ARTICLE IN PRESS
JID: AJSEP [m5GeSdc;July 29, 2022;12:13]

Asian Journal of Sport and Exercise Psychology xxx (xxxx) xxx

KeAi CHINESE ROOTS GLOBAL IMPACT

Contents lists available at ScienceDirect

Asian Journal of Sport and Exercise Psychology

journal homepage: www.elsevier.com/locate/ajsep

Twenty years of PETTLEP imagery: An update and new direction for simulation-based training

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A B S T R A C T

Research has shown that motor imagery (MI) interventions, involving the systematic and repeated imagination of visual and kinaesthetic components of movements, can enhance performance in sport. Twenty years ago, Holmes and Collins (2001) published the PETTLEP model as a framework to improve the delivery and outcome of MI interventions. The model outlined seven principles to be considered when designing effective imagery interventions: Physical, Environment, Task, Timing, Learning, Emotion, Perspective (i.e., PETTLEP). The incorporation of these principles within MI interventions was assumed to facilitate performance through the optimisation of a functional equivalence between the neurophysiological substrates of motor preparation and execution, and that of MI. Since its conception, this model has become a standard for many in the delivery of imagery interventions in sport and has been corroborated through research and practice. This 20-year review first covers the reach and impact of this influential model and the more recent empirical investigations related to PETTLEP. We then outline how PETTLEP-based imagery may be integrated with action observation to support an increasingly popular approach to the delivery of imagery interventions in sport. Research indicates that combining these two simulation states can enhance sport performance whilst also providing the sport psychologist more control over the imagery experience than is possible through traditional imagery interventions. This article discusses the application of PETTLEP within a combined action observation and imagery framework and provides guidance for sport psychologists for the creation of new PETTLEP-informed interventions.

Background to the PETTLEP Model

Motor imagery (MI) involves the generation, maintenance and transformation of both visual and kinaesthetic perceptual representations of movement (Kosslyn et al., 2010). The effect of MI has long been of interest in sport psychology (see Feltz & Landers, 1983), and it is now well documented that, when integrated alongside physical training in a structured manner, MI can contribute to improvements in both physical performance and sport-related psychological processes (e.g., concentration, motivation, arousal and self-efficacy; Cumming & Williams, 2013; for meta-analyses see Simonsmeier et al., 2020; Toth et al., 2020).

Early MI interventions in sport tended to be characterised by variable intervention delivery, a lack of personalisation to meet the athlete's individual needs, and often utilised a relaxation-based approach to deliver the MI (e.g., Hale, 1998). This may have been, at least in part, due to the absence of available evidence-based guidelines for developing MI interventions in sport. Using a multidisciplinary approach, Holmes and Collins (2001) drew on research from neuroscience, cognitive-behavioural psychology, and sport psychology to create the PETTLEP Model for motor imagery. This model served as a set of guidelines for sport psychologists to consider when developing MI interventions and tailoring them to individual athlete needs. PETTLEP is an acronym for seven practical elements that sport psychologists could consider when developing MI interventions with athletes (i.e., Physical, Environment, Task, Timing, Learning, Emotion, and Perspective).

In brief, the model proposes that the MI experience should approximate movement preparation and execution as closely as possible. This can be achieved by engaging in the MI whilst adopting the appropriate stance, performing appropriate movements, and holding relevant implements to encourage afferent feedback of task relevant kinetic and kinematic cues (Physical). The MI could be supported by relevant video footage or dynamic photographs of training or competition environments to facilitate vivid MI generation and prime the visual component of the MI (Environment). MI was recommended to be performed in real-time, rather than in slow- or fast-motion in order to reinforce the temporal components of the skill (Timing), and the content of the MI should be adapted to the athlete's skill level and progressed to ensure that the athlete's MI focus is on aspects relevant to their current performance level (Learning). Within Lang's Bioinformational Theory (Lang, 1979, 1985), an important aspect of PETTLEP, stimulus-response and meaning proposition training are recommended to guide the athlete to convey the feelings and emotions they experience during movement

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https://doi.org/10.1016/j.ajsep.2022.07.002
Received 14 January 2022; Received in revised form 28 June 2022; Accepted 19 July 2022
Available online xxx

Please cite this article as: M.W. Scott, D.J. Wright, D. Smith et al., Twenty years of PETTLEP imagery: An update and new direction for simulation-based training, Asian Journal of Sport and Exercise Psychology, https://doi.org/10.1016/j.ajsep.2022.07.002

execution, and especially the importance she/he attaches to these sensations; these can then be incorporated into the MI instructions (Emotion). In addition, the visual perspective and angle from which the MI is performed (first- or third-person) should be considered and determined based on the task being imagined and the athlete's own visual perspective preferences (Task, Perspective). For further details on the original model and its application, see Holmes and Collins (2001); Holmes and Collins (2002); Wakefield and Smith (2012) and Wakefield et al. (2013).

It is important to note that the inclusion of all seven PETTLEP elements should not be viewed as essential for effective MI interventions, nor indeed as a checklist to tick through when designing MI interventions. This is important as the original model, influenced heavily by Langian theory (Lang, 1979; 1985), stressed the importance of catering to the needs of the individual athlete and personalising the MI accordingly. The notion that all seven elements *must* be included goes against this key premise and reverts to a 'one size fits all' approach (see Wakefield et al., 2013). Although this approach may be more of an issue in PETTLEP research studies, possibly influenced by a desire for experimental control, it is vital to avoid a potential trickle-down effect from research into practice regarding a lack of individualisation of interventions. Sport psychologists are, therefore, advised to spend appropriate time building a rapport and learning about their client to allow the development of personalised PETTLEP interventions (cf. Ely et al., 2020; Ely & Munroe-Chandler, 2021).

