



HAL
open science

Questioning the transfer effect of motor imagery benefits: The neglected variable of interest

Aymeric Guillot, Ursula Debarnot, Yann Monarchi-Comte, Franck Di Rienzo

► **To cite this version:**

Aymeric Guillot, Ursula Debarnot, Yann Monarchi-Comte, Franck Di Rienzo. Questioning the transfer effect of motor imagery benefits: The neglected variable of interest. *Asian Journal of Sport and Exercise Psychology*, 2022, 2 (2), pp.91-98. <10.1016/j.ajsep.2022.08.001>. <hal-04672052>

HAL Id: hal-04672052

<https://hal.science/hal-04672052v1>

Submitted on 5 Nov 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY-NC 4.0 - Attribution - Non-commercial use - International License

Questioning the transfer effect of motor imagery benefits: The neglected variable of interest

Aymeric GUILLOT¹, Ursula DEBARNOT^{1,2}, Yann MONARCHI-COMTE¹ & Franck Di RIENZO¹

¹ Inter-University Laboratory of Human Movement Biology-EA 7424, University of Lyon, University Claude Bernard Lyon 1, 69 622 Villeurbanne, France.

² Institut Universitaire de France, Paris, France.

Correspondence: Aymeric GUILLOT, Inter-University Laboratory of Human Movement Biology -EA 7424, University Claude Bernard Lyon 1, Villeurbanne, France. tel: (00)33.472.432.837, E-mail: aymeric.guillot@univ-lyon1.fr

Word Count: 3765 words (excluding references)

Running title: Transfer of imagery performance gains

Abstract

Over the last three decades, a large amount of experimental research aimed at determining the optimal motor imagery practice guidelines, and provided a comprehensive overview of the main recommendations to develop effective interventions. Yet, the scientific literature paid little attention to transfer effects resulting from motor imagery practice. In the present paper, we examined whether performance gains following motor imagery were task-specific or likely to be transferred to partially distinct motor skills. Twenty-eight golf players of intermediate level were involved in a 12-weeks test-retest design, where swing and putting performances were measured. All participants were subjected to three 4-week imagery interventions (internal visual imagery, external visual imagery and kinesthetic imagery), which were contrasted to a control pre-test measure. During each imagery intervention, they were requested to imagine only the swing shot. All imagery interventions contributed to enhance swing performance, and gains largely transferred to the putting performance in spite of a complete absence of training. A slight superiority of external visual imagery was observed for both shots. Interestingly, individual motor imagery ability scores predicted performance gains under the corresponding motor imagery training condition. Taken together, present findings support transfer effects of motor imagery interventions. Practically, this effect should be considered to achieve optimally effective interventions to enhance performance in relation to individual motor imagery ability profiles.

Keywords: mental practice; motor performance; transfer; Golf.

Introduction

Motor imagery is a multisensory experience during which athletes mentally represent a movement by either recalling previously perceived situations or elaborating on forthcoming events. Motor imagery is performed by athletes of varying levels of expertise, and meets a large range of purposes including achieving excellence and improving motor performance, learning skills and strategies, increasing confidence and intrinsic motivation, managing stress and anxiety, or promoting motor recovery (Guillot & Collet, 2008). Specifically, motor imagery training has been shown to substantially transfer to sport performance. A large amount of experimental studies provided strong evidence that motor imagery involves overlapping patterns of cerebral activation with the physical performance of the same movement, which laid ground to the neurofunctional equivalence theory (for review, see Munzert & Zentgraf, 2009). Functional brain imaging data further demonstrated that connectivity patterns between recruited brain regions were also largely similar (e.g., Gao et al., 2014; Xu et al., 2014). Henceforth, motor imagery can be considered an intermediate form of motor behavior in the continuum extending from the pure mental evocation to the physical execution of the corresponding movement. Practically, motor imagery thus represents a specific action state with the potential to leverage experience based plasticity in case of repeated practice intended to impact motor performance (Kraeutner et al., 2014). Over the last three decades, a large amount of research has been designed to investigate how to effectively deliver appropriate imagery training interventions. Several theoretical frameworks were proposed to summarize consensus imagery guidelines to maximize effectiveness of motor imagery training interventions (e.g., Martin et al., 1999; Munroe et al., 2000; Holmes & Collins, 2001; Morris et al., 2005; Guillot & Collet, 2008; Weinberg, 2008; MacIntyre et al., 2010; Schuster et al., 2011; Cumming & Williams, 2013; Guillot, 2019). For instance, researchers addressed the most effective duration of imagery sessions, the number of repetitions per session, and the ideal number of sessions per week (Driskell et al., 1994; Paravlic et al., 2018; Schuster et al., 2011; for an extensive review, see Morris et al., 2012; Itoh, 2020). They also questioned the influence of the environmental context in which motor imagery training is administered (Holmes & Collins, 2001; Guillot et al., 2005a; Callow et al., 2006; Mizuguchi et al., 2013; MacIntyre et al., 2018), and how

physical fatigue elicited during training might affect motor imagery ability (Guillot et al., 2005b; Demougeot & Papaxanthis, 2011; Di Rienzo et al., 2012; Kanthack et al., 2016, 2020; 2021). Based on this research, several recommendations were provided to athletes to potentiate the benefits of motor imagery training interventions. Yet, the hypothesis of a positive transfer of performance gains following motor imagery training has received little attention.

Early work investigated whether motor imagery might facilitate the transfer of physiological training to performance (Van Gyn et al., 1990). Far less attention, however, has been paid on the transfer of motor imagery-related benefits *per se*. For instance, a motor skill trained on one body side may lead to improvement in the untrained side. Contralateral performance gains after unilateral training reflect a cross-education or sparing effect. Such effect has been extensively demonstrated in the motor learning literature (e.g., Munn et al., 2004, 2005; Hendy & Lamon, 2017). Although not systematically (Romkema et al., 2018), similar effects were reported sporadically after motor imagery practice (e.g. Yue & Cole, 1992; Bouguetoch et al., 2021), most especially in case of intermanual transfer paradigms illustrating changes in motor performance from dominant hand training to non-dominant hand performance (Kohl et al., 1992; Amemiya et al., 2010; Lohse et al., 2010; Land et al., 2016; Oosawa et al., 2019). These results support that cross-education is possible even in the absence of muscle activity in the trained limb, which could have meaningful practical applications in the rehabilitation of motor impairments. Another type of transfer following imagery practice consists in examining whether the benefits provided by a motor imagery intervention might contribute to improve performance of another motor skill. Although this was not the primary aim of their experiment, Lejeune et al. (1994) early explored this issue by examining the effectiveness of mental training in table tennis performance. They compared counterattacked forehand and backhand performances before and after one week of motor imagery intervention, whereby novice players successively and separately repeated each movement mentally (i.e., mirroring a classical learning situation of many successive repetitions of the same motor skill). Interestingly, physical performance was evaluated both in a repeated and an alternated forehand/backhand condition, which was expected to more closely reflect real-game situations. Data revealed that motor imagery contributed to improve performance in both experimental conditions, hence

