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From Simulation to Motor Execution: A review of the impact of dynamic motor imagery on performance

Aymeric Guillot^a, Franck Di Rienzo^a, Cornelia Frank^b, Ursula Debrant^{a,c} & Tadgh MacIntyre^d

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

b Faculty of Psychology and Sports Science, Department of Sports Science, Neurocognition & Action - Biomechanics Research Group, Bielefeld University, Bielefeld, Germany

c Institut Universitaire de France, Paris, France

d Department of Psychology, All Institute Maynooth University, Ireland

Abstract

There is now ample evidence that motor imagery contributes to improve motor performance and promote motor learning and motor recovery. During the last decades, a large amount of experimental studies and imagery frameworks were designed to determine the critical key components for effective imagery interventions. The fact that athletes often move slightly during motor imagery has spawned specific interest in imagery research from a conceptual perspective, hence challenging the traditional idea that imagery requires to remain static. While a wealth of research has extensively decoupled motor imagery from action, more recent imagery theories specifically considered that athletes can perform a dynamic form of imagery, by adopting a congruent body position and embodying spatial and/or temporal invariants of the movement without entirely performing it. Spurred by the wide use of this form of imagery by

athletes and the promising related experimental research, the present paper aims at reviewing the impact and predictive positive effects of dynamic motor imagery on motor performance. Direct implications for applied work including specific instructions that dynamic motor imagery might have during different stages of the coaching process of athletes, are further considered. A framework for the appropriate timing for delivering dynamic imagery interventions is finally discussed.

Keywords: Motor imagery; Mental processes; Motor performance; Mental practice; Dynamic imagery.

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Introduction

The ability to mentally simulate actions in the absence of any sensory input and without engaging in the physical execution of the corresponding movement is one of the most remarkable abilities of the human mind (Moran et al., 2012). Motor imagery has been the center pillar of extensive experimental and fundamental research over the last four decades (Guillot & Collet, 2010). Prior research has considered the neurophysiological underpinnings of motor imagery experience, with an array of theoretical explanations including the motor simulation theory (Jeannerod, 2001, O'Shea & Moran, 2017), the ideomotor approach to action control (James, 1890; Koch et al., 2004) and the related perceptual-cognitive viewpoint on action representation (Frank & Schack, 2017), and most recently, the motor-cognitive model of motor imagery (Glover & Baran, 2017). Motor imagery has been reported as being effective when

used by athletes, surgeons and musicians to prepare themselves for performance and achieve excellence in their respective domains (Collet, Hajj et al., 2021; Driskell et al., 1994; Guillot & Collet, 2008; Schuster et al., 2011). Empirical findings have accumulated to provide robust evidence that engaging in motor imagery contributes to enhance motor performance and facilitates motor learning. Imagery training has also been shown to promote motor learning in children and adolescence, both in competitive sports as well as in school-based physical education (Frank, Bekemeier, & Menze-Sonneck, 2021; Li-Wei, Qi-Wei, Orlick, & Zitzelsberger, 1992; Munroe-Chandler, Hall, Fishburne, Murphy, & Hall, 2012). This extant research findings were subsequently employed in clinical settings through a therapeutic approach, and delivered to both patients and injured athletes suffering from motor impairments, to promote motor recovery and manage harmful consequences of various motor disorders (de Vries & Mulder, 2007; Di Rienzo et al. 2014; Malouin et al., 2013). Advances in experimental research on motor imagery, augmented by the explanatory frameworks and models depicting the optimal conditions for motor imagery practice, combined to provide a comprehensive overview of the main recommendations that need to be considered to develop effective motor imagery interventions (for reviews, see Schuster et al., 2011; Guillot, 2019). For example, with regard to each targeted imagery outcome (Guillot & Collet, 2008), although no single set of procedures achieved universal consensus among practitioners, there is ample evidence of why, when, where, and how athletes should use motor imagery, as well as what they should imagine for optimal results (e.g. Cumming & Williams, 2013; Holmes & Collins, 2001; Martin et al., 1999; MacIntyre & Moran 2010; Munroe et al., 2000). Evaluating and illuminating in greater detail the most appropriate guidelines for motor imagery training and adjusting intervention guidelines to athletes' levels of expertise represents an exciting focus of research. For example, evidence that athletes often move slightly while performing motor imagery has spawned specific interest in motor imagery research from a conceptual perspective. It challenges the

traditional idea that imagery requires to remain static and/or maintain a relaxed body position (Louis et al., 2011; Moran et al., 2012; Sebastiani et al., 2019). Many of us are familiar with video footage of athletes engaging in fine movements of their pending performance: skiers shift their weight, twist their body from side to side and adopt a posture close to that of their actual body position during the race, basketball players slightly and dynamically bend their knees when imagining free-throws, and high jumpers calibrate their mental run-up with finger and hand repetitive movements. This synergistic combination of cognitive rehearsal with a slight concurrent physical activity can be seen as an integrative and coordinative form of preparation for subsequent motor performance, and therefore considered a dynamic form of motor imagery (dMI). The present paper aims at reviewing the impact and predictive positive effects of dMI on motor performance, before elaborating direct implications for applied work including specific instructions that dMI might have during different stages of the coaching process of athletes.