Following its publication, researchers sought to test the model, with a specific focus on the performance effects of PETTLEP-based MI, compared to more traditional imagery methods. This body of research has reported consistent benefits for PETTLEP-informed imagery interventions. For example, Smith et al. (2007) reported significant improvements in field hockey penalty flick accuracy and gymnastic balance beam jump scores in experimental groups that adhered to a six-week duration PETTLEP MI intervention, compared to those that followed more traditional MI interventions. These effects were reported in varsity and junior athletes, respectively. It is noteworthy that in both populations, the performance improvements obtained via engagement in PETTLEP MI were comparable to those obtained through physical practice. In a subsequent study, however, using a golfer bunker shot accuracy task in high level golfers, Smith et al. (2008) identified that the beneficial effects of PETTLEP-based MI were more pronounced when combined with physical practice rather than when performed in the absence of physical practice. This supports the notion that MI interventions are most effective when they serve as an additional training aid, rather than a replacement for physical practice. Similar beneficial effects of PETTLEP MI have been reported across a range of tasks including netball shooting (Wakefield & Smith, 2009), volleyball passing (Afrouzeh et al., 2013), tennis serving (Cherappurath et al., 2020), standing long jump (Post et al., 2015), motor-cognitive tasks (Wright & Smith, 2007), and strength tasks (Wright & Smith, 2009). Further beneficial effects of PETTLEP interventions have also been reported outside of sport, such as in the learning of psychomotor skills in nursing training (Wright et al., 2008). Taken together, the available research provides strong support for the efficacy of PETTLEP-informed MI interventions for enhancing motor skill performance.

A potential mechanism by which PETTLEP-informed MI contributed to enhanced performance was originally proposed to be through the manner in which it promoted similar activity in some areas of the brain involved in motor planning and execution (Holmes & Collins, 2001). It is well-established that MI activates some similar regions of the brain to movement execution (Grezes & Decety, 2001); a concept then termed *functional equivalence* (Finke, 1979; Holmes & Collins, 2001; Jeannerod, 1994). It was assumed that the more optimal activation of some of these shared brain regions achieved through PETTLEP MI may contribute to enhanced physical performance by strengthening connections between neurons involved in movement execution (i.e., Hebbian learning). A key premise of Holmes and Collins' (2001) model was, therefore, that incorporation of PETTLEP principles within MI interventions would do more to promote functional equivalence (i.e., the activation of certain brain regions pertaining to sensorimotor control in a manner similar to that which occurs during movement execution) than more traditional, generic relaxation-based approaches to MI. Since its publication, however, there has been some confusion within the literature and applied practice regarding what was indicated by the term functional equivalence (see Wakefield et al., 2013). PETTLEP-based MI and movement execution processes can never be truly functionally equivalent; at a neural level for example, MI requires multi-modal image generation, maintenance and transformation processes, which are not required during movement execution. It has, therefore, been proposed that a more accurate explanation for the beneficial effects of PETTLEP-based MI may be that it provides a closer behavioural match between the MI experience and physical performance than occurs through more traditional, generic, relaxation-based approaches to MI (Wakefield et al., 2013). MI efficacy is, therefore, a combination of contributing factors. Nevertheless, despite the potential misinterpretation of the presumed mechanisms driving performance during PETTLEP interventions, research continues to show beneficial outcomes when testing the model as whole or the subcomponents independently.

In the 20 years since its publication, the PETTLEP model has become one of the most dominant models for structuring MI interventions in sport. At the time of writing, the original paper (Holmes & Collins, 2001) had been cited 916 times according to Google Scholar (accessed 25th July 2022), as well as featuring in most academic sport psychology textbooks (Smith et al., 2021a). The model has become a core part of undergraduate and postgraduate training in disciplines of sport science and sport psychology. For example, Smith et al. (2021a) reported that all UK institutions delivering sport psychology degree programmes, and approximately 90% of those delivering sport science, teach the PETTLEP model within their curriculum; a considerable number of international institutions do likewise. Upon qualification, therefore, many sport psychology practitioners go on to use PETTLEP to inform MI interventions that they develop in their applied work with athletes. Indeed, Smith et al. (2021b) reported evidence of PETTLEP being used by sport psychologists to support athletes in at least 43 different sports, across 13 countries, with athletes ranging from novices through to those competing at Olympic Games or World Championships. Despite the success and continued use of the model, given advances in technology, neuroscience, and applied practice in the 20 years since its publication, it is now timely to consider the place for PETTLEP in current sport psychology practice. Within the last decade, there has been a growth in neuroscientific and performance-based research advocating the combined and, in some cases, simultaneous integration of MI with video-based action observation (AO; see Vogt et al., 2013; Eaves et al., 2016a). Therefore, we consider the role of PETTLEP imagery approaches within the context of this research to propose a new direction for the optimisation of movement simulation interventions in sport within a combined action observation and imagery framework.

A combined action observation and imagery approach to PETTLEP

Despite the encouraging reach and implementation of the original PETTLEP framework across the previous 20-years, several issues remain for its continued effective delivery. For example, and in contrast to the model's recommendations for the Task element, MI interventions informed by PETTLEP are still commonly delivered by imagery scripts (see Williams et al., 2013). Such scripts usually contain rich verbal detail regarding the stimuli, actions and sensations that the performer should imagine. They are also often presented using second-person pronouns. Although effective, it could be argued that the step-by-step nature of written imagery scripts used may reinforce a depersonalised cognitive control of movement more characteristic of novice, rather than expert, performance. Similarly, detailed and rich visually descriptive verbal instructions, possibly helpful for visual vividness, may direct neural activity via the ventral stream rather than the preferred, faster and less conscious, dorsal stream (Wakefield et al., 2013). The dorsal visual stream is proposed to allow the processing of sensory information and the selection of responses at the unconscious level (Goodale & Milner, 1992), which may explain automatic or unconscious movement processing which is characteristic of expert performance (Meng et al., 2019). Furthermore, the direction of information via the slower ventral stream, as discussed by Wakefield et al. (2013), provides theoretical complications when using the PETTLEP model to explain timing benefits for performance through the use slow motion imagery (Jenny & Munroe-Chandler, 2008; Jenny et al., 2020). It also challenges many of the factors associated with the Task element, which aims to promote processes that are more automatic.

