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Functional Equivalence or Behavioural Matching? A Critical Reflection on 15 years of Research Using the PETTLEP Model of Motor Imagery

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Abstract

Motor imagery, or the mental rehearsal of actions in the absence of physical movement, is an increasingly popular construct in fields such as neuroscience, cognitive psychology and sport psychology. Unfortunately, few models of motor imagery have been postulated to date. Nevertheless, based on the hypothesis of functional equivalence between imagery, perception and motor execution, Holmes and Collins (2001) developed the PETTLEP model of motor imagery in an effort to provide evidence-based guidelines for imagery practice in sport psychology. Given recent advances in theoretical understanding of functional equivalence, however, it is important to provide a contemporary critical reflection on motor imagery research conducted using this model. The present paper addresses this objective. We begin by explaining the background to the development of the PETTLEP model. After that, we evaluate key issues and findings in PETTLEP-inspired research. Finally, we offer suggestions for, and new directions in, research in this field.

Key words: imagery, PETTLEP, movement, functional equivalence, behavioural matching.

Introduction

One of our most remarkable cognitive capacities is our ability to simulate sensations, movements and other types of experience (see review of research on mental simulation by Markman, Klein & Suhr, 2009). For over a century, researchers have investigated the construct of *mental imagery* or the cognitive simulation process by which we can represent perceptual information in our minds in the absence of appropriate sensory input (Kosslyn, Thompson & Ganis, 2006). More recently, another mental simulation process has attracted considerable research attention from cognitive neuroscientists and sport psychologists – namely, motor imagery (also known as 'movement imagery'; Holmes, Cumming, & Edwards, 2010) or the mental rehearsal of actions without engaging in the actual movements involved (see review by Moran, Guillot, MacIntyre, & Collet, 2012).

Motor imagery processes have been been studied in cognitive neuroscience (e.g., Guillot, Collet, Nguyen, Malouin, Richards, & Doyon, 2008; Wei & Luo, 2010; Zhang et al., 2011), sport psychology (e.g., Callow & Hardy, 2004; Roberts, Callow, Hardy, Markland, & Bringer, 2008), motor learning (e.g., Golomer, Bouillette, Mertz, & Keller, 2008) and rehabilitation science (e.g., Steenbergen, Crajé, Nilsen, & Gordon, 2009). This convergence of inter-disciplinary research interest in motor imagery (see Collet, Guillot, Lebon, MacIntyre, & Moran, 2011; Moran et al., 2012) is attributable largely to the 'functional equivalence' hypothesis (e.g., Finke, 1979; Jeannerod, 1994) or the discovery from neuroimaging studies that imagery processes seem to share some neural pathways and mechanisms with like-modality perception (Farah, 1984; Kosslyn, 1994) and with the preparation and production of motor movements (Decety & Ingvar, 1990; Jeannerod, 1994; 2001). This concept of functional equivalence may be traced back at least as far as James (1890) who claimed that "sensation and imagination are due to the activity of the same centres of the cortex" (cited in Decety, 1996, p.46). More formally, however, the term "functional equivalence" was pioneered by Finke (1980), who postulated that "one can think of mental images as being *functionally* equivalent to physical objects or events" (p.113). In sport psychology, an early advocate of functional equivalence was Moran (1996) who, in reviewing research on "mental practice" (i.e., the systematic use of mental imagery to rehearse skills symbolically without engaging in the actual movements involved), suggested that imagery is a "covert simulation of perceptual experience" (pp. 216-217).

Influenced by the functional equivalence hypothesis, Holmes and Collins (2001) developed the PETTLEP model of motor imagery - perhaps the first evidence-based account of imagery in sport psychology to adopt an explicitly neuroscientific rationale. These authors devised the acronym 'PETTLEP' to refer to seven practical issues (i.e., Physical, Environment, Task, Timing, Learning, Emotion and Perspective) which need to be considered in order to optimise the efficacy of motor imagery interventions. A key proposition of this model is the idea that such interventions should simulate, as closely as possible, all aspects of participants' execution situations – especially the sensations associated with relevant movements and their subsequent emotional impact. Over the past decade, this model has proved valuable in many applied settings. For example, PETTLEP-derived imagery interventions have been shown to enhance technical skills in sport (e.g., Wakefield & Smith, 2009) and nursing (e.g., Wright, Hogard, Ellis, Smith, & Kelly, 2008). They have also been used to improve strength performance (Wright & Smith, 2009; Wakefield & Smith, 2011). Nevertheless, in view of recent changes in theoretical understanding of functional equivalence (explained below), it is both important and timely to provide a critical reflection on the current status of the PETTLEP model. Overall, our review will conclude that although some aspects of the original model (e.g., a somewhat literal interpretation of functional equivalence) may have to be discarded in the light of recent research findings, other PETTLEP principles (e.g., the importance of matching closely the imagined and actual skill-learning environments) have been strengthened by empirical evidence gathered over the past decade. And so, we shall argue that the mechanisms underlying PETTLEP effects are more plausibly based on behavioural matching between imagery and action than on neurally-based functional equivalence between these constructs.

