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The Journal of Sports Medicine and Physical Fitness 2020 mese;60(0):000–000
DOI: 10.23736/S0022-4707.20.10335-9

ORIGINAL ARTICLE
SECTION

Occlusion technique in swimming: a training method to improve exchange block time in swimming relays

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ABSTRACT

BACKGROUND: Swimming relay events have the concern regarding a good start is shared between the incoming and outgoing swimmers. The aim of this study was to evaluate changes in exchange block time (EBT) for swimming relay events as a result of a four-week training program using the occlusion technique.

METHODS: Twenty-eight national swimmers, 12 males (age: 17±1.83 years) and 16 females (age: 19.94±5.65 years) participated in this study. Subjects were required to undergo a training program on visual perception in relay swimming over the course of four weeks; they watched videos corresponding to the last movements of a swimmer during a 4×100m freestyle relay event. The videos were presented with temporal occlusion corresponding to predetermined approaching distances (7.5 m, 5.0 m, and 2.5 m). Swimmers were required to simulate a typical position for exiting the block and to estimate the time-to-contact of the incoming swimmer. The EBT was collected during a real 4×100-m freestyle competition before and after the application of the training program.

RESULTS: Female swimmers showed a decreased in EBT, with an improvement of 1.42%, despite there not being a significant difference (P=0.68). The male swimmers had a higher improvement in EBT after the training, with a decrease of 13.34% (P=0.68).

CONCLUSIONS: Visual perception practice using video occlusion techniques seems to have a positive effect. On EBT in swimming relay events, particularly in female swimmers.

(*Cite this article as:* Conceição A, Costa AM, Silva AJ, Sobreiro P, Louro H. Occlusion technique in swimming: a training method to improve exchange block time in swimming relays. J Sports Med Phys Fitness 2020;60:000–000. DOI: 10.23736/S0022-4707.20.10335-9)

Key words: Visual perception; Swimming; Athletic performance; Athletes.

In competitive swimming, a common belief is that performance can be improved when swimmers compete in a relay event compared with their corresponding individual events.[1] Hüffmeier *et al.*[2] proposed that a better performance in a relay event might indicate a higher effort because of an increased motivation for the team outcome; Saavedra *et al.*[3] also suggested that the starting times are very short, and the differences between winning and losing a race are often so small that these times can be decisive.

In relay events, the International Swimming Federation (FINA) rules require that the second, third, and fourth swimmers start their dives from the starting block before the incoming swimmer has finished their bout of the race. The first swimmer must abide by the rules governing the start for individual events; the remaining swimmers can be in motion at the start and parts of the outgoing swimmer's foot must remain on the platform until the incoming swimmer has touched the wall.[4, 5] However, in relay events, the concern about a good start is shared between the incoming and outgoing swimmers.[4]

As the swimmer becomes more competitive, the importance of reducing the overall time of an event becomes apparent, because the ability to improve a relay event start is considered important for competitors seeking to reduce the overall relay time.[4] As such, in a perfect exchange, the toes of the outgoing swimmer leave the starting platform while the incoming swimmer touches the wall with their fingers, possibly improving the sum of their flat-start times by 1 to 2 seconds[3]. Furthermore, the sum of the block times of the three changeover swimmers is about 0.7 s,[6] whereas in individual trials the block time is between 0.6 and 0.8 s.[7, 8] Thus, the total exchange block time is the time that elapses between the incoming swimmer touching the wall and the outgoing swimmer leaving the block.[3] It is considering one of the main concerns of the coaches and swimmers in the training process, in order to minimize this exchange block time (EBT), to save time to the rest of the parts of the race. In this sense, Saavedra[3] showed that for male swimmers the EBT are: 0.64 s, 0.8 s, and 0.66 s, and for female: 0.8 s, 0.94 s, and 0.75 s for 4×100 m free, 4×200 m free, and 4×100 m styles, respectively. Siders[6] indicated that the sum of the block times of the three changeover swimmers in relays events is about 0.7 s, whereas in individual trials the block time is between 0.6 s and 0.8 s[7, 8].