suggesting that the benefits of motor imagery transferred to real-game scenarios. While these results were promising, however, one may question whether the two situations were of increasing difficulty, as the alternation condition did not include the high degree of uncertainty that players usually encounter during real matches. This finding might thus reflect a possible transfer of imagery benefits, however mainly between two situations of comparable difficulties. In a sample of older adults, Nicholson et al. (2018) later supported this hypothesis, as they found that motor imagery of an obstacle course resulted in a positive transfer to the Time Up and Go task. As outlined by the authors, motor elements of the latter task were partially involved in the obstacle course (sit to stand, walking, turning, and stand to sit), therefore confirming a partial transfer of imagery benefits between two motor tasks composed by skilled-elements of the same difficulty.

The study by Roure et al. (1998) is, to our knowledge, the only experimental design investigating whether the benefits provided by an imagery training intervention might be transferred to another sporting situation with different level of difficulty. Using a test-retest procedure, they looked at the effect of imagining a specific volleyball action (returning serve) in a sample of 24 intermediate-level volleyball players. Participants were first evaluated in two game scenarios, namely returning the serve towards a motionless target player standing about 5 m in front of him (simple condition), and towards the same target player who could freely move 2 m to his right/left side when the serve was hit (difficult condition). Participants were assigned to a control or an imagery group for 30-min training sessions including either social conversation with the experimenter or mental rehearsal of the serve return, three times per week over 8 weeks. Participants from the imagery group mentally simulated only the simple condition, i.e. returning the serve toward the motionless target player. Finally, all players were retested in the two game situations at the end of the experimental procedure. Data revealed no performance gains in participants from the control group, while players assigned in the imagery group substantially enhanced their motor performance, but only in the simple fixed-target modality. Taken together, these data not only confirmed the benefits of engaging in a motor imagery training, but also primarily highlighted that to be effective, motor imagery needs to closely mimic the spatiotemporal features of the corresponding movement. This result is of critical importance as it questioned the effect of the intrinsic content of the imagery task,

revealing that the transfer of the imagery benefits from a simple to a difficult motor skill did not occur. However, we may postulate that transfer did not happen because the matched task was quite easy, whereas the transfer task was more difficult. Hence, we think that retesting such effects is required as if participants had imagined the difficult task during the motor imagery intervention, and then performed the easy and difficult tasks, there may have been some positive transfer to the easier task.

Although promising, the scientific literature looking at the transfer effect of the imagery benefits in motor learning paradigms remains sparse. Further experimental contribution is required to understand in greater details the effective/lack of transfer of motor imagery-related gains in motor performances, and to investigate whether the transfer could be systematic from difficult to simple motor skills. This latter question has, to our knowledge, never been considered. As well, the selective influence of the imagery modality on the possible imagery transfer effect has not been measured. A great amount of experimental imagery studies were designed to evaluate the selective effectiveness of different imagery types and perspectives, but there is no data investigating whether performing motor imagery training in a pre-determined motor imagery modality might facilitate the transfer of imagery benefits in relation to individual motor imagery ability profiles. The present study therefore aimed at testing whether performing internal visual, external visual or kinesthetic imagery of a full swing golf shot contributed to enhance the accuracy of this motor skill, and if such benefits on hitting at a long distance (complex motor skill) might be transferred to putting more accurately on the green (simple motor skill).

Methods

Participants

Twenty-eight golf players of regional level (16 men, 12 women, mean age 37.24 ± 12.38 years) volunteered to participate in this study. Before the experiment, they completed the French third-version of the Movement Imagery Questionnaire (MIQ-3f; Robin et al., 2020). Participants' scores (Mean \pm Standard Deviation) was 24.04 ± 2.86 for the EVI dimension, 23.43 ± 5.01 for the IVI dimension, and

24.03 ± 3.00 for the KI dimension. Written informed consent was obtained from all participants before data collection.

Experimental design

The effects of a 12-weeks imagery training intervention were evaluated using a test-retest design, with motor performance testing procedures scheduled every 4 weeks (Figure 1). In this repeated measures design, all 28 participants participated to three distinct motor imagery conditions, i.e. internal visual imagery (IVI), external visual imagery (EVI), and kinesthetic imagery (KI), which were contrasted to a control pre-test measure. All participants were subjected to each imagery condition within a counterbalanced order to prevent carryover effects, which means that each imagery modality was trained in sequence over 4 weeks, making the 12 weeks for the three imagery modalities. Participants' allocation to one of the 6 (3*2*1) possible order for imagery conditions was achieved using block randomization. We used the *blockrand* package in R (Snow, 2020reference). Blockrand achieves block randomization with random block size selection to prevent randomization bias (Efird, 2011). During each period of 4 weeks separating the testing procedures, they were subjected to two sessions per week of one motor imagery condition. Players were requested to systematically imagine the swing performance, using the imagery type which was randomly pre-determined in the corresponding period (i.e. IVI, EVI, or KI; Figure 1). Each session lasted 25 min and included 15 min of imagery trials. An imagery script was systematically read to ensure that all participants received similar imagery instructions. Individual oral debriefings were regularly scheduled to control adherence of the participants to the imagery instructions, and determined whether they encountered difficulty in simulating the motor skill.

During the pre-test measures, as well as each post-motor imagery test (i.e., every 4 weeks), motor performance accuracy of both swing and putting shots were measured. Practically, participants were required to strike five swings at a 100m-distance from the hole, as well as 3 putts (respectively at 80cm, 200cm, and 350cm from the hole) for 5 successive holes. The average distance from the hole was collected and quantified to provide a score for the swing (from 0 point when the ball stopped at more than 50cm from the hole, to 10 points when the ball arrived less than 10cm from the hole). A score was

also computed based on the number of shots performed to successfully complete the putts (from 0 point when participants struck more than 27 strokes to 10 points when they completed each hole in less than 6 strokes, in average). As the swing performance was performed during both pre and post-test measures and the motor imagery intervention, it was considered the congruent task with expected imagery-related performance gains. The putting performance, which was not practice through MI, but only evaluated during pre and post-test measures, was rather a control task designed to measure the transfer effect of the motor imagery intervention.

