

Research Article

The influence of tactile perception of water on motor imagery of swimming and walking

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ABSTRACT

Previous studies on motor imagery (MI) suggest that the more similar the imagined and actual movement contexts are, the better the imagery quality. Thus, one might hypothesize that for movements performed within a medium, MI is more effective when practiced in that medium than outside it. Here, the main experiment explored the effect of tactile perception of water on MI when competitive swimmers were asked to imagine a movement performed in water: the swimming turn. The control experiment was conducted with non-athletes to examine the influence of tactile perception of water on MI of an automatized movement typically performed on land, namely walking. Isochrony was analyzed by dividing the durations of real movement with that of imagined movement. Overall, tactile perception of water did not affect the temporal accuracy of MI. In the main experiment, the imagined movement duration was lower than the real one, but no differences between in water and out of water isochronies appeared. A correlation was observed between MI kinesthetic ability scores and in water isochrony, indicating that prior MI kinesthetic ability is essential for effective in water MI. The control experiment showed no differences between real and imagined walking duration irrespective of the imagery conditions. These findings indicate that MI ability depends on the task being imagined and on the individual's imagery ability. However, it does not seem to be influenced by the tactile perception of the medium, even though tasks like swimming can only be executed when the medium (i.e., water) is present.

Introduction

In sports, athletes and coaches continuously seek strategies to incorporate into their daily training and competition, striving for incremental gains that can lead to long-term performance enhancement and improve competitive outcomes. The adoption of cognitive training techniques, such as Motor Imagery (MI), by athletes in various sports is aligned with this pursuit (Cumming & Hall, 2002). MI can be defined as the mental rehearsal of a specific movement without physically performing it (Jeannerod, 2001), and it is one of the five areas of imagery linked to sports (Rogers, 2006). MI plays a critical role in enhancing motor performance and cognitive understanding of movements,

particularly in sports contexts (Morone et al., 2022).

The scientific literature offered successful examples of MI application to improve athletes' technique. Kanthack and colleagues showed that after a three-minute MI session, young basketball players achieved greater free throw accuracy compared to their performance the next day without the MI session (Kanthack et al., 2014). The benefits of MI on sports technique extend beyond the short term and can also be observed over time. This is supported by studies on young tennis players who underwent several weeks of MI training, resulting in improved accuracy, stroke velocity, and tennis serve performance (De Sousa Fortes et al., 2019; Robin et al., 2022).

With the aim to give practical information to maximize the

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effectiveness of MI training in sports, Holmes and Collins (Holmes & Collins, 2001) proposed a seven-point neuroscientific checklist model. This model includes physical, environmental, task, timing, learning, emotional, and perspective elements of imagery, collectively referred to as PETTLEP. The physical component of PETTLEP implies that an MI intervention involves imagining the kinesthetic sensations felt while performing a skill, wearing the same clothes as those used during the actual performance, and holding any associated implements (Wakefield & Smith, 2012). In fact, having similar afferent information from the body's periphery, as during actual performance, leads to brain activation that more closely resembles that of execution (Mulder, 2007). This is likely due to a facilitation of recalling the sensorimotor memory associated with the skill. During MI, the role of the congruence between the afferent information and that included in the sensorimotor memory is supported by both behavioral (Bisio et al., 2014) and neurophysiological studies (Biggio et al., 2020) involving athletes playing sport that involves the use of a tool. Indeed, their findings showed that familiarity with the tool specifically modulates MI temporal feature, and the cortical motor representation of the muscles involved in haptic contact with the tool.

The latter study (Biggio et al., 2020) also pointed out an interesting aspect that has been explored little in sports literature, namely the importance of the haptic contact that athletes have during the sports gesture, which includes the tactile perception of it. This can apply to sports that require the use of a tool, such as tennis and fencing, as well as to sports that require contact with a medium in which to move, such as swimming. In the PETTLEP model the medium falls inside the element of the environment, where the latter must be as similar as possible to the performance environment (Wakefield & Smith, 2012). In swimming, this would mean doing MI in the pool. However, it is presently unknown whether having a tactile perception of water or simply being in a pool environment (out of the water) changes swimmers' MI ability.