From a perceptual point of view, the perception of the time taken by the incoming swimmer to touch the wall tends to influence the technique used for diving off the block.[5] Whiting and Sharp[9] considered the occlusion period to be the time interval from light-off to interception of the moving object, and also showed the relationship between the occlusion period and the frequency of correct decisions, which increased as the occlusion time increased (0-160 ms). There are only a few scientific studies published on relay swimming starts[1, 3-6, 10-14].

Some of the studies focus on: 1) analyzing the different starting techniques;[4, 6, 10, 11] 2) understanding the association of the relay exchange block time with final performance;[1, 3] 3) feedback methods to improve relay start;[5, 12] 4) predicting temporal outcomes;[13, 15] 5) pacing strategies.[14]

Luedtke and Duoos[12] developed a study in order to compare four methods of feedback regarding relay exchanges (time only; time and video; video only; coach only). They found that none of the four feedback methods was significantly different from others for improving the relay exchanges. Fischer *et al.*[5] compared two different relay start strategy feedbacks: offensive strategy (minimizing change over time (COT) and conservative strategy (maximizing horizontal peak force (HPF)) during take-off. They reported that improvements in relay start time (RST) were related to decreases in COT and also that feedback on the horizontal peak force provided superior effects on RST when compared with COT feedback. Bove *et al.*[13] compared swimmers, water-polo players, and rhythmic gymnastics, and found that swimmers were more accurate than subjects performing other sports in temporally predicting the final outcome of a swimming task in swimming relays; this difference was more obvious for occluded intervals of short duration (3 s). Recently, Ribeiro *et al.*[15] showed that swimmers tend to underestimate the time-to-contact of the incoming swimmer, in the context of a simulated relay race.

Although these previous studies provided useful knowledge concerning relay starts in swimming, but this body of literature remains insufficient to understand relay strategies by considering the analysis of the relay changeover, with the use of new approach of training, the occlusion technique.

Occlusion technique spectacles are popular with researchers because they allow the availability of visual information to be manipulated within in-situ settings and coupled to complex actions such as movements of the whole body to strike a high-speed objects.[16]

For instance, studies with this technique were done in football, squash, and hockey.[17, 18] Five occlusion time points were chosen for the investigation in Squash, 2 before, one during and 2 after a bat-ball contact. Experts were able to predict the direction of the blow more accurate than the novices.

Regarding competitive swimming, the occlusion technique should support the swimmers to predict the output of the incoming swimmer situation as good as possible and in turn the optimization of EBT in swimming events, and also allows to measure the amount of time a swimmer requires to visually detect the environmental context information he or she uses to perform a skill.[13]

According to Appelbaum and Erickson,[19] the effectiveness of traditional analog vision training drills in the last decade has seen a paradigm change in the types of approaches that are being implemented, by perceptual-learning-inspired training programs that use information about the structure and function of the visual system to engender more specific and robust learning.

This approach also can be an advantage regarding other training methods describe in the literature, because can lead to an improvement of the perceptual abilities and decision making in swimmers performance, to a decrease of training time in the pool, and then a transferring of learning-training to the gym or even at home, leading to increased autonomy in swimming training for each swimmer.

The possibility of integrating EBT measures has been previously suggested as a useful means to outline implications for the training process.[6] Accordingly, the purpose of this study was to evaluate changes in EBT during swimming relay events as a result of a four-week training program in swimming relays through the use of the occlusion technique.

The underlying objectives were to: 1) identify in which of these distances the swimmers have a better estimation times; 2) how the swimmers improve the EBT with the occlusion technique in a relay event. We hypothesized that swimmers would be more accurate at short occlusion distances and would improve their EBT in competition after four weeks of using the swimming relay training software.