The concept of dynamic imagery

Motor imagery is a multisensory construct based on the engagement of different sensory modalities, and consists of either recalling previously perceived situations or elaborating on forthcoming events. Due to its covert nature, investigating the content of the motor imagery experience remains a great methodological challenge and requires sophisticated procedures for investigation (Moran et al., 2012). In addition to the type of motor imagery (e.g. visual vs. kinesthetic imagery) or the imagery perspective (i.e. first vs. third-person perspective), assessing both the accuracy and quality of the imagery content is of critical importance. Within the extant scientific literature, we have identified that five imagery dimensions have been extensively considered: *i*) the vividness of motor imagery (which corresponds to the clarity and richness of the mental representation, such as visualizing each body part), *ii*) the exactness of

motor imagery (which reflects the degree of similarity with the corresponding actual movement), *iii*) the controllability of motor imagery (i.e. the ability to manipulate, transform, or maintain the imagery content over time), *iv*) the temporal congruence between motor imagery and actual movement, and *v*) the ease to form appropriate and accurate mental representations of the movement. Assessing and manipulating these dimensions can enable the motor imagery to be performed as close and realistic as possible to the actual corresponding situation (e.g. overt action production). An important challenge for researchers and practitioners in recent years has been determining how improving this overlap between simulated movements and their executed counterparts can elucidate the processes underlying the dynamic properties of the imagery experience.

To our knowledge, imagery researchers first considered a distinction of the imagery static/dynamic processes three decades ago. In 1991, Paivio and Clark provided a comprehensive review of this distinction, by considering motor imagery of either stationary objects or objects in motion (e.g. objects being mentally rotated). This latter form of motor imagery refers to the perception of movement while recalling objects with a dynamic quality, or forming images of objects being transformed and manipulated. Specifically, the authors postulated that vividness would be the main characteristic of static imagery, while controllability might mediate the dynamic form of imagery by implying some motoric elements. Conceptually, D'Angiulli et al. (2013) suggested that by requiring more cognitive resources, dynamic imagery should be less vivid than static imagery. Although interesting, this conceptual approach mainly considered the possible active manipulation of the imagery experience, where the imager, in practice, remains passive to perform a pure cognitive task. This is, however, clearly distinguishable from the fact that some athletes voluntarily decide to engage in small motor movements while imagining, as mentioned previously (MacIntyre & Moran, 2010). Moreover, this example is distinct from situations where involuntary movements can occur and

accompany/facilitate motor imagery while imagining complex sequences of movement (Annett, 1995). Such forms of dMI, where the dynamic properties rely on the person performing motor imagery, refers to the incorporation of some gestures which typically accompany motor imagery without exactly replicating, even in miniature, the exact form of the movements which comprise the physical task, nor fully engage the whole body. Along these lines, dMI can be viewed as a motor imagery task associated with movements partially mimicking those mentally represented. While a wealth of research on imagery interventions across several decades has decoupled motor imagery from the action, more recent imagery theories posit that motor imagery can be clearly understood along a continuum where pure imagery is on one side, and intentional full movement at the opposite (Jeannerod, 2006; Di Rienzo et al., 2016). Here, motor imagery thus appears somewhat coupled with motor execution, and movement become possible during covert action states (MacIntyre & Moran, 2010).

Insert Table 1 about here

Considering movement during a cognitive task requires one to reevaluate its boundaries. Accordingly, Di Rienzo et al. (2016) proposed a definition of dMI as “*a type of motor imagery where athletes adopt a congruent body position and embody spatial and/or temporal invariants of the movement without entirely performing it*”. Both researchers and practitioners should, according to this operationalization, be cogniscant that performing dMI remains different from imagining while performing the whole movement and engaging the full body in the planned activity. Although possible, this form of combination between the two forms of practice has received less attention and is not common (e.g. Hanrahan & Verger, 2001; Kanthack et al., 2017; Nordin & Cumming, 2007; Razon et al., 2010, 2014; Vergeer & Roberts, 2006;). A recent

review proposed that physical and cognitive activities might have a positive synergistic effect, as the cognitive task may promote performance through both facilitation and guidance effects over physical practice (Herold et al., 2018). These authors discussed the concept of “*motor-cognitive training*”, that they differentiated into ‘*thinking while moving*’ or ‘*moving while thinking*’ exercises, where the cognitive task is incorporated into the motor task to enhance neuroplasticity and achieve excellence. They claimed that combining cognitive and physical practice might result in performance gains that exceed the additive benefits of each approach considered in isolation (Fissler et al., 2013; Herold et al., 2018; Kraft, 2012). Applied to imagery interventions, we suggest that the concept of dMI might be considered within their framework, where incorporating slight movements into the main cognitive task would allow participants to benefit from the synergistic effects provided by the guidance of movement during imagination. Consequently, dMI may then provide an integrative and coordinative form of preparation for athletes through a specific motor-cognitive training. But do accompanying movements, if performed at a slower speed or without sufficient force, actually enhance or inhibit the training effect? Given that dMI might bring about potential adverse effects too, which must either be discounted or controlled, we discuss this and other key dimensions in the realm of dMI in the following.