In summary, the purpose of the present paper is to provide a critical reflection on 15 years of research on motor imagery using the PETTLEP model. In order to achieve this objective, the paper is organised as follows. We begin by explaining the background to, and key propositions of, this model. Next, we sketch some key changes (since 2001) in theoretical understanding of the cornerstone of PETTLEP – the functional equivalence hypothesis. Building on this new understanding of functional equivalence, we then provide a critical review of imagery research inspired by PETTLEP, highlighting key issues and findings in this field of imagery research. Finally, we examine the progress and prospects of this model and outline the most important new directions for future research on the PETTLEP model.

Background to, and key propositions of, the PETTLEP model

Although mental imagery has proved to be a popular and fertile construct in sport psychology (e.g., see Morris, 2010; Morris, Spittle, & Watt, 2005), advice on imagery interventions (e.g., Vealey & Greenleaf, 2010) has often lacked theoretical rigour. This gap between imagery theory and practice prompted Holmes and Collins (2001) to develop their PETTLEP model. Before outlining some key propositions of this model, however, let us consider two examples of this gap between theory and practice in imagery research. These examples concern the role of relaxation and individualised instructions ("scripts") for optimal imagery interventions.

First, since Suinn's (1976) research, it has been assumed widely that interventions in which imagery is combined with relaxation are more effective than those in which imagery is practised alone. Thus many sport psychologists appear to believe that relaxation procedures are essential prerequisites of imagery use in sport. Such procedures include adopting a comfortable relaxed position (Cabral & Crisfield, 1996; Miller, 1991; Harris & Williams; 2001; Weinberg & Gould, 2007) and conducting imagery sessions in a quiet room (Miller; 1991, Harris & Williams; 2001). Although the practice of combining relaxation and imagery may, at first glance, seem intuitively plausible, it is not supported by empirical evidence. To explain, most studies that have used relaxation combined with imagery have *not* shown any significant benefits from the relaxation (Gray, Haring & Banks, 1984; Hamberger & Lohr, 1980; Weinberg, Seabourne, & Jackson, 1981) and many of the studies that have demonstrated strong imagery effects have not used relaxation procedures (Clark, 1960; Murphy, 1994; Smith & Holmes, 2004; Woolfolk, Parrish, & Murphy, 1985). In addition, recent research on the timing of motor imagery (see review by Guillot, Hoyek, Louis, & Collet, 2012) has shown that such timing was adversely affected when people performed motor imagery in a relaxed condition (see Louis , Collet, & Guillot, 2011). As Holmes and Collins (2001) pointed out, the idea of performing imagery in a relaxed state seems contradictory to what we know about the relatively high arousal states displayed by most athletes performing in competitive situations.

A second gap between theory and practice in imagery research concerns the question of whether or not imagery scripts should be *individualised* for optimal efficacy. On this issue, Holmes and Collins (2001) identified the danger of adopting a 'one size fits all' approach, based in part on Lang's bio-informational theory of emotional imagery (Lang, 1979, 1985). Specifically, they argued that athletes' emotional, perceptual and physiological responses to a given situation are likely to differ greatly and if the mechanism supporting imagery's use is about 'shared' neural correlates, then it is important to attempt to increase each individual's 'sharedness'. Therefore, although there may be some similarities across imagery designs, the practitioner or experimenter should not use the same imagery instructions or imagery scripts for different individuals – the 'one size fits all' problem. Despite this note of caution, an examination of recent imagery research (see, for example, Lebon, Collet, & Guillot, 2010; Ramsey, Cumming, Edwards, Williams, & Brunning, 2010) would suggest that this lack of individualisation is still a common feature of imagery studies. To illustrate the need for individualised imagery scripts, Smith, Wright, Allsopp, and Westhead (2007) discovered that the physiological, emotional and behavioural responses reported by the participants when performing a simple hockey task differed so much from person to person that it was difficult to believe that they had all performed an identical task. For example, the kinaesthetic sensations emphasised were different in every single case, and the emotions experienced were mixed, with some participants reporting positive feelings and others reporting high levels of performance anxiety. Therefore, according to Lang's (1979) theory, more detail is needed when developing imagery scripts, particularly given that individualised imagery scripts that emphasise response propositions have been shown to produce more vivid images (Lang, 1979), and to enhance motor performance to a significantly greater degree than generic stimulus-laden ones (Smith et al., 2001).