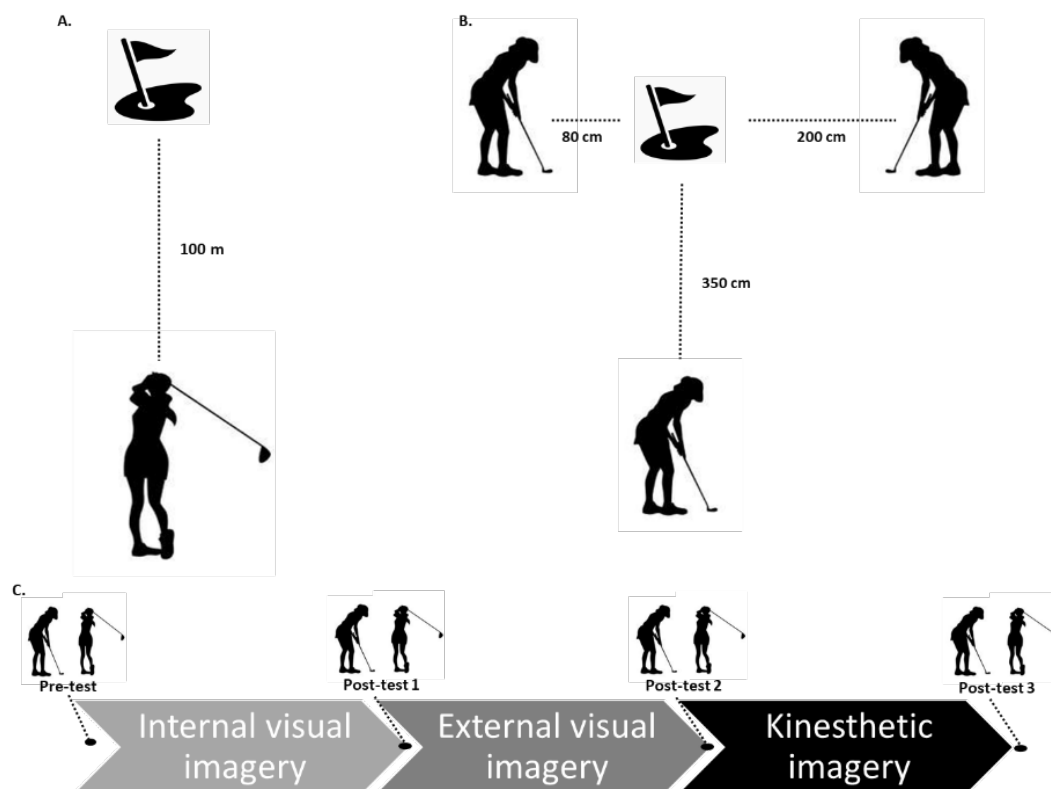


Figure 1. Experimental design. A. Swing performance scoring. B. Putting performance scoring. C. Time-course of the imagery intervention.

Data analysis

We used the R freeware (R Core Team, 2020) to conduct statistical analyses. R is an open-source software dedicated to statistical computing. It benefits from a decentralized development community with leading experts in their field regularly developing, implementing and updating

packages (i.e. binaries for specific functions intended to work in the R environment). We first used the nlme package (Pinheiro et al., 2020) to run a linear mixed effects analysis of swing and putt performance data, with a by-subjects random intercept. As fixed effects, we entered CONDITION (EVI, IVI KI; as well as the first pre-imagery performance, i.e. CONTROL) and its interaction with MIQ IVI, MIQ EVI and MIQ KI scores (numeric regressor). Post-hoc investigations were carried on using general linear hypotheses testing of planned contrasts from the multcomp package (Hothorn et al., 2008). As effect sizes, we calculated the partial coefficients of determination (R²P) using had hoc procedures for linear mixed effects models implemented in the effectsize package (Ben-Shachar et al., 2020). We applied Holm's corrections to control the false discovery rate (Holm, 1979). The level of significance was set at $p \leq .05$.

Results

Swing performance

There was a main effect of condition ($F(3, 44) = 110.32, p < 0.001, R2P = 0.88$). Post-hoc analyses revealed that MIQ-IVI scores had a stronger positive predictive relationship on swing performance after IVI compared to CONTROL ($+0.62 \pm 0.21, p = 0.02$), EVI ($+0.67 \pm 0.22, p = 0.01$) and KI ($+0.60 \pm 0.23, p = 0.04$) conditions (Figure 2). MIQ-EVI scores had a stronger positive predictive relationship on swing performance after EVI compared to CONTROL ($+0.94 \pm 0.25, p = 0.001$) and IVI ($+1.24 \pm 0.27, p < 0.001$) conditions. Likewise, MIQ-KI scores had a stronger positive predictive relationship on swing performance after the KI condition compared to CONTROL ($+1.15 \pm 0.29, p < 0.001$), IVI ($+0.98 \pm 0.32, p = 0.01$) and EVI ($+1.53 \pm 0.36, p < 0.001$) conditions. Participants achieved overall a greater swing performance after IVI ($+8.05 \pm 0.75, p < 0.001$), EVI ($+11.17 \pm 0.72, p < 0.001$) and KI ($+8.12 \pm 0.75, p < 0.001$) compared to CONTROL (Figure 3). EVI performances also outperformed those after IVI ($+3.12 \pm 0.85, p = 0.001$) and KI ($+3.05 \pm 0.85, p = 0.002$). The linear mixed effects analysis further revealed that swing performance was affected by the CONDITION*MIQ-IVI ($F(3, 44) = 2.86, p = 0.04, R2P = 0.16$), CONDITION*MIQ-EVI ($F(3, 44) = 10.36, p < 0.001, R2P = 0.41$) and CONDITION*MIQ-KI ($F(3, 44) = 7.11, p < 0.001, R2P = 0.33$) two-way interactions.