The effects of dynamic imagery

Although accounts of athletes intuitively performing dMI during the preparation of their pending performance have been available for decades, experimental research looking at this issue and specifically designed to characterize the intrinsic properties of dMI, as well as its effects on subsequent motor performance, remains sparse (Table 2). Only a handful of studies have been conducted to determine whether dMI might result in similar or greater performance

gains than interventions based on conventional conceptualizations of imagery requiring to remain static during simulation of action (Figure 1).

Based on the recommendations by Gould and Damarjian (1996), Callow et al. (2006) were the first to examine the selective effects of dMI and static imagery on vividness of imagery, down-hill ski-slalom performance, and self-confidence, in a sample of race standard skiers. Athletes performed dMI directly on the snow while wearing their own equipment, and were instructed to adopt their race position and move their body from side to side, as during an actual ski race. While participants subjected to dMI did not complete the course significantly quicker than athletes who practiced static (motionless) imagery, dMI yielded higher confidence and imagery vividness scores than static imagery. This pioneering work, although only partially supporting the direct benefits of dMI on performance (participants from the dMI group performed significantly better than a third pure control group), highlighted that engaging in this particular form of motor imagery might be useful to improve other imagery outcomes such as self-confidence, which may in turn positively result in delayed performance gains. Furthermore, Callow et al. (2006), reported that dMI improved the accuracy and vividness of participants' self-reported imagery. This study therefore provided tentative support that dMI might contribute to enhance motor imagery quality and effectiveness, hence sketching potentially fruitful new directions for mental training and imagery interventions. They further concluded that dMI was likely to emphasize the degree of behavioral matching, and possibly the functional equivalence (Moran et al. 2012), between motor imagery and the corresponding physical practice. A second cross-over study by Guillot and colleagues (2013) extended these findings and investigated the effects of dMI in a sample of high jumper competitors, who rehearsed their performance either with or without associated arm movements mimicking the run-up preceding the take-off for the jump. They reported that dMI enhanced both the temporal congruence

between motor imagery and motor performance and the technical efficacy of the jump, along with an increased number of successful trials.

Later on, the validity of applying a dynamic support to the imagination in different samples of participants has been questioned in a set of experimental studies by Fusco et al. (2014; 2016; 2019). In a first experiment with a sample of healthy volunteers they assessed the preservation of the actual temporal characteristics of several locomotor tasks (natural walking, light running, lateral walking, and backward walking) during both static and dMI conditions (Fusco et al., 2014). While there was no time differences for the physical execution of both natural and backward walking conditions, participants only achieved temporal congruence during dMI. Furthermore, they significantly underestimated actual times during static imagery, for light running and lateral walking. In a follow-up study to investigate whether ageing, and a possible decline in motor function was likely to prevent from the advantage accruing from dMI (Fusco et al., 2019), comparing data in young and elderly samples revealed that in spite of a slight slowdown in motor performance among older participants, both temporal accuracy and motor imagery vividness were greater during dMI than static motor imagery in all subjects. The authors concluded that the motor imagery experience may be substantially strengthened by the actual feedback generated through dMI, and that this benefit might be unaffected by age, hence highlighting promising applications among older populations. More recently, however, Sacheli et al. (2020) did not replicate these findings. They posited that older participants with good motor imagery ability and no functional limitations found difficulty in controlling actual ankle dorsiflexion while performing gait imagery, and that dMI was a “*motorically more demanding*” task. Although dMI is likely to be applied as a strategy to boost motor imagery in general, the authors stated that it may also be too cognitively demanding in some circumstances, and therefore prevent from positive effects without prior specific training. Interestingly, Fusco and colleagues also looked at the potential superiority of dMI over static motor imagery in a clinical

