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The Contribution of Planning-related Motor Processes to Mental Practice and Imitation Learning

Khalaf, Bassem

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**The Contribution of Planning-related
Motor Processes to Mental Practice
and Imitation Learning**

Bassem Khalaf

**School of Psychology
University of Plymouth**

Ph.D.

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Bassem Khalaf

School of Psychology
University of Plymouth

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requirements for the degree of

Doctor of Philosophy

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Bassem Khalaf

Abstract

It is still controversial whether mental practice – the internal rehearsal of movements to improve later performance – relies on processes engaged during physical motor performance and, if so, which processes these are. This series of experiments investigates this question. It utilizes a framework of ideomotor action planning theories, and tests whether mental practice may specifically draw upon planning- rather than execution-related motor processes, specifically those processes that “bind” intended action features to action plans.

Experiments 1 to 4 utilize a classical stimulus response compatibility paradigm. Participants mentally practiced complex rhythms with either feet or hands while using the same or different body parts to respond to unrelated sounds. In contrast to previous work on stimulus response compatibility, we indeed found that responses were impaired – rather than facilitated – for those body parts that were concurrently used in mental practice. This result was found when participants mentally trained to memorize the rhythms (Experiment 1), to merely improve their performance (Experiment 3), when mental practice and execution directly followed one another and when separated by a different task (Experiment 4). These data link mental practice not to execution but planning related motor processes that are involved in binding intended action features to intended action plans.

Experiment 5 and 6 then extend these results to imitation learning. Participants were instructed to learn the rhythms by observing somebody else, while again making unrelated responses with their hand and feet. While previous work on stimulus response compatibility focussed on testing automatic imitation processes, here imitation was therefore goal directed. We found, as in the previous experiments, that responses with the same body parts as used in the observed rhythms were impaired, suggesting that goal-directed imitation might rely on the same planning-related motor processes as the mental practice of action (Experiment 5). Importantly, these effects were only found as long as participants observed the actions with

the purpose of imitating them later (i.e. formed action plans), but not when they merely tried to memorize the rhythms for later recognition (Experiment 6).

The previous experiments suggest that mental practice and observation learning draw upon body-part specific planning processes. Ideomotor theories suggest, however, that action plans can be relatively abstract, and represented in terms of higher-level goals (i.e. the sequence of left and right button presses independent of the body part used). Experiment 7 and 8 therefore tested whether rhythms learned through mental practice or observation learning could be transferred to other body parts. As expected, we found a relatively high amount of potential transfer when rhythms were mentally practiced with one body part, and then had to be transferred to another body part (Experiment 7). However, this only held when participants learned the rhythms based on an abstract rhythm description, as in Experiments 1 to 4. If participants learned the same rhythms during action observation, any benefits were only obtained when the rhythms later had to be executed with the same (rather than a different) body part.

Together, the present data suggest that mental practice does not rely on execution related-motor processes, and points to an involvement of planning related motor processes instead. We argue that such a planning-based account of mental practice is more compatible with the available evidence from body neuroscientific and behavioral studies, and allows one to resolve several debates. Moreover, it allows one to conceptualize goal-directed imitation in a similar manner as mental practice.

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Chapter 1

General Introduction

1.1. Mental Practice: Definition and Theories

Mental practice, the internal rehearsal of movements to improve later performance, underlies both the development and the execution of many of our motor skills. It can be defined as the mental repetition of a task, without observable movement (e.g., Corbin, 1972), or, as Rodriguez, Lianos, Gonzalez, and Sabate (2008) put it: "... a dynamic mental representation of motor behaviour unaccompanied by real movement". It is assumed to rely on motoric mental imagery and is used in a goal directed manner to prepare an actor for later performance (Driskell, Copper & Moran, 1994; Stuart & Biddle, 1985).

Mental practice is widely used by athletes to achieve best possible performance and by coaches to teach and develop motor skills, particularly with difficult behaviours or complex performance situations. It typically takes one of two forms. First, mental practice can directly precede action execution, taking the form of an explicit act of motor planning (Jeannerod, 1995; 1994). Platform divers may take a few seconds to visualize their movements before jumping off, or weightlifters may visualize the ideal weight distribution relative to their gravity centre. However, second, mental practice can also be used "offline" and be used to play through behaviours the athlete will perform much later, often in circumstances that bear no similarity to the actual performance situation. For example, former England goalkeeper David James supported his training regime by engaging in mental practice. Even when stuck in traffic, he would "do a few crosses in his mind" (Winter, 2002).