In an effort to bridge the preceding gaps between imagery theory and practice, the PETTLEP model was developed. This model was based on the functional equivalence hypothesis (explained earlier in this paper). Subsequently, much research has examined this postulated equivalence, using imagery and other forms of simulation (e.g., action observation - the fact that when we watch someone performing an action that lies within our motor repertoire, our brains simulate performance of that action; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). The process of imagery reveals activity in most areas of the brain across a variety of different studies (Decety et al., 1994; Decety et al., 1997) and a number of methods have been employed to research mental simulation, including mental chronometry, electroencephalography (EEG), positron emission tomography (PET) scanning, functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), and measuring autonomic responses such as blood pressure and heart rate. Many of the early studies that informed the development of the PETTLEP model were completed using these techniques (Decety, Jeannerod, & Prablanc, 1989; Decety, Philippon, & Ingvar, 1988; Dominey, Decety, Broussolle, Chazot & Jeannerod, 1995; Frak, Pavlignan, & Jeannerod, 2001) which, taken together, provided some, albeit limited, support for the postulated equivalence between overt movement and imagery. Over a decade later, the limitations in imaging techniques still do not allow for precise spatial or temporal comparison and similar localized activity may not be functionally related. Therefore, certain caution needs to be exercised when making simulation state comparisons. We propose, therefore, that it is highly likely that some activity reflects inhibited movement rather than functionally 'useful' activity. Until neuroimaging techniques have greater resolution and our research designs become more elaborate and consistent these findings provide a difficult paradox for PETTLEP and functional equivalence.

The development of the PETTLEP model drew on a number of these studies, and subsequent research has attempted to reinforced the importance of the concept of functional equivalence. Research (e.g., Smith & Collins, 2004) supports the idea that imagery and overt movement seem to share neural correlates, at least in part. The precise nature of this shared mechanism is unclear, but its existence is well-documented. The PETTLEP model proposed 'functional equivalence' as a means of attempting to address the abstract concept of neural similarity between movement imagery and overt movement, leaving others to examine the psychophysiological markers of the matched behaviour. Indeed, several studies examined factors prior to the model's conception that were later included as components of the model. These include physical (dynamic imagery, Gould & Damarjian, 1997), environment (Smith & Holmes, 2004), timing (Frak, et al., 2001; Moran & MacIntyre, 1998) and perspective (Hardy & Callow, 1999; Smith, Collins, & Hale, 1998). The importance of including kinaesthetic sensations experienced whilst performing the task was also supported by empirical evidence (Smith & Collins, 2004; Smith et al., 2001). In their original article, Holmes and Collins (2001) proposed that their model would benefit from testing with different tasks and populations. Though researchers were perhaps initially slow to respond to this suggestion, over the last few years studies have tested the model in various settings, although few have used neuroimaging techniques. This section will provide an overview of PETTLEP research to date and provide suggestions for future research.

Changes in theoretical understanding of functional equivalence

Since the PETTLEP model was developed (between 1996 and 1998), fifteen years of significant technological advancement has allowed the work to be critically reviewed based on emerging knowledge of brain structure and function. During its inception, however, the research that considered 'shared neural networks' between imagery and action preparation and execution was limited mainly to theoretical reviews with few accurate empirical accounts. In fact, the PETTLEP model was presented and published before Jeannerod's (2001) neural simulation hypothesis that the motor system is part of a network that is activated under a variety of conditions in relation to action.

The PETTLEP model was developed on the theoretical premise that motor imagery and action preparation and execution share related neural activity, where, it is assumed, the predicted similarities in motor activity allow for refined skill development through either process. The difference between imagery and action - a lack of movement and its associated afferent feedback during imagery - would suggest that the idea is counterintuitive. However, motor imagery involves the generation and rehearsal of an efferent motor command that is inhibited, at least partially, at some level of the cortiocospinal flow. A number of studies (Lotze et al., 1999; Miller, Schalk, Fetz, Nijs, Ojemann, & Rao, 2010) have shown that this activity is seen in many of the same brain areas that are involved in performing actual movements. The aim of the PETTLEP model was, therefore, to propose imagery manipulations that might be most effective in effecting 'shared' neural activity and, indirectly, plasticity, within motor regions of interest related to sensorimotor control. The shared central neural activity patterning, particularly in the motor areas, was termed 'functional equivalence' in Holmes and Collins (2001). There was little discussion of the differences in neural representation underlying motor imagery and action.

Unfortunately, functional equivalence as a descriptive term was also used for the matching of the imagery condition behaviours with those of action preparation and execution. In one case (Holmes & Collins, 2001, p.65), functional equivalence is also used to describe similarity in EMG patterning. Holmes and Collins (2001) were not alone in using the term "functional equivalence" to describe motor similarities across different behavioural states. Regrettably, the multiple meanings of functional equivalence has given rise to a decade of confusion in the sports imagery literature. Interestingly, however, a number of leading authors in this area have recently used the phrase "functional correspondence between states in the motor system" (Uithol, van RooiJ, Bekkering & Haselager, 2011) to describe intrapersonal motor resonance, a process akin to motor imagery. Given the intuitively appealing science of the 'wet-brain', the neural interpretation of functional equivalence seems to have prevailed in the current (mis)understanding of the PETTLEP model. Even with the more detailed spatial and temporal resolution available from imaging techniques such as fMRI, the precise nature of the regional activity and, crucially, its meaning remains at best vague. And so, we conclude that the term "functional equivalence" a may have been more *problematic* than helpful for the validity of the PETTLEP model.