study involving stroke patients (Fusco et al., 2016). Using a similar paradigm, both healthy participants and stroke patients performed static motor imagery of lateral, forward and backward walking, as well as dMI of these tasks while physically stepping in place. The findings revealed that healthy participants completed the task faster during static imagery (i.e. underestimation of motor execution duration), while temporal congruence between the simulated and executed motor action was higher during dMI. Specifically, among stroke patients, the spatiotemporal congruence with actual locomotion was observed only during dMI of the forward walking condition. The authors argued that this pattern of selective effects might be primarily due to the familiarity of patients with the task, hence offering promising avenues for neurorehabilitation. Another recent study by De Bartolo et al. (2020) provided a different perspective and used wearable inertial sensors to measure limb oscillations (e.g. angular velocity, frequency of oscillations and sinusoidal waveform) performed by young adults, older adults and stroke patients, during dMI of walking. Interestingly, they found that dMI contributed to increase the similarity with the actual walking oscillations, even though the effect was more pronounced for upper than lower limbs, regardless the age of the participants. According to the authors, this limb-related difference might be due to the fact that during walking, movements of lower-limbs are performed in a more automatic way that also depends on sensory feedback, reflexes and ground reaction forces. This innovative technique of investigation undoubtedly offers an objective and sensitive evaluation of the motor imagery content to appreciate the degree of congruence between motor imagery and corresponding physical performance.

Insert Table 2 about here

Among recent applied contributions, only two experimental studies were designed to evaluate the potentials benefits of dMI in sporting samples, during pre-performance imagery

routines. Firstly, Kanthack et al. (2016) asserted that dMI right before shooting is likely to enhance shooting performance in basketball players, except when athletes were highly physically fatigued, thus highlighting for the first time possible detrimental effects of dMI. In an original and innovative intervention study focusing on the optimal conditions of static imagery and dMI use, they provided evidence that the current physical state of the athlete may affect his/her body representation, resulting in motor prediction impairments. The authors interpreted the difficulty to use appropriately dMI under fatigue as the result of an interference and a mismatch between the actual and the predicted body state, and an erroneous update of the internal representation of pending actions. Such incongruence between the fatigued body state and the imagery task is likely to affect the positive guidance effect of moving while imagining, hence suggesting that in such circumstances, static imagery should be prioritized by athletes. Secondly, Robin et al. (2019) examined the effects of dMI, combined or not with action observation, on free-throw performances of elite basketball players during pre-performance routines. Their findings revealed greater performance gains when combining dMI with action observation. This is the first work conducted, within the same experimental design, these two variables of influence of the imagery experience (i.e. dynamic content and concurrent action observation). An original recent study further looked at the effects of dMI in sighted non-athletes, sighted unprofessional athletes and high-skilled athletes with visual impairments. They confirmed the superiority of dMI over static motor imagery in terms of temporal features, except in high-skilled athletes who certainly focused more predominantly their attention on the spatial properties of the imagery experience.

An additional set of imagery studies merits to be considered in the present review as they addressed the neural correlates of dMI and illuminate the neurophysiological processes engaged during this specific form of motor cognitive training. With a sample of stroke patients, Dodakian et al. (2014) first compared the patterns of brain activation during

pronation/supination movements of the paretic arm, combined or not with motor imagery of opening and closing a doorknob. The actual movement condition recruited the anticipated motor network including the left sensorimotor cortex and the right cerebellum. When concurrently performing motor imagery, the pattern of activation also involved the left inferior parietal lobule and the right dorsolateral prefrontal cortex. The dMI therefore included activity in additional regions known to play a critical role in planning and cognitive control of the movement, which may be of particular interest post-stroke. Sacheli et al. (2018, 2020) advanced this finding by investigating the neural networks that mediate walking and standing on the spot without (static motor imagery) or with (dMI) concurrent overt ankle dorsiflexions. In a first experiment comparing neuronal activity in healthy participants and patients with chronic knee arthrosis (Sacheli et al., 2018), findings revealed impoverished motor representations of gait in patients both at the cortical and subcortical levels. The motor guidance effect offered by dMI compensated for this weakness and promoted recruitment of posterior parietal visuomotor and mesencephalic locomotor areas. The authors concluded that dMI assisted patients to form a kind of “*cognitive scaffolding that helped them better recall gait kinesthetic sensations while performing the task*” (p.186). Using a similar paradigm designed to integrate a life-span perspective, Sacheli et al. (2020) later examined the neural underpinnings of static motor imagery and dMI in young and older adults without functional limitations. They found distinct patterns of brain activations in their sample, who further used different neurocognitive strategies to complete the dMI condition. Another interesting finding was that dMI was a more complex and demanding task, even in young participants, and that older participants encountered greater difficulty to engage in dMI as the concurrent physical task was already resource-consuming, hence reducing the available resources involving the same neural circuitry. Although the authors recruited older participants with good imagery ability and no

functional limitations, they concluded that a caveat should be added to the application of dMI as it may be too cognitively demanding and, therefore, possibly less efficient.