Materials and methods

Participants

Twenty-eight national level swimmers (qualified to participate in national swimming competitions), including twelve male swimmers (age: 17±1.83 years; years of experience: 8.08±2.36 years; height: 177.5±4.37cm; body mass: 72.64±7.04 kg; FINA points for the 100-m freestyle long course: 579±67.50) and sixteen female swimmers (age: 19.94±5.65 years; years of experience: 5.94±2.01 years; height: 160.56±5.83 cm; body mass: 52.86±6.64 kg; FINA points for the 100-m freestyle long course: 504.56±72.62) volunteered to participate in this study.

All subjects had normal ocular health with no recent history of ocular pathology, medication, or systemic diseases.

All subjects underwent a training program on visual perception in relay swimming. During the experiment, subjects were involved in their regular sporting activities, with no specific training in swimming starts, swimming relays, or exchange block time. Informed consent was provided by all subjects who were told the risks and benefits of the study. All the procedures were approved by the institutional ethics committee and carried out according to the Helsinki Declaration.

Procedures

Exchange block times

The exchange block time that elapses between incoming swimmer touching the wall and the outgoing swimming leaving the block. EBT was collected for all the swimmers who participated in this study taking into account: 1) the same order of delivery for each swimmer during a real 4×100m freestyle competition; 2) the relay technique adopted (no-step start) for each swimmer, that occurred before and after the training program. All the data were taken from a Website specializing in swimming rankings (http://www.swimrankings.net/). Both the EBT of each swimmer and the team´s total time of the race were used for analysis. The total EBT of each swimmer and the team´s total time of the race were used to analysis. The total EBT was additionally computed which results from the sum of the three exchange times, without counting the block time of the first swimmer.[20]

Swimming Relay Training Software

In order to build the software for the training program, we recorded videos in pre-training periods using image capture, in a frontal view with a GoPro® camera (Model HD Hero 2) placed on a tripod with a 170° view, 210 cm from the surface, on the starting block in order to make an image of high quality; the image caught the swimmer on the block and the swimmer approaching the wall until they touched the wall (Figure 1).[10]

The videos were made by recording swimmers with the same characteristics as the sample, and the same team and swim order as previously indicated for both genders by the swimming coach. For each recording we used three approach distances to the wall: 2.5 m, 5 m, and 7.5 m. These distances were selected based on the real points of view from which the swimmers observe their teammates at the time of surrender.[5, 13, 21-23] The distances were marked in the swimming pool with a pull buoy in the swimming pool lane dividers to support the video editions for each distance. Each video was edited using Kinovea® Video Analysis Software for Sport (version 0.8.15) and the outputs (video recordings) were input into Kinovea and made according to the following criteria: 1) the last 25 m of the swimmer swimming towards the wall, with their teammate's feet on the starting block; 2) the flight phase of the swimmer who jumped from the block, up to 25 m. After-

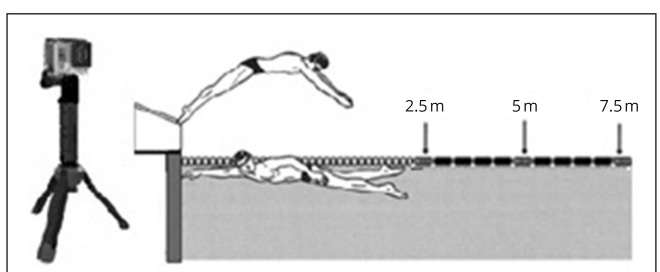

Figure 1.—Illustrative scheme of filming (modified from McLean *et al.*).[10]

wards, we selected the video for each distance of 2.5 m, 5 m, and 7.5 m, marking the real time for each distance, which started when the swimmer in the water reached the line of the distance in question and finished at the wall. To transfer image capture to a digital format, Windows Movie Maker® was used to insert images to show the occlusion that was necessary for the training program.