Based on more recent neuroscientific evidence, the abstract concept of 'functionality' is not useful to describe neural activation where spatial and temporal metabolic activity is ascribed behavioural meaning. Some of the proposals made, therefore, for a partially shared and 'functionally' meaningful neural network across imagery and action execution conditions were ambitious and, arguably, beyond the available data of the time. What is of interest, however, is that fifteen years of direct and indirect research related to the model continue to provide support for many of the bold claims made in the original PETTLEP model. The model continues to attract popularity in many academic texts and has been embraced beyond its original discipline, demonstrating good logical validity.

Brief review of research using the PETTLEP model: Issues and findings

Since the first research testing the PETTLEP model appeared in the public domain at the 2005 meeting of the *International Society for Sport Psychology* (Potter, Devonport, & Lane, 2005), a number of published studies have attempted to test the efficacy of the model as a whole, as well as different components of it. Some of these studies have compared PETTLEP-based interventions, typically comprising personalised, response proposition-laden interventions using strong environmental cues, with interventions emphasising stimulus propositions and often using generic scripts and relaxation procedures. Such studies have found PETTLEP-based interventions to be the more effective (Potter, Devonport & Lane, 2005; Smith, Wright, Allsopp & Westhead, 2007; Wright & Smith, 2007, 2009), using tasks such as the hockey penalty flick, the long jump, a gymnastics jump and a strength task (bicep curl). In addition, Wright, Smith and Cantwell (2008) found that when very experienced (international and county level) amateur golfers replaced some of their physical practice of bunker shots with PETTLEP imagery, their performance improved more than that of golfers who continued with their full quota of physical practice of bunker shots.

The studies mentioned above have all been of relatively short duration (≤ six weeks). Therefore, longitudinal studies are necessary to test the durability of these effects.

Anecdotally, post-experimental interviews in these studies clearly indicate that athletes find PETTLEP imagery very novel, engaging and enjoyable, a finding supported by the follow-up interviews in a study by Wakefield and Smith (2011). Therefore, there may be motivational factors influencing athletes' responses to PETTLEP imagery at this early stage, but whether or not the impressive performance gains still persist once the novelty of this approach wears off is something that merits investigation through further longitudinal studies.

As well as testing the PETTLEP model as a whole, studies have examined its individual components. For example, O and Munroe-Chandler (2008) examined the 'timing' element of PETTLEP by comparing the effects of real-time imagery, slow motion imagery and a combination of both on soccer dribbling performance. All the imagery groups improved performance, with no between-group differences, suggesting that for this task, slow motion imagery may be a viable option for enhancing performance. O and Munroe-Chandler (2008) concluded by suggesting that future research on the timing issue is needed. The influence of type of task, stage of learning of participants and other variables may well help us to better understand the reasons for this finding. Indeed, in the original PETTLEP paper, Holmes and Collins report that "[they acknowledge] the usefulness of the external visual perspective technique isolation approach (in which with slow motion and freeze frame are utilized for certain specific learning-related tasks - a good example of task-perspective-timing interaction)." (p.74). This statement highlights one of the problems with the research that has aimed to investigate PETTLEP elements and the literal approaches to studying elements in isolation. The inclusion of timing in the PETTLEP model was informed by the early cognitive neuroscience research from authors such as Jeannerod (1994), Decety (1996) and Vogt (1995). Indeed, Vogt (1995) suggested that motor images require the imager to "reconstruct or generate a temporally extended event on the basis of some form of memory" (Vogt, 1995. p. 193). Jeannerod's (1994) proposal that the mental representation of time is closely associated with force is intuitively attractive and supported a clear link with the physical element of the model, where kinetic afference from posture and task specific equipment directed the timing of the image. The two visual system (Milner & Goodale, 2006) also has important implications for the timing of motor imagery. If less conscious, motor imagery preferentially accesses the faster dorsal stream (Decety, 1996), and simulation theory supports imagery's use, then the inclusion of more conscious verbal instructions, that direct neural traffic ventrally and more slowly, would certainly seem less optimal within this theoretical framework. However, and importantly, given that there is evidence for other theories to explain motor imagery's effectiveness (e.g., motivational models; Evans, Jones & Mullen, 2004; Martin & Hall, 1995) then PETTLEP, in its most direct form, is less able to explain the performance facilitating effects of slow-motion imagery from a neurological perspective. Our recent attempts to consider imagery mechanisms, indirectly, using eye movement metrics and kinematic comparisons with perception (e.g., McCormick, Causer & Holmes, under review) may add to the imagery chronology literature and inform further the debate regarding the timing element of PETTLEP.