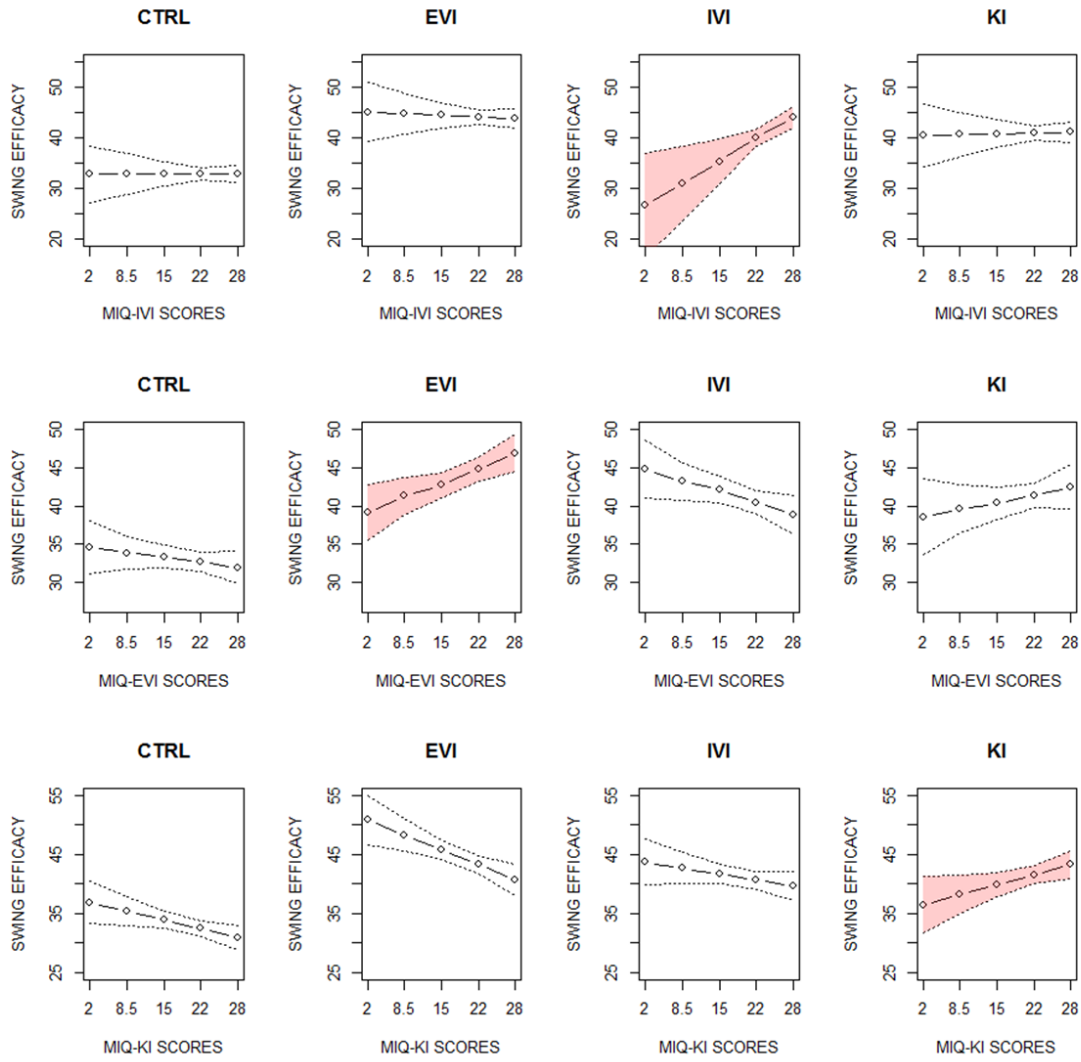


Figure 2. Predictive relationship of imagery ability on swing performance. Individual motor imagery ability scores predicted performance gains under the corresponding motor imagery training condition. IVI: internal visual imagery; EVI: external visual imagery; KI: kinesthetic imagery.

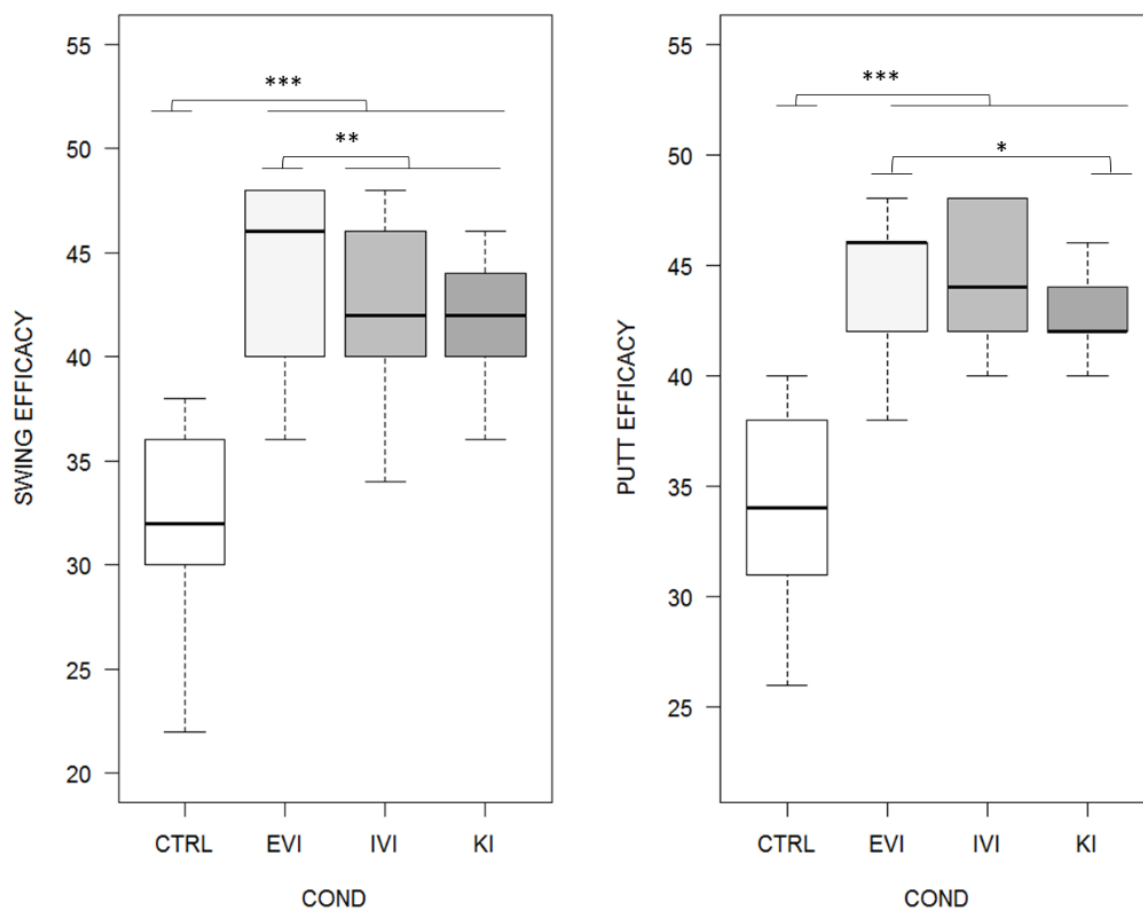


Figure 3. Swing and putt efficacy following imagery interventions. IVI: internal visual imagery; EVI: external visual imagery; KI: kinesthetic imagery.