There are, however, alternative motor simulation techniques that may mitigate the involvement of ventral stream prioritisation. Video footage or dynamic movement photographs of the individual performing in personally meaningful settings were originally recommended by Holmes and Collins (2001) to help the athlete recall vivid stimulus and response propositions, without the need for verbal directives, for use as their imagery script. This approach has been shown to be effective for improving performance in both precision skills such as golf putting (Smith & Holmes, 2004) and strength tasks (Wakefield & Smith, 2011). Since the publication of the PETTLEP model, the prevalence of action observation as an intervention in its own right has increased across populations and settings (see Law et al., 2018; Ste-Marie et al., 2012, 2020). In Holmes and Calmels' (2008) comprehensive review of AO and MI they suggested numerous advantages for using AO over MI. For example, during AO the agent of the action can be controlled. Holmes and Calmels (2008) suggested athletes have the propensity to imagine other athletes performing the task rather than themselves, in contrast to Jeannerod's (1994) argument that self-agency is important for the efficacy of MI. While this is potentially an inherent component of expert cognitive function and processes, there is not a complete overlap of the neural substrates supporting self and other representations (Anquetil & Jeannerod, 2007). As a result, behavioural matching may be decreased at an experienced or phenomenological level. For experts AO could, therefore, control this aspect, ensuring self-agency and encouraging embodiment of the movement. In addition, angle and perspective can be controlled and optimised based on task relevant cues and the form-based nature of the task being performed, satisfying the guidelines to adapt perspective and angle in accordance with the task (Hardy & Callow, 1999; Holmes & Collins, 2001). Finally, the timing of the simulated action can be controlled through video and audio content, reinforcing temporal congruency between covert and overt simulations and the inclusion/exclusion of other sensory modalities.

The behavioural adaptations associated with AO are presumably, in part, dependent on the fronto-parietal network (Molenberghs et al., 2012) – the inferior frontal gyrus (IFG), ventral premotor cortex, and inferior parietal lobule (IPL; i.e., the putative human mirror neuron system). This network, while acknowledged to contribute to functions such as imitation, sequence learning, and action goal and intention, relies on a range of associated brain regions to support these functions, often referred to as the action observation network (Cross et al., 2009). AO shares some similarity in neural networks associated with MI and motor preparation and execution (see Fig. 1; Hardwick et al., 2018). For example, a meta-analysis by Hardwick et al. (2018) examined shared networks for these simulations and indicated overlapping brain regions comprising bilateral postcentral gyrus, IFG, left IPL, left superior temporal gyrus, left precentral gyrus, left posterior-medial frontal and right superior frontal gyrus.

Based on the recommendations of Holmes and Collins (2001) and Wakefield et al. (2013), researchers have begun to integrate AO and MI, informed by the PETTLEP model and thereby replacing much of the content of the imagery script *prior* to any PETTLEP MI. For example, Lu et al. (2020) demonstrated a potential benefit for AO as a replacement for MI scripts in a PETTLEP intervention aiming to improve basketball 3-point shot success. Intermediate level college basketball players were provided with either first-person or third-person videos (viewed from the sagittal plane) of themselves performing 3-point shots. These videos provided content for their subsequent MI, which was to be imagined in the same visual perspective as the videos. Results showed significant improvements compared to a control group for both first- and third-person video groups. No differences were reported between the first- and third-person perspective groups suggesting task relevant visual cues were present in both perspectives. Real-time AO (as a proposed substitute for the visual component of the MI scripts) before MI may reinforce a strong timing-environment interaction for the MI and support greater dorsal stream networks. It also remains to be determined whether this protocol is more effective than the script-based MI protocols typically used in PETTLEP interventions.

In the last decade, there has also been an increased focus on an attempt to combine *simultaneous* use of AO and MI (Vogt et al., 2013; Eaves et al., 2016a). To date, definitions of this combined process have been somewhat vague with reference to what is assumed to occur. The combined use of AO and MI was initially termed 'AO+MI' by Vogt et al. (2013) and was subsequently adopted within literature. This, however, has led to misinterpretations as to when and how the AO and MI are delivered. For example, the intended use of this instruction as described by Vogt et al. (2013) was to use AO and MI *concurrently* (i.e., imagine *whilst* observing an action). In contrast, some research has used the term AO+MI to refer to the viewing of AO that is *followed by* MI (e.g., McNeill et al., 2020). To resolve this confound and reduce the likelihood of misinterpretation, we support the adoption of the 'AOMI' acronym to refer to the parallel and concurrent use of AO and MI simulations, and recommend the abbreviation 'AO+MI' be reserved to describe interventions involving the serial use of each technique (see Table 1 for a summary of AO and MI instructions).

While Vogt et al. (2013) described the use of MI *during* AO as 'AO+MI', papers utilising this technique typically describe instructing imagery of only the kinaesthetic aspect of movement during AO, and not visual properties (see Scott et al., 2021; Wright et al., 2021) since they are ascribed to the AO; the AO replacing the visual component of the motor imagery. In this case, the individual is required to only generate, maintain and transform a kinaesthetic imagery (KI) modality alongside the presented video or picture. Theoretically, MI requires the generation of both kinaesthetic and visual perceptual representations of movement, with auditory and other cues further enriching the experience as appropriate (Holmes & Collins, 2001; Jeannerod, 1994). The adopted acronyms 'AO+MI' and 'AOMI', therefore, may not accurately describe what Vogt et al. termed a congruent use of AO and MI, or at least how the instruction has been administered in research and applied practice. These acronyms may be more appropriate to describe alternative uses of concurrent AO and MI where visual imagery (VI) may be required to support KI generation. For example, despite the provision of instructions that emphasise generating KI, in scenarios where discrepancies exist between the stimuli presented on video and the characteristics of the observer (e.g., the appearance and skill level of the model or visual perspective presented), involvement of VI may be required to facilitate generation of a kinaesthetic movement representation. Alternatively, interventions involving what Vogt et al. termed 'coordinative AO+MI' or 'conflicting AO+MI', may require the aid of visual imagery (VI) to support KI of a different action to what is observed (see Mizuguchi et al., 2016 for similar effects). For example, a boxer observing a first-person perspective video of punches thrown in their direction may require use of VI to support their KI of performing the appropriate ducking or counterpunching action in response to the observed movement. For this review, however, the primary focus will be congruent uses of AO and KI and their optimisation. While seemingly becoming more about semantics, the generation of MI during AO, in contrast to purely generating KI during AO, will inevitably activate different brain regions. Presumably this will involve more cognitive involvement to generate the VI and superimpose this image over the observed display that may not be fully congruent, compromising the intervention goals. For example, ad-