The 'emotion' element of PETTLEP has also recently been studied, with Ramsey et al. (2010) comparing the effects of skill-based and emotion-based imagery interventions on performance in soccer penalty-taking practice. The inclusion of emotional content did not enhance the effectiveness of the imagery, leading the authors to conclude that such content may have a more profound influence during competition than during practice. However, we question the validity of this claim and suggest that from the absence of an effect in practice, inferences cannot be made regarding the effect in competition, without further testing. Again, research examining this hypothesis would be very useful.

Finally, researchers have also begun to examine whether PETTLEP can enhance performance outside of the sporting arena. Wright et al. (2008) examined the effects of

PETTLEP imagery on the performance of student nurses on two basic nursing skills: blood pressure measurement and aseptic technique. Students who received PETTLEP training improved their performance more than those who did not receive the training, though there was no between-group difference for aseptic technique. The authors concluded that PETTLEP imagery was potentially very useful for enhancing psychomotor skills in nursing, suggesting that it may not have been as useful for aseptic technique due to the relative lack of psychomotor elements in this skill. Further research examining the usefulness of PETTLEP imagery in domains outside of sport, and particularly further investigation of these very interesting findings with nursing skills, would be welcome additions to the PETTLEP literature.

Overall, PETTLEP research during the past decade has been encouraging. In particular, most studies in this field appear to support the efficacy of PETTLEP imagery with a wide variety of tasks and populations. Clearly there are many aspects of PETTLEP that require further investigation. There still issues to resolve in terms of the efficacy of PETTLEP on final performance and alternative measures of the effectiveness of imagery interventions, such as examination of the effects of imagery on technical components that may influence performance, are needed. Additionally, questions have been raised about its theoretical underpinnings – a concern which will be explored briefly in the following section.

Progress of, and prospects for, research on the PETTLEP model

Holmes and Collins' (2001) decision to build the theoretical foundations of their model in cognitive neuroscience is laudable. Unfortunately, not enough sport psychology researchers followed suit. Thus Dietrich (2008) lamented recently the "lack of contact between the rapidly expanding knowledge base of cognitive neuroscience on the one hand and other disciplines interested in the effects of exercise on mental processes on the other" (p. 321). In light of the research support from studies that have tested the efficacy of the model, we propose here to consider whether or not the PETTLEP model still has a place in sport and exercise psychology research and practice. At its inception, the model was based on the increasing evidence from neuroscience literature and Holmes' PhD work that action execution and [motor] imagery might 'share' neural substrate and therefore, as proposed in the model, imagery should include behaviors specific to the physical execution of a task.

One of the advancements to the model that was not fully identified in 1998/2001 was the extension of the PETTLEP model's predictions beyond movement imagery to include action observation. This neurologically-related phenomenon has received considerable attention in the neuroscience literature following the discovery of 'mirror neurons' in monkey premotor cortex (Rizzollati & Craighero, 2004). It is this brain region that is postulated to underlie people's ability to infer the goals and intentions of others by observing and imitating their actions (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). There is now an extensive body of research that provides support for the concept of an action-observation matching system in humans that may also be directly involved in the process of movement imagery (cf. Holmes & Calmels, 2008 for a discussion of the relative merits of imagery and observation). It seems likely that not only do action execution and movement imagery share neural substrate, but that action observation may also, in part, share similar neural mechanisms. Holmes, Edwards, Callow, Cumming, Smith and Williams (2007) presented a series of five papers to the FEPSAC Conference that were directly related to this proposition; the schematic shown in Figure 1 is now widely accepted to describe the common and specific substrate among the three conditions.

[Figure 1 near here]