Insert Figure 1 about here

Timing and functions of dynamic imagery interventions

The issue of the optimal motor imagery dose-response relationship, including parameters such as frequency and duration of imagery sessions, or number of imagery trials and imagery training program length, is still debated in the scientific literature (Driskell et al., 1994; Paravlic et al., 2018; Schuster et al., 2011; for review and guidelines for the most effective imagery dosages, see Morris et al., 2012; Ito, 2020). Likewise, determining the optimal timing to implement dMI interventions remains of critical importance, but has received very little attention. We articulated in the previous section that dMI might certainly not be the most relevant form of mental training in all circumstances, such as under intense fatigue. This remains, to the best of our knowledge, the first evidence-based contraindication. The aforementioned effect of aging and the cognitive capacities of the participants have also been considered, and we suggest caution in application on the basis that dMI remains a more demanding/intense form of mental practice (Sacheli et al., 2020). Moreover, we suggest that one should exercise caution when designing the dosage and frequency of dMI practice, to avoid dependence of participants to this form of mental training. One should keep in mind that motor imagery, in its purest form, is the cognitive rehearsal of a task without any overt output, and that dMI merely remains a modified and specific form of mental training. In hindsight, and in the absence of an evidence on the dMI dose-response relationship, we posit that dMI should be specifically *but not systematically* considered, and performed to achieve one of the four following predetermined targeted outcomes (Figure 2).

1/ dMI might be used early in imagery training programs to improve imagery vividness, most especially if the individual encounters trouble to perform appropriate, accurate, exact, and/or real-time motor imagery. Accordingly, experimental data reviewed in previous sections provided converging evidence of the benefits of including slight congruent movements during motor imagery, hence offering actual proprioceptive feedback during mental training, and guidance for more appropriate motor representations. In addition, participants self-reported that dMI facilitated the formation of the mental representation, although recent evidence support the idea that dMI was a motorically more demanding task requiring additional neural resources (Sacheli et al., 2020). In practical terms, this is not a novel recommendation as athletes spontaneously frequently engaged in such form of mental practice for years (MacIntyre & Moran, 2010). Understanding in greater details the conditions where incorporating this form of mental training are optimal, in addition to determining the neural correlates mediating dMI, may definitely contribute to improve the optimal dosage and conditions of practice of this specific form of motor imagery. Further research remains necessary to explore the potential of interference effects when performing incongruent dMI. To date, only one study provided evidence of some beneficial effects of an incongruent form of motor imagery where athletes achieved greater breath-hold performance during breathing motor imagery (Kanthack et al., 2019). Looking for similar/different effects in a dMI paradigm might elucidate more clearly the features of the dMI experience that should be prioritized by athletes and other performers.

2/ An embedded form of dMI practice may be incorporated into motor imagery sessions designed to improve motor performance and promote motor learning. There is now abundant evidence that considering the environmental constraints where motor imagery is likely to be performed is necessary, and that motor imagery should ideally be performed in an environment that is very close to that experienced during actual practice (Guillot, Collet, & Dittmar, 2005; Holmes & Collins, 2001). The context has indeed a wider influence given explanatory accounts

from grounded cognition (MacIntyre et al., 2018). It is usually recommended to perform motor imagery while wearing adequate clothes (Holmes & Collins, 2001; Guillot et al., 2005; Callow et al., 2006), holding a piece of the corresponding equipment (Mizuguchi et al., 2013), and adopting the same body position or posture as during actual practice (Lorey et al., 2009; Saimpont et al., 2012). Such contextual congruence might contribute to specifically improve imagery vividness and promote recall of appropriate kinesthetic sensations (Cumming & Williams, 2012). Similarly, previous research provided evidence that athletes should reach a level of physiological arousal close to that of the physical practice, to ensure motor imagery effectiveness and reduce harmful consequences of relaxation on the ability to achieve temporal equivalence (Guillot and Collet, 2008; Louis et al., 2011). Practically, and based on the studies reviewed in the present manuscript, we believe that the intrinsic characteristics and benefits of dMI might reinforce the degree of congruence between the motor imagery experience and the actual movement, hence resulting in more accurate and appropriate mental representation of the movement sequence. Additionally, performing dMI might somewhat offer a window to the content of the mental representation, hence allowing a better control of covert practice.

3/ A critical use of dMI, which is very frequently and intuitively engaged by athletes, takes place during pre-performance routines (for review, see Cotterill, 2010). In such circumstances, the aim of dMI is to improve self-confidence and reduce anxiety, in order to prepare subsequent motor skills. Pre-performance dMI might thus contribute to calibrate the competitive components at a mental level to achieve optimal athletic performance (Perry and Katz, 2015), and could be implemented at an early stage of learning (Perry et al., 2018). The more complete mental representation of the movement offered by dMI, as well as the greater ability to control the temporal features of the action, are likely to improve the feeling of being well-prepared and the self-confidence on the ability to manage performance and achieve excellence in the pending execution of the motor sequence. Using dMI might further serve to promote narrowing focus

on important goals and cues, while reducing wasted energy on distractions and improving feeling of being ready.