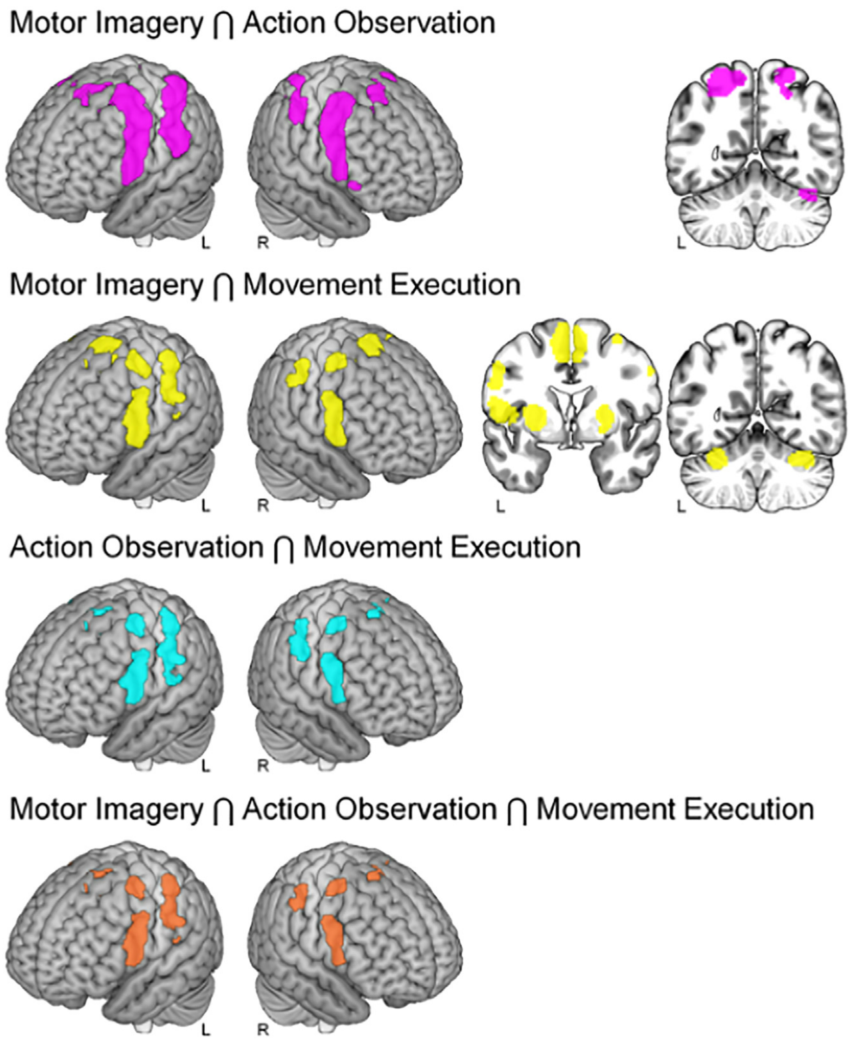

Fig. 1. Conjunction analyses by Hardwick et al. (2018) summarising the overlap between the networks recruited during AO, MI and movement execution.

ditional activation of the visual cortex may occur when using MI during AO (Mizuguchi et al., 2016). Accordingly, it seems more accurate to define the combined and congruent instruction as: *watching a video or live demonstration of a movement while simultaneously generating, maintaining and transforming a time-synchronised kinaesthetic representation of performing the same movement*. In alignment with this definition and recent papers (e.g., Eaves et al., 2016a; Scott et al., 2021; Wright et al., 2021), a more appropriate acronym for this instruction would be 'AOKI' (see Table 1). For this reason, and for the purpose of this review, we will refer to previous literature investigating what has been known as 'AO+MI' or 'AOMI' as AOKI, based on the instructions provided and tasks utilised.

Research investigating what we describe here as AOKI, has demonstrated improvements across behavioural outcomes; for example, aiming (Romano-Smith et al., 2018), cup stacking performance (Sakaguchi & Yamasaki, 2021), strength performance (Smith et al., 2020), improved motor learning of a novel task (Aoyama et al., 2020; Kawasaki et al., 2018) and balance training (Taube et al., 2014). Further support for AOKI has been found across clinical populations, such as in children with developmental coordination disorder (Marshall et al., 2020b). Neurophysiological evidence suggests AOKI is associated with greater activity across motor related regions of the brain (Scott et al., 2021). For example, when stimulating the primary motor cortex (PMC) directly using transcranial magnetic stimulation during AOKI, greater motor evoked potential amplitudes have been reported compared to independent AO and MI (Bruton et al., 2020; Wright et al., 2014). Functional magnetic resonance imaging research suggests greater activations of the bilateral PMC, cerebellum and precuneus compared to MI (Taube et al., 2015). Contrasts to AO reveal greater activations for AOKI across the bilateral PMC, left superior and right inferior frontal gyrus, the IPL, the supplementary motor area (SMA), basal ganglia, and cerebellum (Nedelko et al., 2012; Taube et al., 2015). Across AOKI literature this increased activity has been viewed as a desirable outcome, presumably due to greater motor activity during motor simulation being indicative of expert level capability in the observed or imagined movement (Mizuguchi & Kanosue, 2017). This assumption presents challenges, however, since expert performance is typically associated with reduced motor activity during movement planning and execution (i.e., a neural efficiency effect; Mizuguchi & Kanosue, 2017) and altered motor frequency ratios across alpha and beta ranges (Hatfield, 2018); this greater activity, therefore, should be interpreted with caution. Nevertheless, it is conceivable that the associated greater motor activity during AOKI may facilitate the previously discussed performance improvements via Hebbian plasticity mechanisms (Frank et al., 2020), and there is also evidence of more efficient movement execution following AOKI training in the form of reduced EMG activity in the agonist muscle (Romano-Smith et al., 2019). Due to the consistent positive effects on performance, however, AOKI now appears to have been received as the new panacea for sport psychology, replacing the need for structured MI interventions, but with little consideration of how to control and optimise the technique. In effect, we face similar challenges to those of researchers prior to PETTLEP motor imagery in 2001.