One of the first studies to provide indirect evidence to support this idea and, at the same time, the behavioural modification hypothesis predicted by the PETTLEP model, was presented by Holmes, Collins, and Calmels (2006). In this PETTLEP-based study, elite air rifle shooters' EEG activity was recorded during competitive shooting as well as during three different conditions of action observation. These latter conditions were predicted to differ in terms of their 'functional equivalence' with the physical shooting condition in terms of the task specific relevant afferent information available as a consequence of the behaviours adopted during the action observation. Therefore, standing was predicted to be 'more functionally equivalent' than sitting and holding the rifle more functionally equivalent than not; the proprioceptive information allowing greater 'access' to the neural network or motor representation for the shooting task. The EEG data revealed some surprising findings. All action observation conditions showed some temporal and spatial congruence with the physical execution profile. Additionally, the condition hypothesised as most congruent (standing holding rifle) showed the most similar neural profile to the physical condition. The authors suggested that these data provided support for the predictions of the PETTLEP model, but that the abstract functional equivalence relationship may not be as simple as first thought. Merely including additional PETTLEP elements did not seem to improve the physical EEG fit and challenges the performance-based studies of Smith and colleagues discussed earlier. The PETTLEP model, whilst not explicitly predicting a dose-response relationship (indeed, it suggests "considerable individual differences", p.70) has certainly been interpreted to imply a 'more is better' approach to imagery [and observation] training; this is unlikely to be borne out by empirical studies. The PETTLEP model was deliberately simple in its design; it was not presented as a theory of functional equivalence. It was unlikely that just increasing the proprioception assumed to be relevant to a given motor skill would directly increase the central neural congruence; without some reference to afferent meaning, the increased proprioception is likely to be 'read' as noise and *reduce* the congruence in central neural correlates. The inclusion of Lang's bio-informational theory in the original model, in particular the importance of the concept of meaning propositions, would be consistent with this idea. Indeed, though it has been suggested (Callow & Hardy, 2005) that bio-informational theory is inconsistent with a functional equivalence approach due to the latter being based upon an information processing paradigm, we would argue that there are many similarities between the two approaches. In fact, bio-informational theory also has an information processing emphasis, with Lang (1979, 1985) arguing that images are essentially composed of units of information (propositions) and that the processing of these units of information, particularly response propositions, accesses the memory of the relevant movement. Both approaches also have a strong emphasis on kinaesthesis and physiological responses to imagery, with both Lang (1985) and Jeannerod (1994) arguing that these are important aspects of the imagery experience. In addition, bio-informational theory provides some important, theoretically-grounded suggestions for the implementation of imagery interventions that were included in the original model. These suggestions have since been supported in the sport psychology research literature (Smith et al., 2001; Smith & Collins, 2004). Indeed, Smith and Collins' finding of similar movement-related cortical potentials occurring prior to imagery and movement when response propositions were included in the imagery instructions, and the absence of such potentials when only stimulus propositions were included, suggests that cortical mechanisms may underlie some of the effects suggested by Lang's theory. Therefore, we still think that both these approaches play an important, and complementary, role in the theoretical underpinnings of the model.

One of the improvements that could now be made to the model is the more precise use of terminology (cf., Holmes & Calmels, 2008). This increased precision is necessary because of advances in research on the neuroscientific substrates of imagery. To illustrate, consider the definition of 'motor imagery' that is associated with the original PETTLEP model. Specifically, influenced by Jeannerod's (1994; 1997) approach, Holmes and Collins (2001) described imagery as "a force-generating representation of the self in action from a first person (internal) perspective" (p. 62). The first problem with this definition is that it conflates two different modalities, one of vision and the other of kinesthesis (i.e., the system that regulates our ability to sense the position and movement of our bodies; Proske & Gandevia, 2009). The second problem with this definition is that it appears to limit visual perspective to first person agency only. This confusion of terminology may, in part, have contributed to some of the misunderstanding that has arisen about the PETTLEP model over the past decade. In this regard, terminology such as "internal visual/kinesthetic imagery perspective" (p.71) does little to help the reader to understand the imagery processes involved. Imagery modality, although implied within the text of the original PETTLEP paper (e.g., "motor imagery should, therefore, be personalized through full, multisensory involvement of the performer in the generation of the motor image content" (Holmes & Collins, 2001, p.72) was not one of the seven elements. Indeed, at the time, it did not need to be since Holmes and Collins stated that the model related to "motor imagery script construction" (p.69) and, therefore, by definition, related only to visual and movement imagery. However, since its development, there is increasing evidence that other modalities may contribute to the neural substrate in motor areas of the brain. These include action verb generation and audio mirror neurons[1].

The PETTLEP model was introduced as a "functional equivalence model for sport psychologists" (p.60). However, the original paper did not make clear *what* was or *should be* 'functionally equivalent'. Whilst there was no definition of the term *per se,* Holmes and Collins (2001) proposed that "consideration of the two processes [imagery and motor preparation and execution] and the extent to which they covary (their functional equivalence) is vital..." (p.62). What is confused here, and, in so doing, contributed to the varied interpretations of the term in the sport psychology literature, is the conflation of shared neural substrates and shared actions and behaviours between motor preparation and execution and movement imagery. In any case, the most important issue for applied sport and exercise psychology is the question of how best to develop and deliver evidence-based, optimally-effective imagery for sport and exercise performers. We believe that it is only through behavioural and environmental modification that we can hope to exert some control over the 'sharedness' of neural correlates. Therefore, the primary concern for the applied sport psychologist should be the individually identified functional equivalence of the imagery performance environments and behaviours when compared to the physical conditions. Since specific allocation of behavioural function to neural regions remains, at best, uncertain especially in high performing athletes, an over-emphasis on neural convergence may be problematic. Even where imaging and recording techniques seem to show shared regions, the exact neural patterning and temporal profile may be different. Alternatively, 'shared' neural networks may have an inhibitory function in imagery conditions and an excitatory function for physical execution of the same task (see Holmes & Calmels, 2008, who have discussed this issue for contralateral primary motor cortex where a number of discrepant findings have been shown). Therefore, the last decade has refined our knowledge of the possible shared neural areas between action execution and movement imagery as well as the associated condition of action observation. The rapid improvements in technology used to support research in imagery, particularly fMRI, have changed the understanding of neural functional equivalence quite dramatically, yet the PETTLEP model can, we feel, still be supported from this literature. The general principles of matching characteristics from the physical skill to the imagery conditions can still be supported from the Hebbian learning position and the studies reported elsewhere in this paper provide further support using more indirect performance-based markers. Within the modified version of the model that we present in Figure 1, there is now evidence from both cognitive neuroscience literature and applied sport psychology to support the inclusion of the sub-elements.