4/ Finally, dMI might be relevantly incorporated in motor imagery interventions which are scheduled during the classical course of physical therapy. The therapeutic benefits of pure static imagery are now well-evidenced, but little is known about the additional or selective positive/deleterious effects of dMI. As mentioned in the previous section, preliminary data supported the successful integration of dMI into neurorehabilitation programs. By improving the exactness and quality of the imagery experience, dMI is likely to enhance the beneficial therapeutic effects of motor imagery practice on motor recovery and impact related neuroplasticity. While experimental investigation is warranted to test this working hypothesis in different sample of patients, dMI conceptually appears a relevant and cost-effective adjunctive form of practice in rehabilitation settings. Future work should here inevitably question the possible interference between the expected motor activity during dMI and the functional limitations/residual capacities of the patients resulting from their motor impairments. We further postulate that combining dMI with action observation might be a promising approach (Eaves et al., 2016b). There is great evidence that combined action observation and motor imagery increased activity in brain motor regions, compared to either action observation or motor imagery alone (Nedelko et al., 2012; Taube et al., 2015; Eaves et al., 2016a), and that such combination, in conjunction with physical practice, might contribute to promote motor recovery (Sun et al., 2016; Emerson et al., 2018; Bek et al., 2019). Combining dMI with action observation might thus help to reinforce such positive effects. In reference to the model by Jackson et al. (2001), which considered how motor, cognitive and psychological factors contribute to promote motor recovery, engaging in dMI might improve interaction of the different levels of processes involved in the rehabilitation of motor disorders. Taken together,

further research is warranted before drawing any firm conclusion, since there is yet no universal and standard procedure, and certainly inter-individual differences requiring a wise use of dMI.

Insert Figure 2 about here

From a conceptual viewpoint, other limitations or questioning regarding the use of dMI might certainly emerge from future experimental investigations. For instance, but not exhaustively, does dMI contribute to improve motor performance of movements including different complex coordinative abilities and/or movement speeds? How overcoming the methodological issues when exploring the neural networks mediating dMI, as the actual guidance effect will inevitably interfere with the motor inhibition usually observed during motor imagery (could we even consider that there is still some motor inhibition as we allow movement, to some extent, during dMI)? How managing the possible detrimental effects which may be consolidated in case of inappropriate mental practice resulting from a motor interference between action and motor imagery? These questions definitely require further scientific enquiry to provide a deeper framework for the optimal use of dMI.

Conceptual Implications of dynamic motor imagery

Simulation processes require cognitive effort, planning, attentional and emotional control and meta-imagery abilities. The term meta-imagery emerged from research on the naïve knowledge of students about mental practice effects over three decades ago (Denis & Carfantan, 1985). Moran (2002) defined it as people's knowledge of, and control over, their own mental imagery skills and experiences. Meta-imagery abilities have been linked to expertise effects

(MacIntyre & Moran, 2010). For example, studies athletes with higher levels of imagery abilities demonstrated comprehensive understanding of the key aspects of motor imagery (e.g. temporal congruence). Moreover, athletes differentiated between static imagery and more than one type of dMI. In qualitative interviews athletes demonstrated both synchronous movements (e.g., moving the appropriate limbs to simulate the executed skill) or asynchronous movements (e.g., other movements in which, for example, their hand may simulate the carving movement of a kayak) during imagery. These significant elaborations on the dMI provided tentative evidence for the role that knowledge-based structures in supporting the application of imagery interventions. The degree to which performers can inhibit to some degree the motor execution during motor imagery (Guillot et al., 2012) raises the potential for an evolving research domain. While embodied cognition perspectives are now a burgeoning research area (Cappuccio, 2019), grounded cognition accounts merit further enquiry with regard to dMI (MacIntyre et al., 2019). This approach can help us to understand the evidence that simulation processes are predominantly grounded in our physical experiences (Olsson & Nyberg, 2011). In other words, dMI may be limited by expertise considerations but may also be acquired more readily by meta-imagery training to upskill athletes on the declarative knowledge underlying the cognitive and procedural skills of dMI.

Conclusions

Imagery research has been one of the most challenging domains for psychological enquiry given the covert nature of the experience (MacIntyre et al., 2018). Decades of theorizing, experimentation and methodological advances have emerged from the interaction of sport psychology, cognitive neuroscience and the rehabilitation sciences (Moran et al., 2012). Motor imagery, a term outlined by Jeannerod (1994), became illuminated more clearly when differentiated from simulation processes more generally (Moran et al., 2012). Investigators have

historically artificially decoupled action and cognition. Ironically, the future of research in this field may well depend upon exploring these synergies more systematically by focusing on dMI.

Declaration of interest statement

The authors declare that there is no financial interest or benefit that has arisen from the direct applications of this research.

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Figure Captions

Table1: Key Operational Definitions relating to Motor Imagery Constructs.

Table2: The effects of dynamic motor imagery.