Table 1
Summary of different delivery methods of congruent AO and MI and the neurophysiological and behavioural correlates.

Instruction acronym	Timing of deliveries	Imagery modalities involved in MI	Influencing factors	Neurophysiological activity	Behavioural adaptations
AO+MI	Serial – Action observation *followed by* MI. Could be repeated cycles of AO and MI.	Visual and kinaesthetic imagery. Other modalities (e.g., auditory, olfactory) not excluded based on individual choice and imagery abilities.	1. Instructions provided – *same* self- (or other) actions observed *then* imagined. 2. Task – individuals may train actions within or not yet in their motor repertoire (e.g., McNeill et al., 2020; Romano-Smith et al., 2018; 2019). 3. Model – self or other. AO of self-actions will facilitate MI (shared repertoires), more so than AO+MI of others' actions (different repertoires). Observation of others should be shown in the first-person to give illusion of self. Third-person should be shown using a similar featured model and by manipulating angle to give illusion of self (more congruent).	Both AO and MI independently facilitate corticospinal activity (Clark et al., 2004). The summative amplitude of independent AO and MI does not equate to that AOMI (Sakamoto et al., 2009). When used separately, AO activates bilateral premotor and parietal regions and occipital regions; MI activates bilateral premotor, rostral inferior and middle superior parietal, basal ganglia, and cerebellar regions and the left dorsolateral prefrontal cortex (Hardwick et al. 2018). The summative volume of blood oxygenated level dependent activity of independent AO and MI does not equate to that of AOKI (Taube et al., 2015).	Improved golf putting performance (McNeill et al., 2020); improved 3-point basketball throw accuracy (Lu et al., 2020); improved dart throwing accuracy (Romano-Smith et al., 2018) and form (Romano-Smith et al., 2019); improved function of the hemiplegic limb following stroke (Sun et al., 2016).
AOMI	Concurrent – MI *during* action observation.	Primarily kinaesthetic imagery but with some limited VI. Occurrence of VI may not be intentional as not instructed.	1. Instructions provided – *similar or different* actions observed and imagined *simultaneously* and *in synchrony*, including forms of coordinative or conflicting AO+MI as described by Vogt et al. (2013). 2. Task – actions within or beyond the individual's motor repertoire. Topographical differences may occur between the imagined and observed action, requiring VI to support KI (Mizuguchi et al., 2016). AOMI may be refined to AOKI after repeated simulation-based training and physical training of tasks. 3. Model – AOMI more likely to be used when observing someone else of differing characteristics, biomechanical profile or of greater proficiency in the task (Mizuguchi et al., 2016). Perspective and angle may not be optimised for task and KI generation, so VI may be required.	Greater activation of the SMA and primary visual cortex during AOMI compared to AO alone (Mizuguchi et al., 2016). Greater activation of the primary visual cortex during AOMI than during AOKI (Mizuguchi et al., 2016). Significantly greater event related desynchronisation of mu/alpha and beta frequency bands than AO across sensorimotor and parietal regions and greater event related desynchronisation of beta frequency bands across parietal regions (Eaves et al., 2016b). Additional activity may be found in the rostral prefrontal cortex (Broadmann area 10; Eaves et al., 2016b; Emerson et al., 2022).	Greater eccentric strength (Scott et al., 2018); enhanced unintentional imitation (Eaves et al., 2014; 2016b; Scott et al., 2019); improved intentional imitation (Bek et al., 2016; Scott et al., 2020); greater function of the hemiplegic limb following stroke than for AO+MI (Sun et al., 2016); improved learning of a novel skill (via observation of a skilled model; Kawasaki et al., 2018); improved motor function in Parkinson's disease patients (Bek et al., 2021).
AOKI	Concurrent – KI *during* action observation.	Kinaesthetic imagery.	1. Instructions provided – *same* actions observed and imagined *simultaneously* and *in synchrony*, akin to congruent AO+MI as described by Vogt et al. (2013). 2. Task – Good knowledge and experience of the task. Actions within or very close to the individuals' motor repertoire (Mizuguchi et al., 2016; Kawasaki et al., 2018). Simple or well-known actions most likely to facilitate AOKI rather than AOMI. 3. Model – Self-observation (Fujiwara et al., 2021; McNeill et al., 2021), or someone relatable (e.g., age and sex) and of similar capability in the task (Mizuguchi et al., 2016; Kawasaki et al., 2016). Observation of others should be shown in the first-person to give illusion of self, allowing KI to be generated (Fujiwara et al., 2021). Third-person AO using a similar featured model and by manipulating angle to give illusion of self to encourage embodiment and KI (e.g., Taube et al., 2015).	Increased corticospinal activity compared to AO and MI independently (Bruton et al., 2020; Wright et al., 2014). Greater oxy-haemoglobin concentrations for self-AOKI across the PMC, pre-motor area and SMA than for other-AOKI and MI alone (Fujiwara et al., 2021). Further investigations are required to determine the similarities and discrepancies between motor, prefrontal (BA10) and visual activations between AOMI and AOKI.	Improved dart throwing accuracy and form (Romano-Smith et al., 2018; 2019) than AO+MI; improved learning of a novel skill (Marshall et al., 2020a; 2020b); enhanced learning of a novel skill (via observation of a similarly unskilled model; Kawasaki et al., 2018); greater learning of a novel skill (observation of a moderately skilled model; Aoyama et al., 2020); faster performance of a cup stacking task (Sakaguchi & Yamasaki, 2021).