The structure of the Swimming Relay Training Software (SRTS) was developed based on a previously carried out pilot research study. Given the characteristics that were known to matter, some buttons were created in the computer application menu: 'Start', 'Videos', and 'Questionnaire'. The computer application was developed using software (for Windows, version 10.0) that allowed the collection of: 1) general data about each swimmer (*e.g.*, name, age, sex, swimming echelon, experience, and occurrence of specific relay training); 2) their stated visual strategies regarding orientation of gaze at the time of surrender; 3) the comparison between estimated time and real time contact in edited relays videos. Subsequently, the videos were inputted into the software and associated with routines in Python. Accordingly, the characteristics of the project and the adopted language (Python) were used in the paradigm of structured programming as advocated by Jackson.[24] The application was developed using the principle that a program is composed of elementary blocks of code which interconnect through three basic mechanisms: sequence, selection, and iteration. Any of these constructs has a starting point (the top of the block) and an end point (the block end) of execution. To start the program, we had to select the swimming club, enter the data of the swimmers with i) name, ii) date of birth, iii) gender, iv) category, and v) years of practice, and select the video corresponding to the swimmer and their relay order as defined previously.

Swimming relay training intervention

The swimming relay training intervention was conducted in a four-week learning protocol,[10] once a week, using the SRTS training program. This approach was considered to be a feasible intervention strategy for national swimmers in temporary proximity, four weeks ahead of competition. Male and female participants were randomly assigned.

The SRTS was used in a gym with adequate conditions of light and noise near the swimming pool, in order to reproduce as closely as possible a real pool situation. The swimmer was positioned at a distance of 2.25 m from the projection screen with an image size of 2.00×2.50 m (Figure 2);[25] each swimmer held a computer mouse securely with both hands in front of their body.[26]

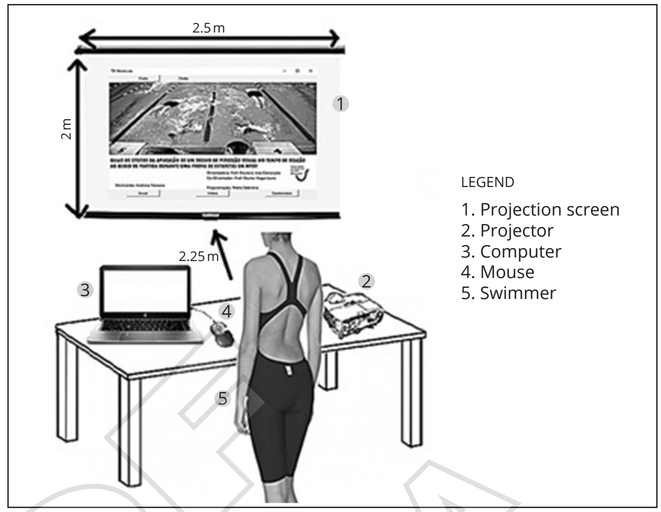

Figure 2.—Schematic view of the experimental design (modified from Manzanares *et al.*).[25]

The edited videos showed only the last 25 m of 4×100-m freestyle relay trials, with temporal occlusion of the scene at predetermined moments, corresponding to distances of 7.5 m, 5 m, and 2.5 m between the swimmer filmed and the contact on the wall. For each scene's occlusion distance, the swimmer was asked to estimate the time for the swimmer to touch the wall, by pressing a mouse button with their finger, thus mimicking the cognitive process of determining the time to make a decision (*i.e.*, the time of leaving the block).

The training session lasted approximately 30 minutes and consisted of: 1) swimmers watching the 4×100-m freestyle video that was previously recorded; 2) a video image which became obscured when the swimmer approached the wall at 7.5 m, 5 m, and 2.5 m randomly, and the swimmer had to predict by mouse click the time that the swimmer would take to touch the wall; 3) the SRTS presented the estimated times and the actual times. Participants did not receive any other feedback about the occluded distances or about their performance throughout the whole session. Before carrying out the training intervention, each swimmer experienced a familiarization session with all occlusion distances (2.5 m, 5 m, and 7.5 m) during 5 minutes (Figure 2).