Figure 1: Predicted positive effects of dynamic motor imagery.

Figure 2: Appropriate timing for delivering dynamic imagery interventions.

Table 1

Term	Definition	Source
Mental Imagery	Refers to the cognitive simulation process by which we can represent perceptual information in our minds in the absence of appropriate sensory input.	Munzert, Lorey, & Zentgraf (2009)
Motor Imagery	Motor imagery is a mental state during which the representation of a given motor act or movement is rehearsed in working memory without any overt motor output.	Guillot & Collet (2010)
⇒ <i>Dynamic</i> Motor Imagery (dMI)	An enriched type of motor imagery where adopting a congruent body position and embodying spatial and/or temporal features of the movement without entirely performing it	Di Rienzo et al. (2016) updated by Guillot et al. (<i>current work</i>)
⇒ <i>Static</i> Motor Imagery (sMI)	Usual type of motor imagery where athletes remain motionless and perform covert mental representation of the corresponding movement.	<i>Classical and universally accepted definition of motor imagery</i>

Table2.

<i>Authors</i>	<i>Year</i>	<i>Participants</i>	<i>Imagery task</i>	<i>Actual guidance offered by dynamic imagery</i>	<i>Main results</i>	<i>Impacted motor imagery dimensions</i>
Callow et al.	2006	24 high-level junior skiers	Down-hill ski slalom course	Moving body from side to side in a race position	Dynamic imagery increased imagery vividness and self-confidence scores	Imagery vividness / Self-confidence
Guillot et al.	2013	12 elite high-jumpers	High-jump	Slight sequential upper-limb movements	Dynamic imagery enhanced technical performance, facilitated temporal congruence and improved imagery vividness	Imagery vividness / Temporal congruence Motor performance
Dodakian et al.	2014	8 stroke patients	Opening/closing doorknob	^a Pronation/supination of the forearm	Dynamic imagery recruited additional brain regions known to play a critical role in planning and cognitive motor control	-
Fusco et al.	2014	20 healthy participants	normal/lateral/backward walking light running	Stepping in place	Greater temporal congruence was observed during dynamic imagery for light running and lateral walking	Temporal congruence
Fusco et al.	2016	12 stroke patients, 12 elderly and 20 young adults	normal/lateral/backward walking	Stepping in place	Temporal congruence was better during dynamic imagery in healthy participants, but only in the familiar normal walking condition in stroke patients.	Temporal congruence
Kanthack et al.	2016	10 high-level basketball players	Shooting (free-throw)	Slight arm movements and semi-flexions of the legs	Dynamic imagery substantially improved shooting performance, but was less effective than static imagery under fatigue.	Motor performance
Sacheli et al.	2018	22 patients pending total knee arthroplasty	Standing/walking	Ankle dorsiflexions	Dynamic imagery compensated the impoverished motor representation of gait and facilitated recall of kinesthetic sensations	Imagery vividness
Fusco et al.	2019	15 young and 15 older adults	normal/lateral/backward walking	Stepping in place	Temporal and spatial imagery accuracy were greater during dynamic imagery in all participants	Imagery vividness / Temporal congruence
Robin et al.	2019	46 regional basketball players	Shooting (free-throw)	Slight arm movements and semi-flexions of the legs	Greater performance gains were observed when combining dynamic imagery with action observation	Motor performance
De Bartolo et al.	2020	27 young and 15 older adults, 15 stroke patients	Walking	Limb swinging	Dynamic imagery increased the similarity with actual walking oscillations, with a more pronounced effect for upper than lower limbs	-

Sacheli et al.	2020	21 young and 21 older adults	Standing/walking	Anke dosriflexions	Distinct age-related brain activations, revealing different neurocognitive strategies, were observed. Dynamic imagery is a motorically more demanding task
Fusco et al.	2021	10 high-skilled athletes with severe visual impairments, 10 sighted volunteers, and 10 unprofessional university athletes	normal/lateral/backward walking light running	Stepping in place	Temporal congruence was better during dynamic imagery in sighted volunteers and unprofessional athletes, but not in high-skilled athletes with severe visual impairments Temporal congruence