While AOKI appears to result in desirable outcomes, it has been acknowledged that potentially stronger effects could be found if PETTLEP principles were integrated into concurrent observation and imagery-based interventions (Carson & Collins, 2017; Frank et al., 2020; Wright et al., 2021). There are several potential advantages when delivering PETTLEP interventions via AOKI format, rather as MI alone. For example, use of modern video recording equipment to create the AO component of the intervention can provide more vivid stimuli (environment) than could be imagined, maintained, and transformed than when instructing MI alone. In addition, less verbal and de-personalised

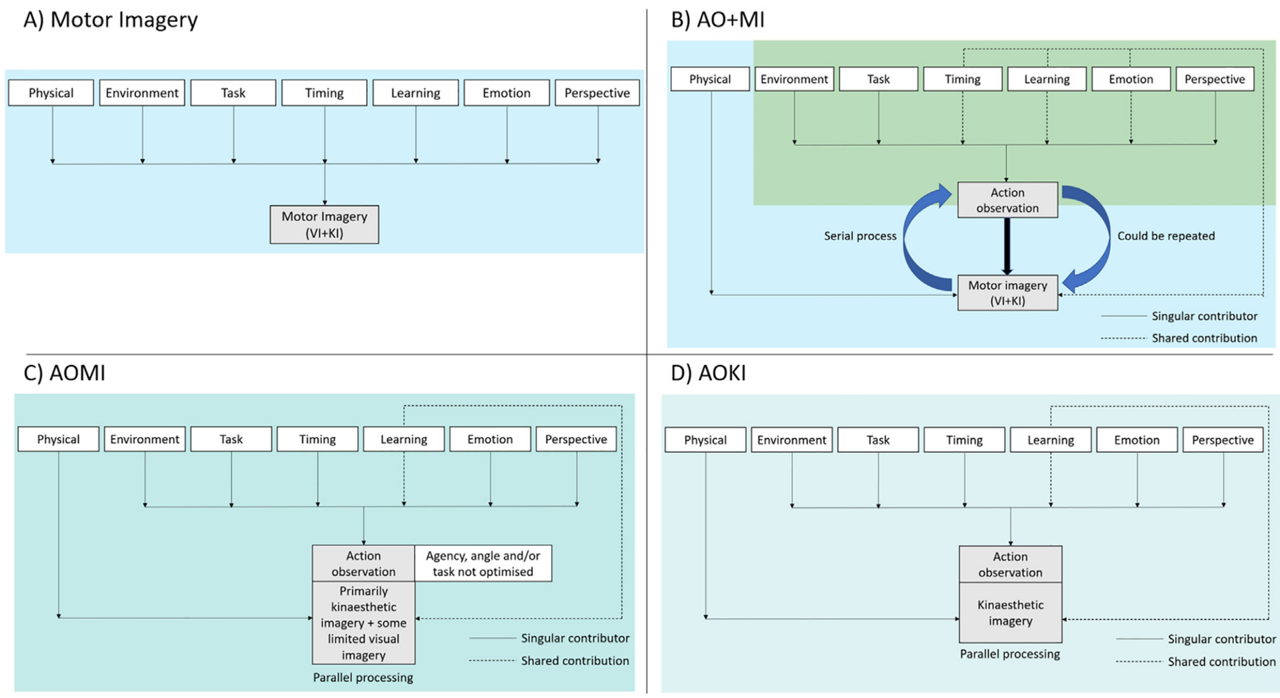

Fig. 2. Model progression for PETTLEP and integration of imagery and observation. Panel A (colour coded blue) represents the original script-based PETTLEP model (Holmes & Collins, 2001) showing each principle contributing to MI generation, transformation and maintenance. Panel B shows the model representing AO+MI (serial use of AO and MI; e.g., Lu et al., 2020; see Table 1). In comparison to Panel A, many of the PETTLEP principles are integrated into AO (green) in order enrich subsequent MI (blue). Solid and dashed lines represent shared contributions of principles to AO and MI representations or indicate a principle as lone contributor to AO or MI, respectively. The use of AO provides greater control of MI content than scripts may provide (i.e., panel A); however, control can be reduced in this model once the athlete imagines the previously observed scenario, where principles may be altered (e.g., timing, perspective). Panel C and D represent the parallel uses of AO and imagery, AOMI and AOKI, respectively. Similar to Panel B, elements of PETTLEP are controlled by the AO content, however, these delivery models offer greater control than AO+MI. As imagery is generated concurrently with AO, timing and perspective are controlled providing greater behavioural matching. Although, one consideration for concurrent uses is that video content (e.g., model, video angle and task) may result in the generation of VI to support KI (Panel C; Mizuguchi et al., 2016) as opposed to KI alone (Panel D). Colour coding for Panel C can be interpreted as the combination of AO and MI (AOMI), whereas the subtle colour change in Panel D represents AOKI, KI absent of VI. Self-agency will facilitate AOKI through memorial experiences and embodiment of the action. Conversely, other-agency may result in biomechanical differences between imagined actions and the observed actions resulting in VI generation to support KI during AO (AOMI).

scripts are required, likely promoting more dorsal stream function, as the need to describe the scenario is removed as relevant stimuli are presented in high fidelity. While studies comparing PETTLEP AOKI and PETTLEP MI are sparse, some researchers have compared similar interventions. Romano-Smith et al. (2018) compared the effects of PETTLEP integrated into AOKI, against a PETTLEP AO+MI intervention and a PETTLEP-based MI intervention on the accuracy of a dart throwing task. In this study, PETTLEP-informed AOKI was found to significantly improve performance accuracy compared to PETTLEP MI alone. Smith et al. (2020) later compared the effects of PETTLEP-informed AOKI and MI interventions on the performance of a one repetition maximum bicep curl. This was a single case account in which 4 participants completed training over an 11-week period involving a 3-week baseline followed by the two 4-week imagery interventions in a counterbalanced manner. Due to the small sample size the results should be treated with caution but showed similar benefits for both interventions across participants. Despite some research integrating PETTLEP into AOKI, no guidelines currently exist on how PETTLEP principles apply to AOKI. The following section, therefore, provides recommendations on how this can be achieved, informed by current AOKI literature using PETTLEP principles.

Holmes and Calmels (2008) suggested advantages for the use of AO in sport over the use of MI. This review proposes that the combined and simultaneous use of these instructions (AOKI) may be superior to their individual counterparts. To explain this position further, Fig. 2 provides an account of how the AO and KI aspects of AOKI may be facilitated by a PETTLEP approach to produce a greater behavioural match between the simulated experience and movement execution. As previously discussed, AO had several advantages over MI; for example, the control of agency, perspective, percepts and subject-task angles (Holmes & Calmels, 2008). AOKI inherits these advantages through the AO component; however, AOKI also provides more extensive brain activations across regions associated with motor preparation and execution (Eaves et al., 2016a; Scott et al., 2021). Moreover, attention is partially controlled and eye gaze is drawn to the agent of the movement in the video when the observer is instructed to generate and maintain the feelings and sensations of the movements, an important factor for motor learning (Bruton et al., 2020). While AO previously provided more control than MI during simulation-based training, AOKI may supersede AO for this purpose.