In this study, we conducted a main experiment investigating whether swimmers' kinesthetic imagery ability of a swimming turn, a movement performed inside the water varied depending on whether it was executed in- or out-of-water. In the control experiment, participants without competitive swimming experience were asked to perform MI of walking either in or out of water. While the main experiment focused on investigating the role of the tactile perception of water during MI a sport-specific skill executed in water, the control experiment aimed to shed light on this aspect during MI of a well-known and automated movement typically performed on land but also possible in water.

Methods

Participants

A total of 26 subjects participated in this study. Sixteen competitive young swimmers volunteered to participate in the Main experiment. Participants' demographic characteristics and swimming performance metrics were assessed by collecting data on age, height, weight, FINA points, years of swimming experience, and best time in the 50 m swim (T50). Ten non-athlete participants performed the Control experiment (3 females, 7 males, mean age \pm SD = 28.70 \pm 5.42). The research was approved by the Ethics Committee of the University of Genoa (Comitato Etico per la Ricerca di Ateneo, Genoa, Italy, n° 2020/21) and in agreement with the Declaration of Helsinki on human experimentation. Parental consent was obtained for participants under the age of 18. Regarding sample size considerations, a post hoc power analysis was conducted using G*Power (version 3.1.9.7) for a repeated-measures ANOVA with within-subject factors. Based on the observed main condition effect in the swimming turn task (partial $\eta^2 = 0.554$; Cohen's $f = 1.11$), and considering one group with three repeated measurements, the achieved statistical power for the sample of 16 competitive swimmers was greater than 0.99 at an alpha level of 0.05, indicating that the study was sufficiently powered to detect the observed effect.

Experimental design

In both experiments, the specification of imagery modality, task content, and temporal coupling adhered to the Guidelines for Reporting Action Simulation Studies (Moreno-Verdú et al., 2024). In particular, they were instructed to perform only kinesthetic imagery, without deliberate visual imagery, adopting a first-person internal perspective. A completed GRASS checklist indicating where each reporting item is addressed in the manuscript is provided in the [Supplementary Materials](#).

Main experiment

To assess the MI ability of the participants, the Motor Imagery Questionnaire Revised (MIQ-R) was administered (Hall & Martin, 1997). The MIQ-R consists of four movements that should be executed following the instructions and then imagined kinesthetically or visually, in a different order. After imagining each movement, the participant must evaluate how vivid or how sensitive the imagination was on a scale from 1 to 7, with 1 being very easy and 7 being very hard. The scores are divided into visual and kinesthetic categories, based on the total points for each type of imagery received. No cutoff point was used to include or exclude participants, but the MI scores were used in correlation analysis.

Tests were performed in the afternoon by all the swimmers in the same 25 m indoor swimming pool with a water temperature of 27°C, where they were used to training. First, participants were instructed to perform a swimming turn at maximal effort. They started in the water at a distance of 10 m from the wall to reach the maximal velocity. Outside the swimming pool, the researchers placed a sign at 10 m and another at 5 m from the wall to indicate when to start (5 m) and stop (10 m) the chronometer after the turn for measuring the actual swimming turn (REAL) time (Fig. 1). Each swimmer performed the swimming turn six times, with a three-minute rest between trials. After completing the REAL trials, participants were instructed to kinesthetically imagine the same movement they had just performed remaining motionless. In particular, they were asked to imagine the movement, starting from the same initial position 10 m from the wall, progressively accelerating toward the turn. Participants were explicitly instructed to focus on kinesthetic sensations associated with the task, including the force of the arm strokes, the body movement, the muscle tension, the resistance of the water, and the rotational movement during the turn. When, in their imagination, they reached the 5 m mark from the wall, participants verbally said "start" to signal the beginning of the imagined turn. They were then instructed to continue imagining the turn and to say "stop" when, in their imagination, they reached the 10 m mark after completing the turn. During the MI-IN condition, swimmers remained in the water, holding onto the pool's edge with their hands and keeping their knees flexed, simulating a seated position. During the MI-OUT