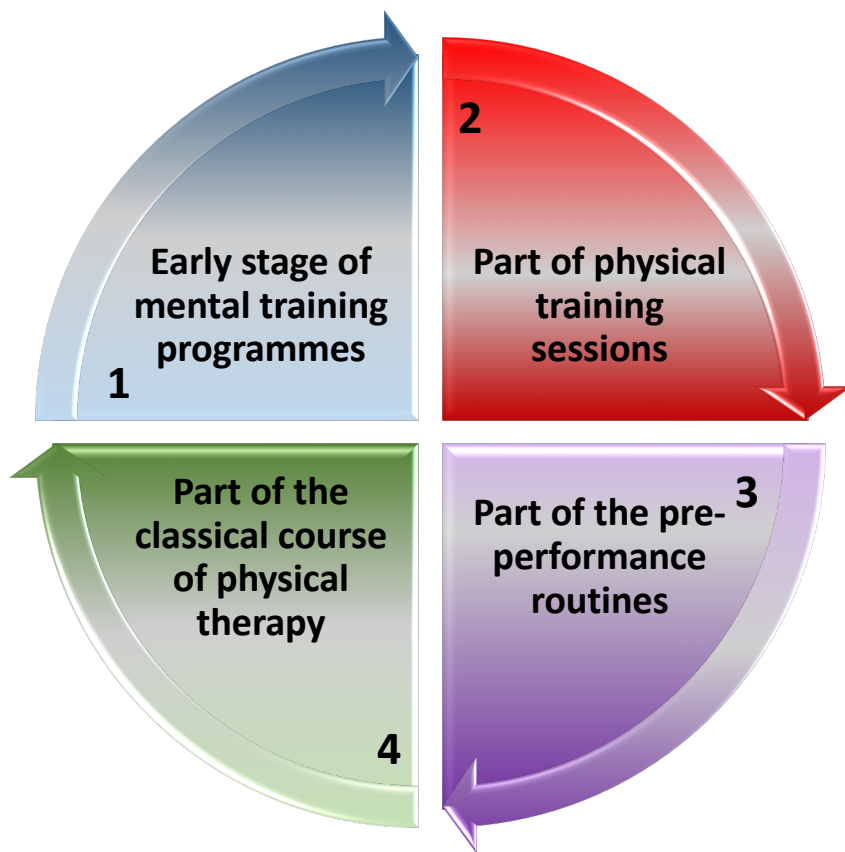


Figure 1

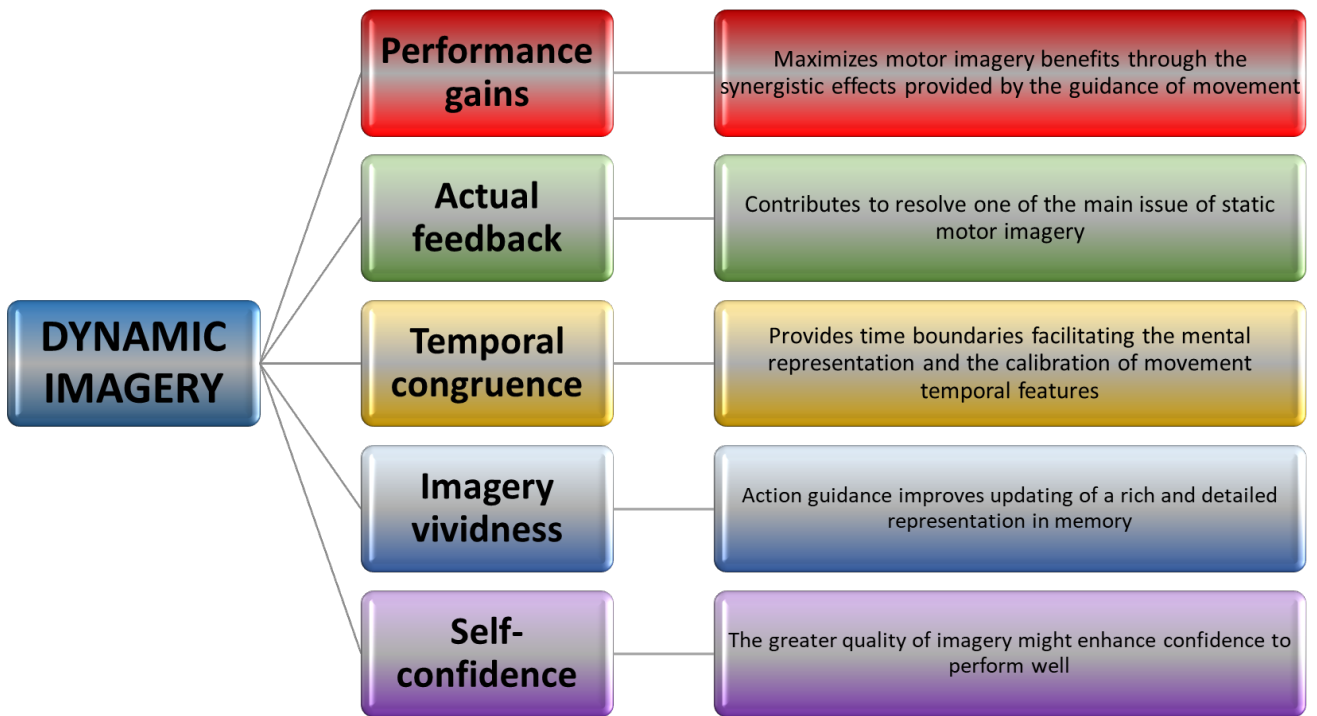


Figure 2.