Evidencing and establishing the AOKI model of PETTLEP

Physical

Recent AOKI research has incorporated the physical principle into task protocols. For example, Marshall and Wright (2016) instructed participants to hold a golf putter in a putting stance and on a putting surface while using AOKI of a model performing the putting task. The results, however, indicated no significant improvements for AOKI in this study. In the study by Smith et al. (2020), participants were required to hold cylinder-shaped items while simultaneously observing and imagining the performance of a bilateral bicep curl. Although the weight of these cylindrical items did not match that of the equipment in the video (providing a potential sensory discrepancy), the haptic feedback and kinetic afference gained may have enhanced the imagined kinaesthesis facilitating performance as per the Physical element of PETTLEP (see Fig. 2).

Environment

Several studies have incorporated the environment component into AOKI protocols by recording the AO component in the same environment as movement execution occurs (e.g., Marshall & Wright, 2016; Romano-Smith et al., 2018; 2019; Smith et al., 2020). For example, Romano-Smith et al. (2018; 2019) showed favourable outcomes when AOKI training content was filmed in the same setting where participants performed a dart throwing task. This manipulation incorporated the same dartboard and throwing lane which provided a strong experiential match between simulation and physical performance. In contrast to the original PETTLEP model, during AOKI the environment component is dependent on the visual display. As previously discussed, this provides a much richer visual account of the contextually relevant environment to where the performance will take place, than could be achieved through imagery. This is particularly important when considering the stimulus and response propositions that could be included, and if meaningful to the athlete, may reinforce and interact with the emotion principle. However, no studies have yet investigated the manipulation of contextually-relevant environments during AOKI. In AO literature the manipulation of environment and context have been shown to increase activations across motor related regions of the brain (Iacoboni et al., 2005; Riach et al., 2018). Riach et al. (2018) found that observation of actions performed in contextually meaningful environments facilitated corticospinal excitability more than those observed in non-meaningful environments, despite there being more visual fixations on the background during the meaningful condition than the non-meaningful conditions. This demonstrates the importance of integrating meaningful environments into AOKI. For example, the environment (i.e., stimulus propositions) may provide information vital for generating a kinaesthetic representation based on memorial experiences (Vogt, 1995). These contextually meaningful environments have further been proposed to facilitate social processes such as understanding the intentions of others through a cortical hierarchy involving the putative human mirror neuron system (i.e., predictive coding; Kilner et al., 2007).

Task

Originally, the task aspect of PETTLEP was to be considered in relation to the level of expertise of the individual, and therefore the extent of cognitive-autonomous control, whilst also optimising the perspective and timing for the imagined performance (Holmes & Collins, 2001). Although AO controls the task to be imagined and is developed to match the observer's skill level (Fig. 2), it is important to ensure the task imagined and observed are congruent through instructions. As only kinaesthetic imagery is instructed for AOKI, the model in the video must be manipulated to show task content and match the skill and biomechanical proficiency of the individual to facilitate learning. Kawasaki et al. (2018) and Aoyama et al. (2020) recently considered this manipulation, whilst participants learnt a novel manual dexterity task. Findings indicated that participants learnt best when observing an unskilled model (similar proficiency; Kawasaki et al., 2018) or moderately skilled model (Aoyama et al., 2020) than when observing a highly skilled model. This highlights the importance of identifying the athlete's proficiency, possible biomechanical constraints, and psychological factors (e.g., perceived competence) associated with the observed task, as together they may impede or facilitate KI generation depending on the task and proficiency of the observed model (see Panel C and D of Fig. 2). Furthermore, it is imperative that the athlete understands the task to be simulated and knows the goal and intention of the simulation (e.g., to imitate the observed action at a later time). Holmes and Calmels (2008) previously outlined the significance of understanding these aspects of the intervention as observing meaningful or meaningless actions may activate ventral and dorsal stream pathways, respectively. However, additional instructions such as to imitate an actions may direct activity via the dorsal pathway for both meaningful and meaningless actions (Grèzes, 1998). Moreover, this understanding can be further facilitated by reinforcing a strong environment component, ensuring familiar stimuli and response propositions.

Timing

In the AOKI model of PETTLEP (Fig. 2, Panel D) the AO component provides a consistent temporal guide informing the athlete's KI, reinforced by a clear audio component. Together, visual and auditory cues inform important Kosslynian KI characteristics (e.g., generation, maintenance and transformation; Kosslyn et al., 2010) associated with movement execution timing. Previously, it was suggested that time was represented as a function of force during MI (Decety et al., 1989; Munzert et al., 2015), and that interactions with the physical principle may mitigate the perceived increased movement times associated with imagined forceful actions (Holmes & Collins, 2001). In contrast, the visual display during AOKI controls the timing aspect, allowing KI of forceful movements to be temporally congruent and biomechanically accurate with movement execution. Accordingly, when compared to MI alone, AOKI provides consistency and a greater behavioural matching to the timing of actual performance. Scott et al. (2020) demonstrated such effects when instructing AOKI compared to an AO+MI condition; although demonstrated in a child population, this instruction significantly improved timing when asked to imitate rhythmical actions. It cannot be confirmed, however, whether participants would have been required to use AOMI instead of AOKI due to disparities between participants and the model involved (see panels C and D of Fig. 2). Future research would benefit from investigating actions which are more sport-related and meaningful to the individuals to further investigate the effect of timing.