In light of the preceding discussion, how successful has the PETTLEP model been in achieving its objective? In order to answer this question, we need to combine empirical evidence with conceptual analysis. At first glance, there is an encouraging body of empirical evidence to support the efficacy of PETTLEP-based imagery interventions. Specifically, as noted previously, a number of studies report that imagery interventions based on PETTLEP principles tend to produce significant improvements in skill and strength performance relative to traditional imagery interventions. But in attempting to account for these imagery findings using the terminology and principles of functional equivalence, some PETTLEP researchers have unwittingly added to, rather than resolved, conceptual confusion in at least two aspects of this field. For example, when Ramsey, Cumming, and Edwards (2008) referred to "… *more* functionally equivalent imagery compared to *less* functionally equivalent imagery" (p. 209; italics ours), they appear to have assumed that 'equivalence' is a quantifiable property of imagery such as vividness. Unfortunately, there is, as yet, no agreed independent measure of the 'amount' of functional equivalence that exists between movement imagery and motor production/motor behaviour. In order to counteract against this terminology, we believe that PETTLEP researchers should always specify, as precisely as possible, what imagery is deemed equivalent *to* - and at what level of cognitive analysis this hypothetical equivalence exists. Put simply, as a relational term, 'functional equivalence' is meaningful only when two or more phenomena are compared. Historically, the functional equivalence hypothesis (e.g., Finke, 1979; Jeannerod, 1994) proposed that mental imagery shares, to some extent, certain representations, neural structures and mechanisms with like-modality perception and with motor preparation and execution. For example, neuroimaging studies indicate that imagined and executed actions tend to rely on similar neural representations and activate many common brain areas (e.g., the parietal, premotor and supplementary motor cortex; de Lange, Roelofs, & Toni, 2008). Therefore, caution is required when PETTLEP researchers refer to "functionally equivalent imagery" (Wright & Smith, 2009, p. 29) because 'equivalence' does not describe a property of imagery but instead, the relationship between imagery and motor preparation and/or behaviour. The second source of conceptual confusion in PETTLEP research stems from the fact that it is easy to confuse representational and experiential levels of analysis when referring to movement imagery. For example, Ramsey et al. (2008) claimed that "the degree of equivalence between *the imagery experience* (our emphasis) and *the physical experience* (our emphasis) is a major determinant of imagery's effectiveness at modulating behaviour" (p. 209). The problem here is that the original functional equivalence hypothesis (as postulated by Finke, 1979, and Jeannerod, 1994) specified explicitly that equivalence occurs at the mental representational level rather than at the phenomenological level. Taking these two points together, a key question arises. Do we actually need the term 'functional equivalence' in PETTLEP theory? Could this term be replaced with no loss of meaning (and perhaps with a greater degree of precision than is currently the case). If so, could the term 'functional equivalence' be replaced by the term 'behavioural matching' in future research using the PETTLEP approach?

Conclusion

In conclusion, we have reviewed a growing body of research on the PETTLEP model of imagery in sport and exercise psychology. Since the development of the PETTLEP model it has become apparent that the concept of functional equivalence for brain activity is much more complicated than it appeared to be at the model's conception. Therefore, at times, mistakes have been made in attribution of some of the apparent similarities in brain activity. Whilst the importance of some components of the model have been scrutinised and upheld by empirical evidence, others may have to be discarded as a result of recent research findings.

Therefore, we propose that the mechanisms underlying PETTLEP effects are likely grounded in behavioural matching between imagery and action (i.e., an experiential and/or phenomenological similarity), rather than a functional equivalence (i.e., a hypothetical relationship between two or more psychological processes at the representational level) between these constructs, and that individualised imagery interventions produce a closer 'behavioural match' than their generic counterparts. We encourage imagery researchers to make clear this distinction within their work to enable further understanding of imagery to be developed.