Putting performance

Data showed a main effect of CONDITION ($F(3, 44) = 86.42, p < 0.001, R^2P = 0.85$). MIQ-IVI scores had a stronger positive predictive relationship on the putting performance after IVI compared to CONTROL ($+0.74 \pm 0.24, p < 0.01$) and KI ($+0.65 \pm 0.26, p < 0.05$) conditions (Figure 4). Similarly, MIQ-EVI scores had a stronger positive predictive relationship on putting performance after EVI compared to CONTROL ($+0.48 \pm 0.11, p < 0.001$) and IVI ($+0.53 \pm 0.12, p < 0.001$) conditions. MIQ-KI scores had a stronger positive predictive relationship on swing performance after KI compared to CONTROL ($+0.42 \pm 0.13, p < 0.01$) and EVI ($+0.45 \pm 0.15, p = 0.01$) conditions. For the main effect

of CONDITION, greater putting performance was observed after IVI (-9.81 ± 0.84 , $p < 0.001$), EVI (-10.41 ± 0.82 , $p < 0.001$) and KI (-7.78 ± 0.85 , $p < 0.001$), compared to CONTROL. Participants also had a higher performance after EVI than after KI ($+2.63 \pm 0.95$, $p = 0.02$; Figure 3). The linear mixed effects analysis carried on putting performance revealed a CONDITION*MIQ-IVI ($F(3, 44) = 3.98$, $p = 0.01$, $R^2P = 0.21$), CONDITION*MIQ-EVI ($F(3, 44) = 9.71$, $p < 0.001$, $R^2P = 0.40$) and CONDITION*MIQ-KI interaction ($F(3, 44) = 3.97$, $p = 0.01$, $R^2P = 0.21$).

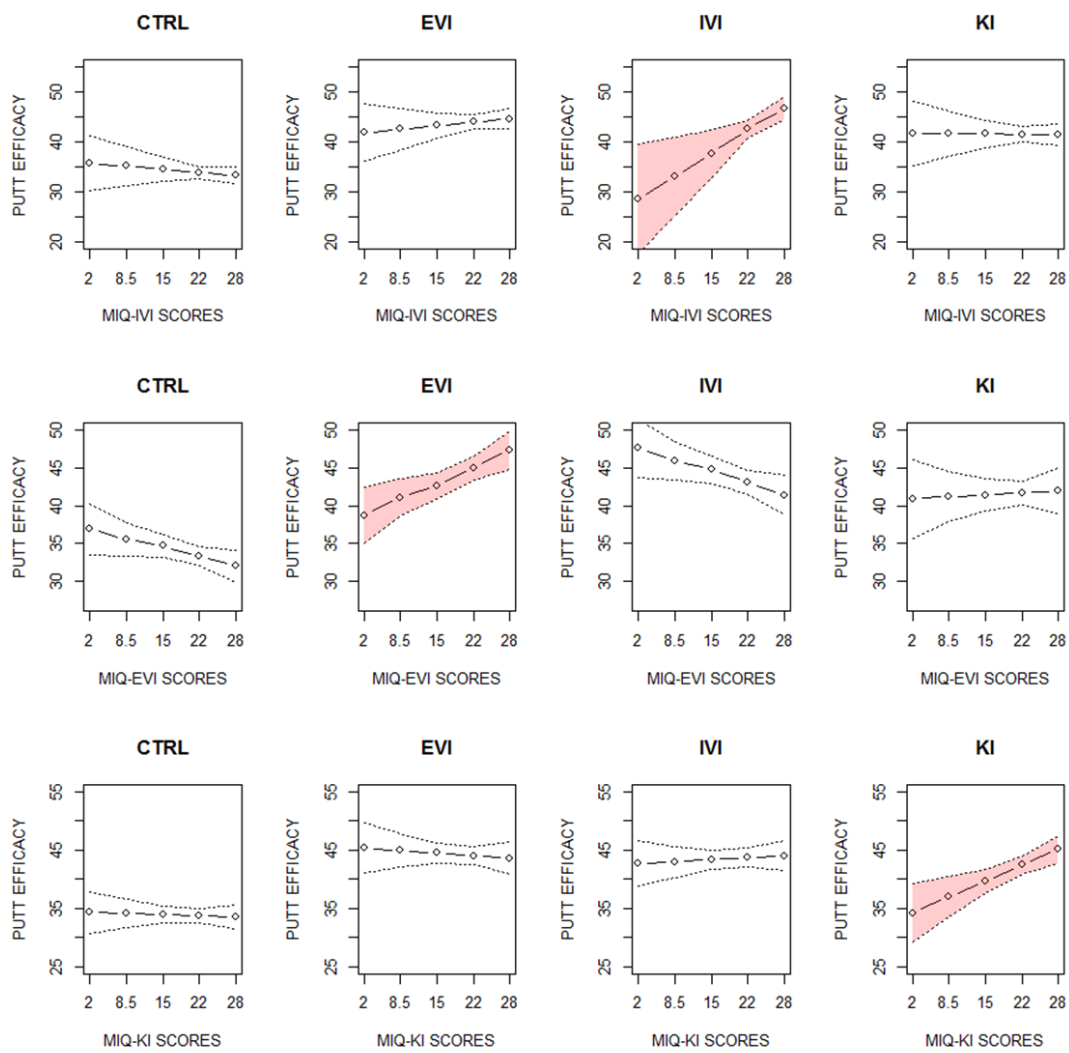


Figure 4. Predictive relationship of imagery ability on putting performance. Individual motor imagery ability scores predicted performance gains under the corresponding motor imagery training condition. IVI: internal visual imagery; EVI: external visual imagery; KI: kinesthetic imagery.