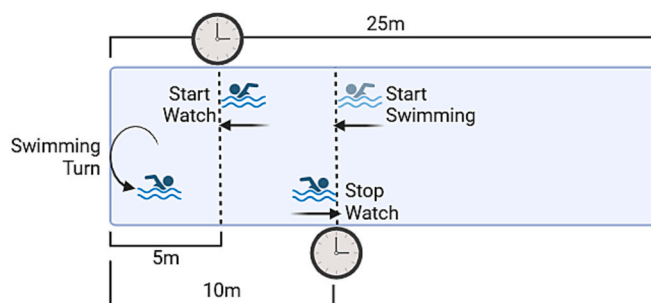


Fig. 1. Schematic representation of the experimental design for swimming turn time assessment. Participants were instructed to perform a swimming turn at maximal effort in a 25 m swimming pool. They started in the water at a distance of 10 m from the wall to reach the maximal velocity. Outside the swimming pool, the researchers placed a sign at 10 m and another at 5 m from the wall to indicate when to start (5 m) and stop (10 m) the chronometer after the turn for measuring the actual swimming turn time.

condition, they performed the task while sitting on a chair next to the pool. In both conditions, which were executed in a random order, participants kept their eyes closed throughout the imagery process. Participants performed 6 trials in MI-IN and 6 trials in MI-OUT. Chronometry data were collected using a stopwatch operated by two experienced researchers for the REAL, MI-IN, and MI-OUT conditions. For statistical analysis, the average of the two recorded times was used.

Control experiment

Tests were performed in the afternoon by all participants in an 8 m indoor swimming pool with a water temperature of 32°C. First, participants were instructed to walk inside the swimming pool at their normal pace. They walked 7 m, from the head to the tail of the pool, both marked with a cone outside the pool. Two researchers were positioned at the center of the pool, outside the water, and started their stopwatches as soon as the participant began walking, stopping the acquisition when the participant reached the second cone (REAL). Each subject performed the walking task six times, with a three-minute rest between trials. After completing the REAL trials, participants were instructed to kinesthetically imagine the same walking pace they had just performed. In particular, they were asked to imagine walking from the same initial cone to the final cone at the same pace. Importantly, participants were instructed to focus on kinesthetic sensations related to walking in water, including the resistance of the water, the force required to overcome it, weight transfer, and the rhythm of gait. When, in their imagination, they began walking from the initial cone, they verbally said “start”, and they said “stop” upon reaching the final cone. Motor imagery was conducted both inside (MI-IN) and outside (MI-OUT) the water of the swimming pool in a random order. During the MI-IN condition, participants remained in the water, standing still at the same spot where they had initiated walking. During the MI-OUT condition, they performed the task while standing still outside the water, at the corresponding position relative to the pool. In both conditions, participants kept their eyes closed throughout the imagery process. Participants performed six trials in MI-IN and six trials in MI-OUT. Chronometry data were collected using a stopwatch operated by two experienced researchers for the REAL, MI-IN, and MI-OUT conditions. For statistical analysis, the average of the two recorded times was used.

Data and statistical analysis

To evaluate participants' imagery ability (walking in Control experiment, swimming turn in Main experiment), the duration of the gesture was computed in REAL, MI-IN and MI-OUT conditions. No maximum time cut-off was imposed for the duration of the imagined movement. Furthermore, isochrony values were obtained by dividing the movement duration in REAL condition by the duration of the imagined movements in both MI-IN and MI-OUT conditions, obtaining ISO-IN and ISO-OUT values, respectively. Perfect isochrony corresponds to 1.

Statistical analysis

All analyses were conducted using IBM SPSS Statistics 21. Data normality was assessed using the Shapiro-Wilk test. Data were considered outliers if their values were higher or lower than the mean \pm 2 standard deviations. Data with a normal distribution are presented as mean \pm standard deviation, while not-normally distributed data are represented by median value and interquartile range. The level of significance adopted was $p < 0.05$. Cohen's d and partial η^2 reported were appropriate to quantify the effect size.