Learning

As learning progresses, the generation and maintenance of the KI will become easier for athletes, constructing imagined movements from experience and newly established memories of performing. As these representations become more refined, the model proficiency and task complexity in the video should be adapted to further facilitate learning (see Fig. 2). Research by Marshall et al. (2020b) incorporated and progressively developed AOKI in line with participants' learning. In this case, children with developmental coordination disorder learnt to perform a novel computerised task with a 90° visuomotor rotation. AOKI visual stimuli (i.e., model performance) and instruction complexity were progressively refined to reflect participants' learning (also see Sakaguchi & Yamasaki, 2021 for similar learning principle development in AOKI). While the meaningfulness of this task may not have resonated as strongly with the participants as would a task imagined by an athlete in their own discipline, regular response training sessions can be used to ensure that the imagery instructions remain personally meaningful as learning progresses. One consideration is that skill complexity should be changed gradually, so not to completely exceed the athlete's ability and knowledge of the task but providing sufficient opportunity for learning (Aoyama et al., 2020). Research by Mizuguchi et al. (2016) suggests that AOKI can be used for actions within or close to an individual's motor repertoire; however, when the action completely exceeds their ability, VI is required to support KI during AO (Fig. 2, Panel C). Indeed, this recruitment of VI may be unintentional (Mizuguchi et al., 2016); nevertheless, its generation may result in greater cognitive involvement and processing during the intervention, which could reduce behavioural matching.

Emotion

Despite being an under researched area of the original PETTLEP model, some benefits have been reported when incorporating emotional content into MI interventions (Ramsey et al., 2010). To date, no research has yet investigated the autonomic responses associated with emotion or self-reported interpretations of these feelings as a result of AOKI. Heavily influenced by Langian theory (Lang, 1979, 1985), emotion in the original PETTLEP model was instructed through tailored scripts and promoted through the use of personalised response and meaning propositions, referring to autonomic responses associated with performances (e.g., changes in heart and respiration rates or galvanic skin responses). When using AOKI, however, KI is the principal focus. Appropriately, instructions are limited, focusing on the kinaesthetic aspects of the movement. Previous AO research has demonstrated increased autonomic responses when observing others exercise, which can be indicative of emotional responses and arousal (e.g., increased respiration rate; Paccalin & Jeannerod, 2000). During AOKI, it is therefore crucial to use videos with environments (stimulus propositions) that are relevant to the individual containing relatable response and meaning propositions (Lang, 1979). In addition, by incorporating relatable models (or the athlete her/himself – agency provided; Fig. 2, Panel D) in the video, embodiment of the movement can be encouraged, and if shown in a meaningful environment may allow emotions associated with the actual performance to be experienced. An understated benefit of AOKI is the presence of a clear audio component (instead of imagining auditory cues), which can contribute to multisensory experience during the intervention. The presence of this recorded audio (e.g., the sound of a crowd or teammates) may further reinforce the emotion component of the performance while reducing the cognitive involvement typically required in traditional PETTLEP formats, which may help to further enrich the emotion principle and kinaesthetic experience of the simulated movement.

Perspective

Research has continually taken into consideration perspective during AOKI in order to optimise task specific visual stimuli and information (Hardy & Callow, 1999; Holmes & Collins, 2001); for example, third-person perspective for gross motor tasks during AOKI (Taube et al., 2014; McNeill et al., 2021) and first-person perspective for fine motor tasks (Marshall et al., 2020a; 2020b; Kawasaki et al., 2018; Romano-Smith et al., 2018; 2019; Aoyama et al., 2020; Fujiwara et al., 2021). Results by Kawasaki et al. (2018) and Marshall et al. (2020a; 2020b) demonstrate the effectiveness of a first-person perspective for learning novel manual dexterity tasks, and first-person perspective AOKI can enhance aiming performance (Romano-Smith et al., 2018). Future research should now investigate perspective manipulations across varying tasks to establish possible task-perspective-learning interactions and establish optimal delivery techniques for AOKI.

An aspect of AOKI which has gained little attention to date is the issue of agency. The reviewed AOKI research has focused on the observation of others while generating KI. When referring back to Lang (1985), in order to increase the emotional response, it is important for the individual to access memorial experiences when processing response propositions, and the meaning proposition should be processed to fully access the memory of the performance. Theoretically, self-AOKI would provide the strongest behavioural match, facilitated through accessing memorial structures of the performance when generating a kinaesthetic representation (Vogt, 1995). Furthermore, AOKI may improve psychological aspects of performance such as self-efficacy through both mastery and vicarious experience (Wright et al., 2021). In a recent paper, Fujiwara et al. (2021) demonstrated a benefit of self-AOKI for skill learning. Participants performed a task requiring blocks to be moved using chopsticks with their dominant hand while being recorded from the first-person perspective. These videos were then inverted horizontally and displayed as AOKI content for learning the task with the contralateral (non-dominant) limb. Results showed greater learning of the task and greater vividness of 'MI' for self-AOKI than other-AOKI and MI. While MI was assessed using a visual analogue scale, and measures of MI often conflate kinaesthetic and visual modalities, these findings are still encouraging. In addition, recordings using near-infrared spectroscopy showed significantly greater oxy-haemoglobin concentrations across motor regions for self-AOKI than for other-AOKI and MI (see Table 1). Additional benefits for self-AOMI have been found on a putting task demonstrating improved club-path kinematics in skilled golfers showing improved error detection (McNeill et al., 2021). Taken together, findings by Fujiwara et al. (2021) and McNeill et al. (2021) indicate limited learning potential for self-AOKI but with benefits for skill refinement, without manipulating video content of oneself (also see feedforward self-modelling by Ste-Marie et al, 2011). In the context of Fig. 2, self-AOKI would theoretically provide a greater congruency between AO and KI content due to controlled agency, and shared experiences and motor repertoires. This would provide much stronger interactions between PETTLEP principles and greater behavioural matching than could be achieved through MI or AO independently.

Conclusion

The current review outlines the impact and reach of the PETTLEP model since its publication. In addition, potential limitations have been outlined, and accordingly, an alternative delivery of imagery interventions has been proposed – combined action observation and kinaesthetic imagery (AOKI). Originally the PETTLEP model was introduced to provide sport psychologists more control of MI interventions; however, AOKI now provides an alternative delivery method which permits even greater control over the delivery of imagery content. AOKI research to date has integrated some PETTLEP principles, but as highlighted, there is much to be done for its optimisation by assessing the effects of the PETTLEP principles individually and together on AOKI. Research involving manipulation of the individual principles during AOKI to determine the best means of delivery, and establishing the interactions between these principles as previously done for AO and MI, would be a valuable addition to the imagery and observation literature.

Declaration of Competing Interests

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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