Statistical analysis

The non-normality of the data was confirmed by a Kolmogorov-Smirnov test. Anaconda and IPython were used for all calculations,[27] except for the non-parametric tests: 1) Friedman test (analysis of the evolution of the three occlusion distances during the four weeks of training for males and females); 2) Wilcoxon test (comparisons between EBT before and after competition) and the effect size was calculated[28] and classified by Cohen[29] thresholds: 0.1 = small effect, 0.3 = medium effect, 0.5 = large effect. The EBT distribution was confirmed also to be not normally distributed after training (Shapiro-Wilk normality test). The analyses were conducted using Statistical Package for Social Sciences (IBM SPSS v. 23.0). The data were stored and organized using Pandas[30] and NumPy.[31] The significance level was set at $P \leq 0.05$.

Results

Female swimmers showed improvements in the estimated times after four training weeks in all time differences for each occlusion distance (Figure 3); the occlusion distance of 2.5 m was the most constant in estimated times in each intervention weeks during application of the training program. Instead, the male swimmers were more irregular in the estimated times for all the occlusion distances (Figure 3).

Table I shows that, regarding the estimated time for the occlusion distances, only at 2.5 m were there statistically

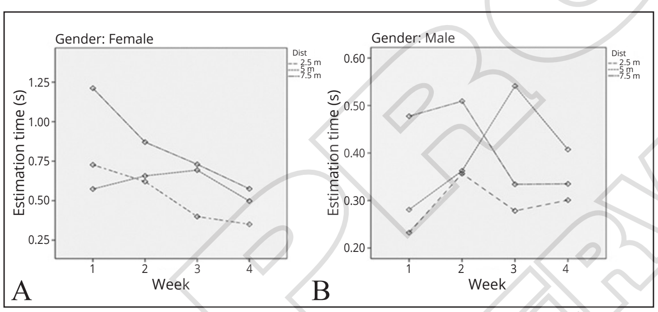

Figure 3.—Mean and standard deviations of the estimated times of four training weeks for female swimmers (A) and male swimmers (B) for all the occlusion distances (2.5 m, 5 m, 7.5 m).

Table I.—*Significance test results of the analysis of the evolution of the estimated time for three occlusion distances during the four weeks of training for male and female swimmers.*

Occlusion distances	Female		Male	
	Estimated time	P value	Estimated time	P value
2.5 m	χ^2 (3) = 8.80	0.03*	χ^2 (3) = 5.37	0.14*
5 m	χ^2 (3) = 1.02	0.80	χ^2 (3) = 8.70	0.03
7.5 m	χ^2 (3) = 4.47	0.21	χ^2 (3) = 1.50	0.68
All distances	χ^2 (11) = 19.32	0.05	χ^2 (11) = 14.03	0.23
Male and female all distances	χ^2 (3) = 3.79 P = 0.28			

Values represent means±SD.
Differences represent the P value of Friedman test: *P<0.05.

Table II.—*Exchange block times (EBT) before and after the application of the training program in male and female swimmers.*

Gender	EBT (s) Before training program	EBT (s) After training program	P value
Males	1.35±0.41	1.17±0.48	0.04*
Females	1.40±0.047	1.38±0.038	0.68

Values represent means±SD.
Differences represent the P value of Wilcoxon test: *P<0.05.