Main experiment

The variables MIQ-R Scores (Total, Kinesthetic and Visual), ISO-IN, ISO-OUT, REAL, and MI-IN were normally distributed, while MI-OUT did not follow a normal distribution. To verify possible differences in movement duration among conditions, a General Linear Model (GLM)

was used with CONDITIONS (3 levels: REAL, MI-IN, MI-OUT) as factor. Bonferroni post-hoc comparisons were applied to analyze differences in movement duration among conditions. To ensure consistency and accommodate variables that did not follow a normal distribution, we also used the Wilcoxon signed-rank test for comparisons involving MI-OUT and for all conditions when necessary. Additionally, the isochrony values inside (ISO-IN) and outside (ISO-OUT) the swimming pool were compared by means of paired t -test. The relationships between the kinesthetic and the visual MIQ-R scores and isochrony values inside (ISO-IN) and outside (ISO-OUT) the swimming pool were analyzed using Pearson correlation. Bonferroni correction was applied for multiple comparisons defining a new p level equal to $0.05/4 = 0.0125$.

Control experiment

The variables REAL, ISO-IN and ISO-OUT were normally distributed, while MI-IN and MI-OUT did not follow a normal distribution. To verify possible differences in movement duration among conditions, a General Linear Model (GLM) was used with CONDITIONS (3 levels: REAL, MI-IN, MI-OUT) as factor. Bonferroni post-hoc comparisons were applied to analyze differences in movement duration among conditions. Additionally, the isochrony values inside (ISO-IN) and outside (ISO-OUT) the swimming pool were compared by means of paired t -test.

Results

All participants completed all imagery trials successfully in both experiments.

Main experiment

Participants' characteristics and swimming performance metrics are summarized in Table 1. No data points were removed from the dataset since no outliers were found.

The GLM revealed a significant main effect of CONDITION (Greenhouse-Geisser corrected: $F(1.11, 16.65) = 18.63$, $p < 0.001$, partial $\eta^2 = 0.554$). Bonferroni-corrected post hoc comparisons showed that movement duration during REAL execution (8.77 ± 0.80 s) was significantly longer than during MI-IN (6.32 ± 2.15 s) (mean difference = 2448.94 ms, $p = 0.002$, Cohen's $d = 1.08$, 95% CI [917.88; 3980] ms) and MI-OUT (6.18 ± 2.17 s) (mean difference = 140.38 ms, $p = 0.001$, Cohen's $d = 1.12$) (Fig. 2A), with no significant difference between MI-IN and MI-OUT. No significant differences were observed between ISO-IN (1.52 ± 0.52) and ISO-OUT (1.57 ± 0.53).

A significant positive correlation was observed between kinesthetic MIQ-R scores (11.17 ± 3.19) and in-water isochrony (ISO-IN; $r = 0.62$, $p = 0.011$, 95% CI [0.08; 0.83]) (Fig. 2B), which remained significant after Bonferroni correction. In contrast, no significant correlation was found between kinesthetic MIQ-R scores and ISO-OUT ($r = 0.48$, $p = 0.058$; 95% CI [-0.05; 0.71]). Additionally, no significant correlations were observed between visual MIQ-R scores (8.00 ± 3.60) and ISO-IN ($r = 0.75$, $p = 0.783$; 95% CI [-0.44; 0.43]) or ISO-OUT ($r = 0.23$, $p = 0.386$; 95% CI [-0.34; 0.57]).

Table 1

Characteristics of the participants of the Main experiment and swimming performance metrics. Values are presented as mean and standard deviation.

	Mean	SD	Min	Max
Age (years)	17.8	1.8	15	21
Height (cm)	172.8	8.8	157	187
Weight (kg)	64.5	7.5	52	75
Experience (years)	9.8	1.7	7	13
T50 (s)	27.2	2.1	24.2	30.8
FINA Points (au)	482.7	64.2	391	587
Total MIQ-R	19.3	5.4	12	32
Kinesthetic MIQ-R	11.3	3.2	8	20
Visual MIQ-R	8.0	3.6	4	17