Discussion

The present study was designed to investigate the potential transfer of motor imagery benefits from a complex to a simple golf motor skill, and to explore the selective influence of different imagery modalities. Overall, data confirmed that mentally rehearsing hitting the ball at a long distance (swing), either through visual or kinesthetic imagery, enhanced performance of the corresponding movement, but also transferred to the putting performance. A slight superiority of EVI was observed. Interestingly, imagery ability scores for each imagery modality were also found as relevant predictors of performance gains under the corresponding motor imagery training modality.

Data first revealed that each motor imagery intervention, regardless the imagery type, contributed to improve the accuracy and effectiveness of the swing, hence supporting the benefits of motor imagery on motor performance enhancement. In particular, these results are in line with those reporting the positive influence of an imagery intervention, either combined with physical practice or action observation, in both expert and novice golfers (Smith & Holmes, 2004; Brouziyne Molinaro, 2005; Smith et al., 2008; Ramsey et al., 2008; Robin & Blandin, 2021). Present data also showed the superiority of performing EVI, compared to both IVI and KI. The selective effects of different imagery modalities are well-documented in the scientific literature. Some authors recommended to combine the imagery modalities and perspectives (e.g., Holmes & Collins, 2001; Guillot & Collet, 2008), while others did not find significant differences when comparing IVI and EVI (e.g. Harris & Robinson, 1986; Mahoney & Avener, 1977; Spittle & Morris, 2011). In contrast, a set of experimental studies provided evidence that EVI may be more effective for form-based and closed skills, whereas IVI may be more advantageous for goal-directed and open motor skills (Hardy & Callow, 1999; Nordin & Cumming, 2005b; White & Hardy, 1995). Finally, internal and external perspectives were found to differently affect performance accuracy of the serve, forehand, and backhand tennis strokes (Dana & Gozalzadeh, 2017), which may help to punctually explain the superiority of a perspective over the other. In addition to the influence of the motor skill, the individual preference for a given imagery modality must also be considered. Accordingly, the fact that the individual preference might not systematically match the imagery perspective presumed to be more relevant in a given motor task may explain why there are equivocal findings regarding a ‘superior’ imagery perspective (Sho, 2021). In a qualitative descriptive

study designed to investigate imagery functions, Bernier and Fournier (2010) collected data in expert golfers to explore their imagery use. The authors reported that IVI was principally used, and that expert golfers were capable to adapt the imagery modality according to the context and the rehearsed situation. The superiority of EVI in the present study should therefore be interpreted with extreme caution, more especially since each imagery modality was found to be effective to enhance motor performance. As recommended by Morris et al. (2005), researchers and athletes should certainly consider the individual imagery type/perspective preference and match them with the desired imagery type for the performance skill. Another explanation for the superiority of EVI might come from the nature of the task where imagery effects were transferred. Accordingly, the transfer may have been slightly limited by the fact that KI involves imagery of the feeling of a specific action (here the swing performance), and thus attenuates the transfer to another task with less matched muscle-motor activity (the putting performance). This may be extended to IVI as well, as IVI requires to consider the body as a generator of forces, and previous work showed that IVI recruited more intensively the motor systems than EVI (Jackson et al., 2006; Lorey et al., 2009). EVI, on the other hand, may involve less precise motor representations that could be more easily transferred between tasks. This remains at this stage a working hypothesis, and future experiments should certainly question this issue and shed light on the transfer effects of different imagery modalities.

The most important finding of the present work is that the imagery effects were also observed on the putting performance, hence highlighting a transfer of motor imagery benefits. This data adds to previous work by Lejeune et al. (1994), Nicholson et al. (2018), and Roure et al. (2008), by providing first evidence that performance gains promoted by imagery training effects of complex motor skills (hitting at a long distance) might generalize to more simple game situations (putting accurately on the green). This is a critical point for designing effective imagery interventions. It should help coaches and athletes to identify which situations should be practiced. In open skills, athletes cannot mentally rehearse every single situation or game plan. In keeping with previous experimental data supporting that motor imagery should primarily focus on the technical aspects of motor skills (Olsson et al., 2008), present results suggest that the most complex and demanding motor skills of a given sporting speciality should

be prioritized. Spurred by these findings, future research should certainly confirm the transfer of imagery benefits from a complex to a simple game situation, and explore whether such effect is observed in different motor skills and in athletes with different levels of expertise. Future experiments dealing with this issue should also consider a third performance measure in which no effect of motor imagery and no transfer are expected. This may help to show that motor imagery improves performance, and MIQ moderates performance, for both the trained and the transfer tasks, but not the pure control task. This would definitively demonstrate that the effects are specific to the skill, and not simply a general improvement of motor performance.

Finally, a predictive value of motor imagery ability on performance gains in response to the corresponding motor imagery modality training condition was systematically observed. The individual score on each imagery modality (i.e. IVI, EVI and KI) was a robust predictor of performance gains in the corresponding modality. In other words, when participants performed IVI during their imagery program, the IVI score of the MIQ-3f was the best predictor of subsequent motor performance, and so on for the other imagery modalities. This fundamental relationship provides strong practical support to this imagery questionnaire. By comparing self-report ratings and chronometric assessments of imagery ability using the MIQ-3, Williams et al. (2015) already provided evidence that this questionnaire may not only contribute to subjectively assess imagery ease and vividness, but could also be a valid tool for concurrently assessing the temporal features of motor imagery. Present data therefore support and reinforce the relevance of subjective ratings provided by athletes on their own imagery experience and its usefulness to look beyond the assessment of imagery ability as a proxy to the potential benefits of motor imagery interventions.

References

Amemiya, K., Ishizu, T., Ayabe, T., & Kojima, S. (2010). Effects of motor imagery on intermanual transfer: a near-infrared spectroscopy and behavioural study. *Brain Research*, 1343, 93-103.

