462. doi: 10.3390/app132011462
6. Lobietti R. A review of blocking in volleyball: From the notational analysis to biomechanics. J Hum Sport Exerc 2009;4(2):93-9. doi: 10.4100/jhse.2009.42.03
7. Mann DT, Williams AM, Ward P, Janelle CM. Perceptual-cognitive expertise in sport: a meta-analysis. J Sport Exerc Psychol 2007; 29(4): 457-78. doi: 10.1123/jsep.29.4.457
8. Formenti D, Trecroci A, Duca M, Vanoni M, Ciovati M, Rossi A, et al. Volleyball-specific skills and cognitive functions can discriminate players of different competitive levels. J Strength Cond Res 2022; 36(3): 813-9. doi: 10.1519/jsc.0000000000003519
9. Fortin-Guichard D, Laflamme V, Julien A-S, Trottier C, Grondin S. Decision-making and dynamics of eye movements in volleyball experts. Sci Rep 2020; 10(1): 17288. doi: 10.1038/s41598-020-74487-x
10. Zwierko M, Jedziniak W, Popowczak M, Rokita A. Reactive agility in competitive young volleyball players: a gender comparison of perceptual-cognitive and motor determinants. J Hum Kinet 2022; 85: 87-96. doi: 10.2478/hukin-2022-0112
11. Fleddermann MT, Heppe H, Zentgraf K. Off-court generic perceptual-cognitive training in elite volleyball athletes: task-specific effects and levels of transfer. Front Psychol 2019; 10: 1599. doi: 10.3389/fpsyg.2019.01599
12. Fortes LS, Freitas-Júnior CG, Paes PP, Vieira LF, Nascimento-Júnior JRA, Lima-Júnior DRAA, et al. Effect of an eight-week imagery training programme on passing decision-making of young volleyball players. Int J Sport Psychol 2020; 18(1): 120-8. doi: 10.1080/1612197x.2018.1462229
13. Formenti D, Duca M, Trecroci A, Ansaldi L, Bonfanti L, Alberti G, et al. Perceptual vision training in non-sport-specific context: effect on performance skills and cognition in young females. Sci Rep 2019; 9(1): 18671. doi: 10.1038/s41598-019-55252-1
14. Wilkins L, Appelbaum LG. An early review of stroboscopic visual training: insights, challenges and accomplishments to guide future studies. Int Rev Sport Exerc Psychol 2020; 13(1): 65-80. doi: 10.1080/1750984x.2019.1582081
15. Zwierko M, Jedziniak W, Popowczak M, Rokita A. Effects of in-situ stroboscopic training on visual, visuomotor and reactive agility in youth volleyball players. PeerJ 2023; 11: e15213. doi: 10.7717/peerj.15213
16. Condello G, Kernozek TW, Tessitore A, Foster C. Biomechanical analysis of a change-of-direction task in collegiate soccer players. Int J Sports Physiol Perform 2016; 11(1): 96-101. doi: 10.1123/ijspp .2014-0458
17. Koźlenia D, Domaradzki J, Trojanowska I, Czermak P. Association between speed and agility abilities with movement patterns quality in team sports players. Medicina dello Sport. 2020; 73(2): 176-86. doi: 10.23736/s0025-7826.20.03662-5
18. Freitas TT, Pereira LA, Alcaraz PE, Comyns TM, Azevedo P, Loturco I. Change-of-direction ability, linear sprint speed, and sprint momentum in elite female athletes: differences between three different team sports. J Strength Cond Res 2022; 36(1): 262-7. doi: 10.1519/jsc.0000000000003857
19. Spiteri T, Newton RU, Nimphius S. Neuromuscular strategies contributing to faster multidirectional agility performance. J Electromyogr Kinesiol 2015; 25(4): 629-36. doi: 10.1016/j.jelekin.2015.04 .009
20. Spiteri T, Nimphius S, Hart NH, Specos C, Sheppard JM, Newton RU. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. J Strength Cond Res 2014; 28(9): 2415-23. doi: 10.1519/jsc.0000000000000547

21. Hülsdünker T, Gunasekara N, Mierau A. Short- and long-term stroboscopic training effects on visuomotor performance in elite youth sports. Part 1: Reaction and Behavior. Med Sci Sports Exerc 2021; 53(5): 960-72. doi: 10.1249/mss.0000000000002541
22. Mitroff SR, Friesen P, Bennett D, Yoo H, Reichow AW. Enhancing ice hockey skills through stroboscopic visual training: a pilot study. Athl Train Sports Health Care 2013; 5(6): 261-4. doi: 10.3928/19425864-20131030-02
23. Palmer T, Coutts AJ, Fransen J. An exploratory study on the effect of a four-week stroboscopic vision training program on soccer dribbling performance. Braz J Mot Behav 2022; 16(3): 254-65. doi: 10.20338/bjmb.v16i3.310