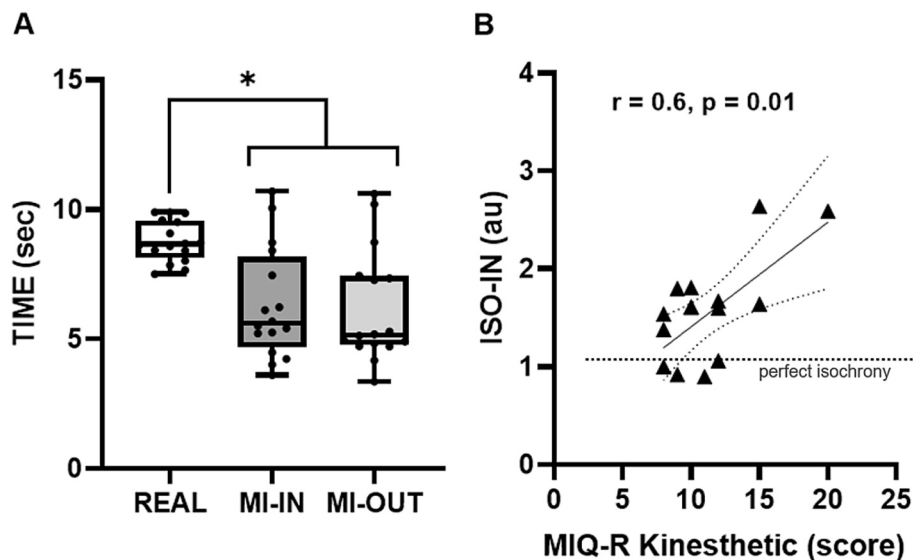


Fig. 2. Results. (A) Movement durations of actual swimming turn execution (REAL, white), motor imagery inside the swimming pool (MI-IN, blue) and motor imagery outside the swimming pool (MI-OUT, green). The box indicates the inter-quartile range, the middle line represents the median value, and the bars represent the minimum and maximum value. Black dots represent the mean data for each participant in the three conditions. * $p < 0.0001$. (B) Correlation between MIQ-R kinesthetic score and isochrony inside the swimming pool. Values are presented as mean \pm standard deviation. ISO-IN isochrony inside the swimming pool; au arbitrary units.

Control experiment

Participants in this experiment had age of 28.70 ± 5.42 years, height of 1.73 ± 0.07 m, weight of 70.05 ± 15.16 kg. The results of the GLM found no significant effect of the factor CONDITION on movement duration (REAL 9.38 (8.19 – 10.57) s, MI-IN 8.60 (6.64 – 10.56) s, MI-OUT 8.67 (6.48 – 10.86) s). No significant differences were observed between ISO-IN (1.01 ± 0.17) and ISO-OUT (1.06 ± 0.31).

Discussion

Results of the main experiment showed that the duration of the imagined swimming turn, both inside and outside the water, was significantly lower than the duration of the real movement. Furthermore, when comparing the isochrony in the two motor imagery conditions (ISO-IN and ISO-OUT), no significant differences were found. At last, a significant positive correlation appeared between ISO-IN and the athletes' kinesthetic motor imagery ability. The results of the Control experiment showed that participants were isochronous with the real movement when they imagined walking while inside and outside the water, with no difference between imagery conditions.

Isochrony between imagined and real movement depends on the task

The congruence between the duration of the real and the imagined movement has often been used as a test to unveil the goodness of MI. This congruence was observed in the Control experiment across both imagery conditions, where participants were instructed to imagine walking in water. Previous studies have reported isochrony between real and imagined walking (Personnier et al., 2010); however, no research has examined this phenomenon when walking occurs in water. Although these data were obtained from a small sample of participants, and should therefore be interpreted with caution, the observed congruence suggests that: (i) participants successfully imagined a movement typically performed on land while executing it in water, presumably accounting for the drag force exerted by the aquatic environment; (ii) the tactile perception of the medium in which the real movement took place did not influence MI. The highly consolidated and automatic nature of walking may explain the perfect isochrony between the imagined and real

movement, even when performed in water.