- Ben-Shachar M, Lüdtke D, Makowski D (2020). effectsize: Estimation of Effect Size Indices and Standardized Parameters. *Journal of Open Source Software*, 5(56), 2815.
- Bernier, M., & Fournier, J. (2010). Functions of mental imagery in expert golfers. *Psychology of Sport and Exercise*, 11 (6), 444 - 452.
- Bouguetoch, A., Martin, A., & Grosprêtre, S. (2021). Does partial activation of the neuromuscular system induce cross-education training effect? Case of a pilot study on motor imagery and neuromuscular electrical stimulation. *European Journal of Applied Physiology*, 121(8), 2337-2348.
- Brouziyne, M., & Molinaro, C. (2005). Mental imagery combined with physical practice of approach shots for golf beginners. *Perceptual and Motor Skills*, 101(1), 203-211.
- Callow, N., Roberts, R., & Fawkes, J. Z. (2006). Effects of dynamic and static imagery on vividness of imagery, skiing performance, and confidence. *Journal of Imagery Research in Sport and Physical Activity*, 1(1), 1-13.
- Cumming, J., & Williams, S. E. (2013). Introducing the revised applied model of deliberate imagery use for sport, dance, exercise, and rehabilitation. *Movement and Sport Sciences / Science et Motricité*, (82), 69-81.
- Dana, A., & Gozalzadeh, E. (2017). Internal and external imagery effects on tennis skills among novices. *Perceptual and Motor Skills*, 124(5), 1022-1043.
- Demougeot, L., & Papaxanthis, C. (2011). Muscle Fatigue Affects Mental Simulation of Action. *Journal of Neuroscience*, 31(29), 10712–10720.
- Di Rienzo, F., Collet, C., Hoyek, N., & Guillot, A. (2012). Selective effect of physical fatigue on motor imagery accuracy. *PloS One*, 7(10), 1-11.
- Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology*, 79(4), 481-492.

- Efird, J. (2011) Blocked Randomization with Randomly Selected Block Sizes. *International Journal of Environmental Research and Public Health*, 8, 15-20.
- Gao, Q., Tao, Z., Zhang, M. & Chen, H. (2014). Differential contribution of bilateral supplementary motor area to the effective connectivity networks induced by task conditions using dynamic causal modeling. *Brain Connectivity*, 4, 256-264.
- Guillot, A., & Collet, C. (2008). Construction of the motor imagery integrative model in sport: A review and theoretical investigation of motor imagery use. *International Review of Sport and Exercise Psychology*, 1(1), 31-44.
- Guillot, A., Collet, C., & Dittmar, A. (2005a). Influence of environmental context on motor imagery quality. *Biology of Sport*, 22, 215-226.
- Guillot, A., Haguenaer, M., Dittmar, A., & Collet, C. (2005b). Effect of a fatiguing protocol on motor imagery accuracy. *European Journal of Applied Physiology*, 95, 186-190.
- Guillot A. Neurophysiological foundations and practical applications of motor imagery. (2019). In: A. Abraham (Eds.), *Cambridge handbook of the imagination*, Cambridge University Press, pp. 207-226.
- Hardy, L., & Callow, N. (1999). Efficacy of external and internal visual imagery perspectives for the enhancement of performance on tasks in which form is important. *Journal of Sport and Exercise Psychology*, 21(2), 95-112.
- Harris, D. V., & Robinson, W. J. (1986). The effects of skill level on EMG activity during internal and external imagery. *Journal of Sport Psychology*, 8(2), 105-111.
- Hendy, A. M., & Lamon, S. (2017). The Cross-Education Phenomenon: Brain and Beyond. *Frontiers in Physiology*, 8, 297.
- Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian journal of statistics*, 65-70.

- Holmes, P. S., & Collins, D. J. (2001). The PETTLEP approach to motor imagery: A functional equivalence model for sport psychologists. *Journal of Applied Sport Psychology*, 13(1), 60-83.
- Hothorn T., Bretz F., & Westfall P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, 50(3), 346-363.
- Itoh, S. (2020). *Effect of imagery dose variables on performance in sport*. Unpublished doctoral dissertation, Institute for Health and Sport, Victoria University, Australia.
- Jackson, P. L., Meltzoff, A. N. & Decety, J. (2006). Neural circuits involved in imitation and perspective-taking. *NeuroImage*, 31, 429-439.
- Kanthack, T. F. D., Guillot, A., Altimari, L. R., Nùnez Nagy, S., Collet, C., & Di Rienzo, F. (2016). Selective efficacy of static and dynamic imagery in different states of physical fatigue. *PLoS One*, 11, e0149654.
- Kanthack, T. F. D., Guillot, A., Clémençon, M., & Di Rienzo, F. (2020). Effect of physical fatigue elicited by continuous and intermittent exercise on motor imagery ability. *Research Quarterly for Exercise and Sport*, 91(3), 525-538.
- Kanthack, T. F. D., Guillot, A., Blache, Y., & Di Rienzo, F. (2021). Revisiting the acute effects of resistance exercise on motor imagery ability. *Behavioural Brain Research*, 412, 113441.
- Kohl, R. M., Ellis, S. D., & Roenker, D. L. (1992). Alternating actual and imagery practice: preliminary theoretical considerations. *Research Quarterly for Exercise and Sport*, 63(2), 162-170.
- Kraeutner, S., Gionfriddo, A., Bardouille, T. & Boe, S. (2014). Motor imagery-based brain activity parallels that of motor execution: evidence from magnetic source imaging of cortical oscillations. *Brain Research*, 588, 81-91.
- Land, W. M., Liu, B., Cordova, A., Fang, M., Huang, Y., & Yao, W. X. (2015). Effects of physical practice and imagery practice on bilateral transfer in learning a sequential tapping task. *PLoS One*, 11(4), e0152228.

- Lejeune, M., Decker, C., & Sanchez, X. (1994). Mental rehearsal in table tennis performance. *Perceptual and Motor Skills*, 79, 627-641.
- Lohse, K. R., Healy, A. F., & Sherwood, D. (2010). Mental Practice in the Intermanual Transfer of Motor Skills. *Journal of Imagery Research in Sport and Physical Activity*, 5.
- Lorey, B., Bischoff, M., Pilgramm, S., Stark, R., Munzert, J. & Zentgraf, K. (2009). The embodied nature of motor imagery: the influence of posture and perspective. *Experimental Brain Research*, 194, 233-243.
- Macintyre, T., & Moran, A. (2010). MacIntyre, T. & Moran, A. P. (2009). Meta-Imagery processes among elite sports performers. In A. Guillot & C. Collet (Eds.), *The neurophysiological foundations of mental and motor imagery* (pp.227-244). Oxford: Oxford University Press.
- MacIntyre, T. E., Madan, C. R., Moran, A., Collet, C., & Guillot, A. (2018). Motor imagery, performance and motor rehabilitation. *Progress in Brain Research*, 240, 141-159.
- Mahoney, M. J., & Avenier, M. (1977). Psychology of the elite athlete: An exploratory study. *Cognitive Therapy and Research*, 1(2), 135-141.
- Martin, K. A., Moritz, S. E., & Hall, C. R. (1999). Imagery use in sport: A literature review and applied model. *The Sport Psychologist*, 13(3), 245-268.
- Mizuguchi, N., Nakata, H., Hayashi, T., Sakamoto, M., Muraoka, T., Uchida, Y., & Kanosue, K. (2013). Brain activity during motor imagery of an action with an object: a functional magnetic resonance imaging study. *Neuroscience Research*, 76, 150-155.
- Morris, T., Spittle, M., & Watt, A. P. (2005). *Imagery in sport*. Champaign, IL: Human Kinetics.
- Morris, T., Fazel, F., Maher, R., Azizuddin Khan, T. K., Kuan, G., & Spittle, M. (2012). *How much imagery is enough? Developing a research protocol*. Paper presented at the 3rd Chinese Conference on Sport Psychology, Macau.
- Munn, J., Herbert, R. D., & Gandevia, S. C. (2004). Contralateral effects of unilateral resistance training: A meta-analysis. *Journal of Applied Physiology*, 96(5), 1861-1866.