A number of models of imagery have been proposed and tested in sport psychology, such as Symbolic Learning Theory (Sackett, 1934) and Visuomotor Behaviour Rehearsal Model (VMBR; Suinn, 1976). However it is interesting that few of these, if any have been revisited and revised in the light of subsequent empirical evidence. The process of reviewing the PETTLEP model based on neuroscientific findings has been engaging and worthwhile. Therefore we recommend that other imagery authors should follow us in conducting a similar type of critical reflection, resulting in the development of models that are relevant and applicable to other areas of scientific research. Additionally, it is key to consider the role of observational learning and its relationship within this process. We suggest that scholars conducting work within this area pay careful consideration to the points raised here, both in the testing and the reporting of imagery interventions.

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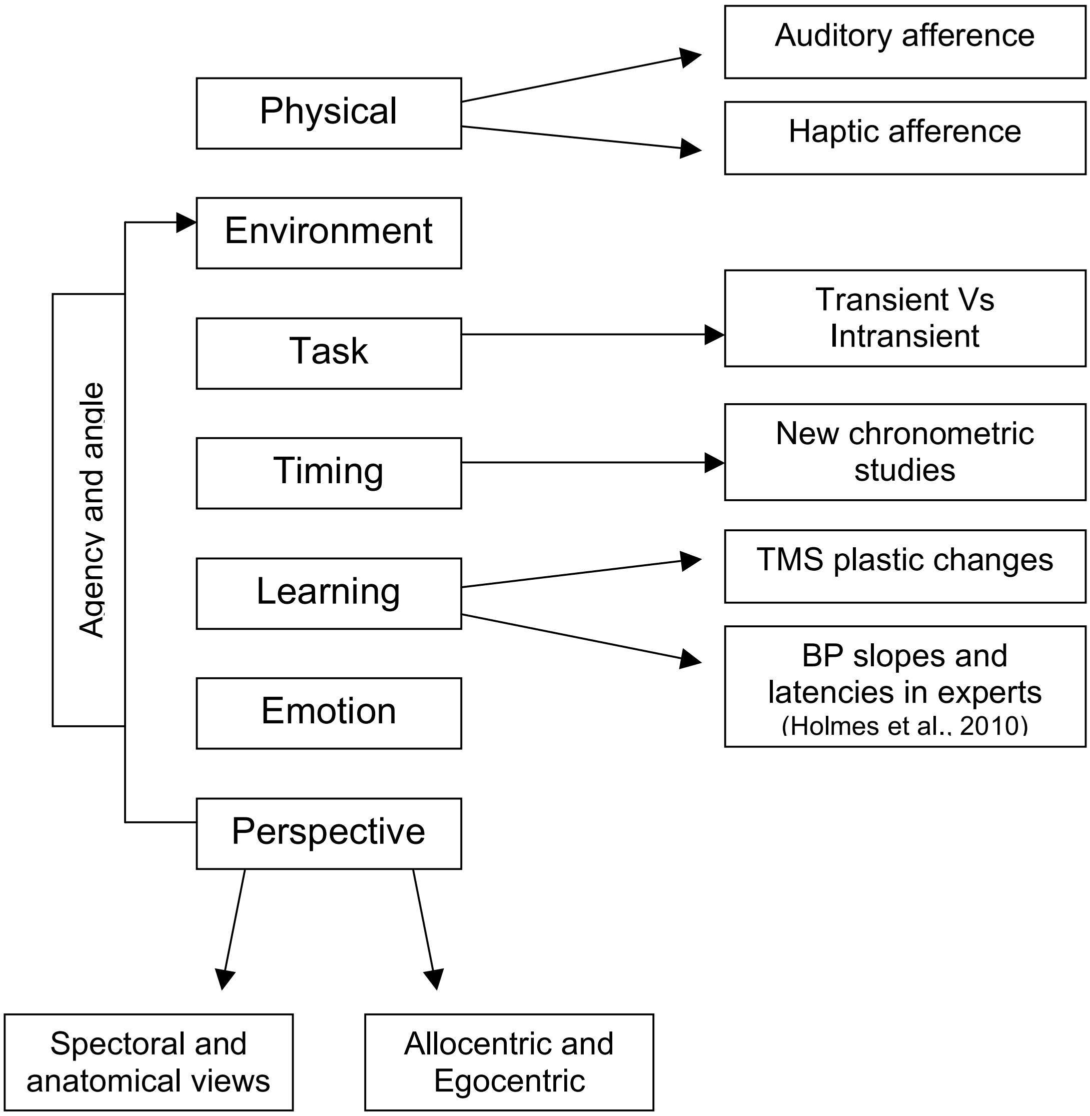
Figure 1: Schematic of common substrate



Footnotes

1. The more recent development of a research forum, Research in Imagery and Observation (RIO), of which all the authors of this paper are contributing members, has attempted to address some of these concerns and to separate out the modality-perspective-agency problems.