In contrast, this congruence was not observed for the swimming turn task in the Main experiment. Guillot and Collet (2005) identified several external factors that induce athletes during MI to either underestimate or overestimate the movement duration. These appeared in different sport disciplines such as climbing (Vieilledent, 1996), shooting (Deschaumes-Molinario et al., 1991), gymnastics (Calmels & Fournier, 2001). Possible reasons for this discrepancy between real and imagined movement was attributed to the image content and the difficulty of the task perceived by the participants (Guillot & Collet, 2005). This interpretation may also apply to the present results. Although the average durations of walk (Control experiment) and turn (Main experiment) were comparable, isochrony occurred in one case but not in the other. This suggests that the lack of isochrony between real and imagined turn duration may not be due to task duration per se, but rather to other factors, such as the greater complexity of the movement being imagined. However, it has to be noted that the duration of the real turn was underestimated (more than 2 s) during MI in both conditions. As suggested by Collet and colleagues (2011), such distortions of MI duration do not mean that MI is inaccurate systematically. Furthermore, since faster MI can accelerate movement execution (Louis et al., 2008), this feature could contribute to an increase in athletes' subsequent turn speed. On the other hand, underestimation may indicate that swimmers either skipped certain parts of the movement or did not focus enough to accurately reproduce its duration during MI. To clarify this issue, valuable insights could have been gained by asking athletes to rate the vividness of their imagined experience after each MI session. Unfortunately, this data was not collected, representing a limitation of the present study. Another factor that may have influenced the correspondence between real and imagined movement duration is the swimmer expertise level; athletes are to a greater or lesser degree aware of the technical complexity of a movement, and this reflects on their ability to accurately create an image of the gesture (Guillot & Collet, 2005). The athletes enrolled in the present study were experts in their category but cannot be considered elite swimmers. This may have affected their ability to accurately perform MI of the turn, leading to a significant underestimation of turn duration. Supporting this interpretation, in the Control experiment isochrony was observed across all conditions. Since walking is an automatic ability, all participants can be considered

proficient in it, which explains the correspondence between the durations of imagined and actual movements. Another difference between the skills tested in the two experiments is that in the Control experiment participants performed only a single cyclic motor pattern, whereas in the Main experiment the cyclic pattern of the swimming stroke was interrupted during the turn and then resumed at the end of the task. This difference might have increased the difficulty of the turn imagery, leading to the lack of isochrony.

Isochrony does not rely on tactile perception of the medium

The key innovative finding of this study is that the duration of the imagined movement remained unchanged whether MI was performed in-water or out-of-water. Previous research suggests that the greater the similarity between the conditions of MI and actual movement execution, the more accurate the imagined movement becomes. In particular, having afferent information congruent with that incorporated within the sensorimotor memory of the athletes seems to be crucial for accurate MI. For instance, [Bisio and colleagues \(2014\)](#) showed that isochrony was influenced by the type of implement held by the tennis player; isochrony improved when the athletes held the tennis rackets rather than other objects. A neurophysiological correlate emphasizing the importance of familiarity with a handled tool during MI emerges from the study by [Biggio et al. \(2020\)](#) on expert fencers showing that familiarity with the tool specifically modulates the cortical motor representation of the muscles of the corporal segment involved in haptic contact with it. These data are in line with the PETTLEP model, and with the importance of doing MI in an environment that is as similar as possible to the performance environment ([Wakefield & Smith, 2012](#)). In swimming, the performance environment could refer to the room housing the swimming pool, where athletes perform MI outside the water. However, the performance environment could be the swimming pool itself, meaning swimmers execute a MI while in the water where, with respect to outside the water, they experience tactile perception of the medium.

This study addressed the issue by having participants wear swimsuits (a physical component of the PETTLEP model) while performing MI both in and out of the water. Regarding water sensation, a previous study examined the perception of water flow over the skin during passive propulsion in a distance estimation task, showing that swimming expertise influences sensitivity to tactile information, such as the perception of water flow, compared with non-expert swimmers and allows a lower error in distance estimation ([Kusanagi et al., 2017](#)). Therefore, having this tactile perception during MI might have played a role in building the mental image. Nevertheless, since the temporal characteristics of MI of the swimming turn remained unchanged regardless of being in or out of the water, one can conclude that tactile perception of the water was not a crucial factor during MI of the swimming gesture. Beyond swimming, the present findings may have implications for other aquatic sports, such as diving, artistic swimming, and water polo in which interaction with the medium is intrinsic. These results may also be relevant for training in immersive settings, which are designed to replicate key perceptual, spatial, and contextual features of real-world performance and where participants may be asked to imagine moving inside them. Indeed, because tactile perception of the medium did not influence MI in our study, the absence of realistic tactile feedback may not be a critical limitation when performing imagery in immersive environments. However, such generalizations should be considered with caution, as the present study did not directly assess other sports or tasks.