- Munn, J., Herbert, R. D., Hancock, M. J., & Gandevia, S. C. (2005). Training with unilateral resistance exercise increases contralateral strength. *Journal of Applied Physiology*, 99, 1880-1884.
- Munroe, K. J., Giacobbi, P. R., Hall, C., & Weinberg, R. (2000). The four Ws of imagery use: Where, when, why, and what. *The Sport Psychologist*, 14(2), 119-137.
- Munzert, J. & Zentgraf, K. (2009). Motor imagery and its implications for understanding the motor system. *Progress In Brain Research*, 174, 219-229.
- Nicholson, V. P., Keogh, J. W. L., & Low Choy, N. L. (2018). Can a single session of motor imagery promote motor learning of locomotion in older adults? A randomized controlled trial. *Clinical Interventions in Aging*, 13, 713-722.
- Nordin, S. M., & Cumming, J. (2005b). Professional Dancers Describe Their Imagery: Where, When, What, Why, and How. *The Sport Psychologist*, 19(4), 395-416.
- Olsson, C. J., Jonsson, B., & Nyberg, L. (2008). Internal imagery training in active high jumpers. *Scandinavian Journal of Psychology*, 49, 133-140.
- Oosawa, R., Iwasaki, R., Suzuki, T., Tanabe, S., & Sugawara, K. (2019). Neurophysiological analysis of intermanual transfer in motor learning. *Frontiers in Human Neuroscience*, 13, 135.
- Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2020). *nlme: Linear and nonlinear mixed effects models*. R package version 3.1-149, <URL: <https://CRAN.R-project.org/package=nlme>>.
- Paravlic, A. H., Slimani, M., Tod, D., Marusic, U., Milanovic, Z., & Pisot, R. (2018). Effects and dose-response relationships of motor imagery practice on strength development in healthy adult populations: a systematic review and meta-analysis. *Sports Medicine*, 48(5), 1165-1187.
- R Core Team (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Ramsey, R., Cumming, J., & Edwards, M. G. (2008). Exploring a modified conceptualization of imagery direction and golf putting performance. *International Journal of Sport and Exercise Psychology*, 6(2), 207-223.

- Robin, N., & Blandin, Y. (2021). Imagery ability classification: Commentary on «Kinaesthetic imagery ability moderates the effect of an AO+MI intervention on golf putt performance: A pilot study» by McNeill et al. (2020). *Psychology of Sport and Exercise*, 57, 102030.
- Robin, N., Coudeville, G. R., Guillot, A., & Toussaint, L. (2020). French translation and validation of the Movement Imagery Questionnaire-third version (MIQ-3f). *Movement and Sport Sciences - Science et Motricité*, 108, 23-31.
- Romkema S., Bongers, R. M., & van der Sluis, C. K. (2018). Influence of mirror therapy and motor imagery on intermanual transfer effects in upper-limb prosthesis training of healthy participants: A randomized pre-posttest study. *PLoS One*, 13(10), e0204839.
- Roure, R., Collet, C., Deschaumes-Molinaro, C., Dittmar, A., Rada, H., Delhomme, G., & Vernet-Maury, E. (1998). Autonomic nervous system responses correlate with mental rehearsal in volleyball training. *European Journal of Applied Physiology*, 78(2), 99-108.
- Schuster, C., Hilfiker, R., Amft, O., Scheidhauer, A., Andrews, B., Butler, J., . . . Ettlin, T. (2011). Best practice for motor imagery: a systematic literature review on motor imagery training elements in five different disciplines. *BMC Medicine*, 9, 75-75.
- Smith, D., & Holmes, P. (2004). The effect of imagery modality on golf putting performance. *Journal of Sport and Exercise Psychology*, 26(3), 385-395.
- Smith, D., Wright, C. J., & Cantwell, C. (2008). Beating the bunker: the effect of PETTLEP imagery on golf bunker shot performance. *Research Quarterly for Exercise and Sport*, 79(3), 385-391.
- Snow, G. (2020). blockrand: Randomization for Block Random Clinical Trials. R package version 1.5. <https://CRAN.R-project.org/package=blockrand>.
- Spittle, M., & Morris, T. (2011). Can internal and external imagery perspectives be trained? *Journal of Mental Imagery*, 35(3-4), 81-104.
- Van Gyn, G., Wenger, H. A., & Gaul, C. A. (1990). Imagery as a method of enhancing transfer from training to performance. *Journal of Sport and Exercise Psychology*, 12(4), 366-375.

- Weinberg, R. (2008). Does imagery work? Effects on performance and mental skills. *Journal of Imagery Research in Sport and Physical Activity*, 3(1), 1-23.
- White, A., & Hardy, L. (1995). Use of different imagery perspectives on the learning and performance of different motor skills. *British Journal of Psychology*, 86, 169-180.
- Williams, S., Guillot, A., Di Rienzo, F., & Cumming, J. (2015). Comparing self-report and mental chronometry measures of motor imagery ability. *European Journal of Sport Sciences*, 15, 703-711.
- Xu, L., Zhang, H., Hui, M., Long, Z., Jin, Z., Liu, Y. & Yao, L. (2014). Motor execution and motor imagery: a comparison of functional connectivity patterns based on graph theory. *Neuroscience*, 261, 184-194.
- Yue, G., & Cole, K. J. (1992). Strength increases from the motor program: Comparison of training with maximal voluntary and imagined muscle contractions. *Journal of Neurophysiology*, 67(5), 1114-1123.