significant differences in female swimmers (χ^2 (3) = 8.80, P=0.03) and for male swimmers the statistically significant differences were (χ^2 (3) = 8.70. P=0.03) for the distance of 5 m. A post-hoc analysis with Wilcoxon signed-rank tests was conducted with Bonferroni correction, resulting in a significance level of P<0.008. There were no significant differences in the estimated time in females between the occlusion distance and the weeks 1-2 (Z=-0.966, P=0.33), weeks 2-3 (Z=-0.942, P=0.35), weeks 3-4 (Z=-0.207, P=0.84), weeks 1-3 (Z=-2.327, P=0.02), and weeks 2-4 (Z=-1.914, P=0.05). However, there was a statistically significant decrease in estimated time for occlusion distance of 2.5 m between weeks 1 and 4 (Z=-2.636, P=0.001); the effect size was d=0.65, indicating a large effect size. In males, there were no significant differences between weeks 1-2 (Z=-0.549, P=0.58), 2–3 (Z=-1.57, P=0.12), weeks 3-4 (Z=-0.86, P=0.39), weeks 1-3 (Z=-2.35, P=0.02), weeks 1-4 (Z=-0.78, P=0.43), and weeks 2-4 (Z=-0.35, P=0.72).

Regarding the EBT in competition (Table II), the female swimmers showed a decrease of EBT (from pre-training-program EBT: 1.40±0.047 s to post-training-program EBT: 1.38±0.038 s), reflecting an improvement of 0.025 s or 1.42% compared with the pre-training-program EBT. The male swimmers had a higher improvement in EBT after the intervention; a decrease of 0.18 s or 13.34% was observed compared with the pre-training-program EBT (pre-training-program EBT: 1.35±0.41 s to post-training-program EBT: 1.17±0.48 s).

The effect in the exchange block time for male swimmers before the training program and after training, was, Z=-1.97, P=0.04, and r=0.42; for female swimmers there were no significant differences between the EBT before and after the training (Z=-0.41, P=0.68).

Discussion

The aim of this study was to evaluate changes in EBT during swimming in relay events as a result of a four-week training program in relay swimming through the use of the occlusion technique.

The main finding was that this study can provide an interesting contribution related to the characterization of the visual perception of the time of the incoming swimmers during the 4×100-m freestyle event, specifically with regard to the distance of occlusion and EBT: where swimmers of both genders more regularly estimated the time in the short occlusion distance of 2.5 m of the incoming swimmer, and also that swimmers tend to improve their estimated time for all the occlusion distances and also in EBT after the training program; male swimmers were more irregular during the estimated time for all the occlusion distances and also improved their EBT after the application of the training program.

The occlusion technique has been used in several works investigating how motor repertoire affects action prediction; participants were asked to observe familiar actions that were briefly occluded from view, in order that the participant can judge whether the part of the action appearing after the occlusion is an accurate continuation of that observed before the occlusion or not.[32-34]

Bove *et al.*[13] recently showed that swimmers were more accurate than subjects performing other sports in temporally predicting the final outcome of a swimming task; this difference was more obvious in occluded intervals of short duration (3 s). These findings were in line with our results, where swimmers of both genders more regularly estimated the time in the short occlusion distance of 2.5 m of the incoming swimmer.

These results confirm partially the hypothesis that female swimmers were the ones that more regularly estimated at shorted occlusion distances, than male swimmers just were more accurate at a 5 m distance.

The different distance occlusion showed different results, this could be due to the fact that swimmers only start to predict the touch of the incoming swimmer very near to the wall, which can mean that they weren´t familiarize to training this task frequently, with a well-oriented training that operates under the logic that practice with demanding visual perceptual and oculomotor tasks for improve vision, leading to quicker sensory processing, swifter and more accurate motor movements, and improved swimming performance while also potentially reducing injury.[35] Other reason could be associated to the fact that latter is a much more varied and open skill, often performed whilst in motion, and thus less likely to be linked with a static visual measure such a depth perception.