Furthermore, the temporal features of MI remained stable even when considering a well-learned and highly automatized motor skill, such as walking. This suggests that this aspect is not modulated by the level of motor expertise. Future studies that explicitly consider different levels of expertise and investigate the neurophysiological correlates of MI during tactile perception of a medium may provide deeper insight into the cerebral mechanisms underlying this phenomenon.

A potential confounding effect related to the different visual information available to participants immediately before closing their eyes for motor imagery should also be considered, as this information was more consistent in the in-water than in the out-of-water condition in both experiments. Nevertheless, the results of both experiments, showing no differences in isochrony values as a function of the medium, argue against this interpretation.

Role of individual kinesthetic imagery ability

Another result that may give some hints on how to apply MI in swimming comes from the significant correlation between the athletes' kinesthetic imagery ability, as assessed by MIQ-R kinesthetic score, and the isochrony value when the turn was imagined inside the water (i.e., ISO-IN). The higher the kinesthetic imagery ability (lower MIQ-R values), the better the isochrony (values closer to 1). This result highlights that the individual kinesthetic MI ability play a key role in the athletes' ability to generate an accurate image that reflects the temporal characteristics of the actual movement. Therefore, this technique might be less effective in individuals with poor imagery ability. Previous neurophysiological investigations might help to explain this finding. A significant correlation has been reported between kinesthetic MI ability and the increase in primary motor cortex excitability during MI compared with rest ([Williams et al., 2012](#)). This suggests that imagery ability may influence the fidelity with which MI reproduces actual movements, as poor and good imagers exhibit different patterns of brain activation during MI ([Guillot et al., 2008](#)). This interpretation is also supported by another study showing different functional connectivity between the frontoparietal region in individuals with high compared to poor motor imagery controllability ([Furuta et al., 2024](#)). In turn, individual imagery vividness and ability have been found to influence performance improvements following MI training in sport contexts ([Robin et al., 2024](#); [Vergeer & Roberts, 2006](#)). However, it should be acknowledged that in the study by Williams and colleagues (S. E. [Williams et al., 2015](#)) no relationship between imagery ability and isochrony was found in athletes. Notably, the participants in that study came from various sports, were older than those included in the present study and showed a wide range of sport experience (ranging from 1 to 17 years of experience) and competitive levels, whereas the participants in the present study were all youth athletes competing at a similar level. Therefore, all these differences might explain the discrepancy between the two studies.

Furthermore, the fact that the correlation emerged only when the turn was imagined in water may be linked to the effects of repetitive practice of swimming-specific movements, which could enhance sensorimotor skills both during water immersion and on land, as suggested by [Sato and colleagues \(Sato et al., 2020\)](#).

Unfortunately, we do not have data on imagery ability of participants in the Control experiment, so the impact of this factor on MI of walking cannot be assessed, representing a limitation of the present study.

Conclusion

In conclusion, these findings demonstrate for the first time that, when considering motor imagery of both gestures performed in water and those typically executed outside it, the duration of the imagined movement is not influenced by tactile perception of the medium but rather by the type of task being imagined. Furthermore, the athletes' kinesthetic imagery ability appears to influence the extent to which the duration of imagined movements mirrors that of actual movements. These results also have practical implications in sport neuroscience, particularly for coaches and practitioners interested in integrating motor imagery as a complementary training tool in swimming, as well as in other aquatic sports and immersive training contexts.

CRedit authorship contribution statement

Ricardo Muller Bottura: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Marco Fassone:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Laura Avanzino:** Writing – review & editing, Validation, Conceptualization. **Piero Ruggeri:** Writing – review & editing, Validation. **Marco Bove:** Writing – review & editing, Validation, Conceptualization. **Ambra Bisio:** Writing – original draft, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.neuroscience.2026.04.010>.

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