24. Sala G, Aksayli ND, Tatlidil KS, Tatsumi T, Gondo Y, Gobet F. Near and far transfer in cognitive training: a second-order meta-analysis. Collabra Psychol 2019; 5(1): 18. doi: 10.1525/collabra.203
25. Krzepota J, Zwierko T, Puchalska-Niedbal L, Markiewicz M, Florkiewicz B, Lubinski W. The efficiency of a visual skills training program on visual search performance. J Hum Kinet 2015; 46: 231-40. doi: 10.1515/hukin-2015-0051
26. Zwierko T, Jedziniak W, Florkiewicz B, Stępiński M, Buryta R, Kostrzewa-Nowak D, et al. Oculomotor dynamics in skilled soccer players: The effects of sport expertise and strenuous physical effort. Eur J Sport Sci 2019; 19(5): 612-20. doi: 10.1080/17461391.2018.1538391
27. Tramel W, Lockie RG, Lindsay KG, Dawes JJ. Associations between absolute and relative lower body strength to measures of power and change of direction speed in division ii female volleyball players. Sports 2019; 7(7): 160 doi: 10.3390/sports7070160
28. Sattler T, Hadžić V, Dervišević E, Markovic G. Vertical jump performance of professional male and female volleyball players: effects of playing position and competition level. J Strength Cond Res 2015; 29(6): 1486-93. doi: 10.1519/jsc.0000000000000781
29. Piasecki L, Florkiewicz B, Krzepota J, Steciuk H, Zwierko T. System FitLight Trainer™ - Nowoczesna technologia w kontroli procesu treningu sportowego w piłce siatkowej. Mark Rynek. 2015; 11: 41-8.
30. Bosquet L, Berryman N, Dupuy O. A comparison of 2 optical timing systems designed to measure flight time and contact time during jumping and hopping. J Strength Cond Res 2009; 23(9): 2660-5. doi: 10.1519/JSC.0b013e3181b1f4ff.
31. Cohen J. Statistical Power Analysis for the Behavioral Sciences. New York, NY: Routledge Academic; 1988.
32. Carroll W, Fuller S, Lawrence J, Osborne S, Stallcup R, Burch R, et al. Stroboscopic visual training for coaching practitioners: a comprehensive literature review international. J Kinesiol Sports Sci 2021; 9(4): 49-59. doi: 10.7575/aiac.ijkss.v.9n.4p.49
33. Spiteri T, McIntyre F, Specos C, Myszka S. Cognitive training for agility: the integration between perception and action. Strength Cond J 2018; 40(1): 39-46. doi: 10.1519/ssc.0000000000000310
34. Hülsdünker T, Gunasekara N, Mierau A. Short- and long-term stroboscopic training effects on visuomotor performance in elite youth sports. part 2: brain-behavior mechanisms. Med Sci Sports Exerc 2021; 53(5): 973-85. doi: 10.1249/mss.0000000000002543
35. Zwierko T, Jedziniak W, Domaradzki J, Zwierko M, Opolska M, Lubiński W. Electrophysiological evidence of stroboscopic training in elite handball players: visual evoked potentials study. J Hum Kinet 2024;90. doi: 10.5114/jhk/169443
36. Kroll M, Preuss J, Ness BM, Dolny M, Louder T. Effect of stroboscopic vision on depth jump performance in female NCAA Division I volleyball athletes. Sports Biomech 2020: 1-11. doi: 10.1080/14763141.2020.1773917
37. Fleddermann M-T, Zentgraf K. Tapping the full potential? Jumping performance of volleyball athletes in game-like situations. Front Psych 2018; 9: 1375 doi: 10.3389/fpsyg.2018.01375
38. MacMahon C, McPherson SL. Knowledge base as a mechanism for perceptual-cognitive tasks: Skill is in the details! Int J Sport Psychol 2009; 40(4): 565–579.
39. Walton CC, Keegan RJ, Martin M, Hallock H. The potential role for cognitive training in sport: more research needed. Front Psych 2018; 9: 1121. doi: 10.3389/fpsyg.2018.01121
40. Marques MC, van den Tillaar R, Gabbett TJ, Reis VM, González-Badillo JJ. Physical fitness qualities of professional volleyball players: determination of positional differences. J Strength Cond Res 2009; 23(4): 1106-11. doi: 10.1519/jsc.0b013e31819b78c4
41. Domaradzki J, Popowczak M, Zwierko T. The mediating effect of change of direction speed in the relationship between the type of sport and reactive agility in elite female team-sport athletes. J Sports Sci Med. 2021; 20(4): 699-705. doi: 10.52082/jssm.2021.699