Our study also shows differences between genders in the perception time for each occlusion distance; female swimmers improved their perception in each week of training, showing that their learning process is more regular than their male peers. The results presented differences between genders for different visual–spatial tasks: spatial perception, spatial visualization, mental turn, spatial temporal ability, and generation and maintenance of mental images and animation.[36, 37]

Improving EBT can have a meaningful impact on overall team performance and higher placing teams typically display shorter exchange times on average.[1, 3] Our results of EBT before and after application of the training program were higher for both genders (male: 1.17±0.48 s and female: 1.38±0.038 s) than the results shown by Saavedra *et al.*[3] (0.64 s [male] and 0.8 s [female]) and Siders *et al.*[6] (between 0.74 s for non-disqualified teams in NCAA divisions). These findings are not surprising when one considers the competitive level of swimmers of the previous studies; our swimmers were at a national competitive level, unlike the swimmers in the studies[3, 20] which used elite swimmers participating in Olympic Games and NCAA swimming divisions.

The results of this study showed also improvements in EBT of 1.42% for female and 13.34% for male swimmers. In a series of studies assessing visual perception on different visual and oculomotor drills, little evidence was found indicating that these training interventions improved either visual or motor performance.[38, 39]

Studies taking this approach have reported improvements in judgement of stroke direction and number of serves returned in tennis,[40] serve prediction accuracy in tennis,[41] as well as prediction of pitch type and location in baseball[42, 43] that have transferred from video temporal occlusion training to a perception-action coupled motor skill test.

This methodology can be used as an extremely informative training tool in dry land workouts and for designing more individualized and effective training programs in the water.

The goal of the training program proposed in this current study was to allow the swimmer to increase EBT and visual prediction of the time of the incoming swimmer while maintaining a good level of skill and efficiency in the relay event.

It appears that the very large majority of the swimmers participating in this study presented a lower EBT during the swimming relay event after the application of a training program. It is reasonable to think that such a performance improvement occurred thanks to important specific motor training using the occlusion technique.

Therefore, the individual evaluation of a swimmer's metabolic profile and simulation of their responses to training and competition appears to be a rich, reliable, and promising method for performance enhancement which could be added to in future studies.

Traditionally, swimmers spend only a limited amount of time specifically training for relay events, given the lack of certainty about which swimmers will be included in the relay teams until close to the competition and also the lack of time dedicated to practicing with teammates other than training in the water.

This study demonstrates that the relay training program's focus on visual perception seems to be an alternative which: 1) optimizes the exchange time between the swimmer on the starting block and the incoming swimmer to the wall; 2) improves the performance of the swimmer in the relay and, later, their exchange block time; 3) demonstrates that greater emphasis should be placed on relay training exercises; 4) enable expert swimmers to rapidly recognize patterns and predict outcomes, thereby priming their impossibly fast reactions.

It is important to note the methodological limitations of the present study. For example, the small population used in this study and consisted exclusively of national swimmers and not using a control group. Moreover, the use of 2D videos does not represent true augmented reality, one training sessions per week and also the use of a manual trigger timer may restrict the broad range of movements of performers in sports that requires lower and upper body positioning during the swimming relays.

Further could be interesting to integrate an automated force plate trigger in order to not prevent the natural striking pattern of swimming relays.

Conclusions

This study is a novel and also a topic with great research potential in the domain of visual behavior in swimming relays, which could be a basis for further studies regarding the application of a training program to improve the visual perception of relay exchanges and the impact of exchange block times during competition.

This study implemented and evaluated a training program that used occlusion principles to train the perceptual-cognitive skill of relay exchanges, that suggests that relay swimmers can improve exchange block time in competition through the use of a teaching-learning process supported by the application of a dry-land training program used temporal occlusion embodied in a video-simulation on a laptop computer and also incorporated occlusion principles into "live" drills that essentially simulated the computer simulation for visual perception by simulating EBT during competition.

Thus, we can conclude that the relay training program showed a positive effect on the EBT in competition after its application.

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Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Funding.—This work is supported by national funding through the Portuguese Foundation for Science and Technology, I.P., under project UID04045/2020.

History.—Article first published online: April 6, 2020. - Manuscript accepted: April 3, 2020. - Manuscript revised: March 11, 2020. - Manuscript received: September 4, 2019.