Mental practice lends its users various general benefits. For example, mental practice has direct emotional benefits. It helps develop self-confidence and reduce worry and is therefore used as a mental management skill in the physical education curriculum (Hall & Fishburne, 2010). In a typical intervention, a coach might ask the athlete to mentally practice the task

with positive outcomes before the actual performance for increasing self-confidence (Bertollo, Saltarelli, & Robazza, 2009; Hall, & Fishburne, (2010; Munroe-Chandler, Hall, & Fishburne, 2008). Such interventions have indeed been shown to help athletes to prepare and cope with the general atmosphere of the competition day (Hall, Rodgers & Barr, 1990).

Other general benefits arise from the use of mental practice to control attention focusing and refocusing. For example, before throwing a dart, coaches might instruct the athlete to picture the centre of the board and make it as large as possible in their mind. Evidence suggests that such practice, especially when directed towards the intended goals of the action, leads to direct performance improvements, increasing outcomes and reducing cognitive demands on motor control (for a review, see Wulf, 2007).

Another use is the correction of potential errors before task execution. Before attempting a high jump, for example, the coach might ask the athlete to mentally practice the approach towards the bar and to image running towards it without actually taking a jump. This allows the athlete to focus and calculate an accurate run-up before the actual attempt. If the athlete feels that the last step is too close to the bar, then he or she moves his/her starting point back a few inches. If the athlete feels that the last step is too far away from the bar, he/she moves it forward. It usually takes several (mental) attempts to find the exactly right starting point.

Finally, and perhaps most importantly, mental practice has been shown to have powerful effects on skill learning and the acquisition of motor tasks, both when used in the performance situation and when used outside of it. It is effective across a broad range of skills, ranging from simple manual movements to expert movements in sports, such as diving, swimming, or golf (e.g., Grouios, 1992; Martin & Hall, 1995; Noel, 1980; for meta-analyses, see Feltz, Landers, & Becker, 1988; Hinshaw, 1991). Overall, mental practice has been

shown to be superior to no practice, but not as effective as physical practice (Feltz & Landers, 1983; Allami, Paulignan, Brovelli, & Boussaoud, 2008). Still, some skills benefit more from mental rather than physical training (Wohldmann, Healy, & Bourne, 2008), and generally the greatest performance improvements arise when mental and physical practice are combined (Hall and Fishburne, 2010). Various studies have shown that mental practice not only facilitates performer's cognitive representations of the skill, but also helps their automatization (Sackett, 1934). For these reasons, more than 90% of professional athletes and 94% of coaches now incorporate mental practice in their training regimes (Jowdy, Murphy, & Durtschi, 1989), and it is increasingly used in other fields as well, such as surgery, music performance, and rehabilitation after stroke (e.g., Arora et al., 2011; Ross, 1985; Zimmermann-Schlatter, Schuster, Puhan, Siekierka & Steurer, 2008). Finally, the benefits of mental practice appear to be related to the benefits of observational learning and imitation, and the effectiveness of mental practice can be enhanced when it is supported by video demonstrations of the skill (e.g., Hall and Erffmeyer, 1983).

1.2. From Symbolic to Embodied Theories of Mental Practice

Despite much research on the benefits of mental practice, it is very much unclear on what processes mental practice relies on and how these benefits emerge. Over the years, different theories have been proposed, which can be broadly distinguished between abstract/symbolic and embodied accounts of mental practice.

1.3. Symbolic Views of Mental Practice

Early conceptions arose from the view that the mind is an abstract information processor (for discussion, see Anderson, 2003; Holt and Beilock, 2006; Purves et al., 2008; Sprague, Ballard & Robinson 2007; Wilson, 2002). Motor skills were similarly seen to be based on abstract descriptions or semantic mental models. For example, according to schema theory, motor skills are based on abstract representations stored in memory, which are retrieved in the performance situation to function as controller images of the motor apparatus (see Annett, 1996; Schmidt, 2003). Complex motor skills were assumed to be organized in a tree-like structure that subdivide the phases of a motor action, and control the different postures that are required in each stage.

The trees have been shown to indeed have a cognitive foundation. In a recent example, Weigelt, Ahlmeyer, Lex, & Schack, (2011) used structure dimension analysis to reveal the cognitive representation of the judo throw uchi mata in judo expert. They showed that the skill is represented in a distinctive hierarchical tree like structure in long term memory, consisting of fourteen parts, which can be subdivided in preparation phase, the main throwing phase and the final phrase (see Figure 1.1). Importantly, they could show that problems in these cognitive representations of the skills coincided with similar problems when performing the associated motor actions.

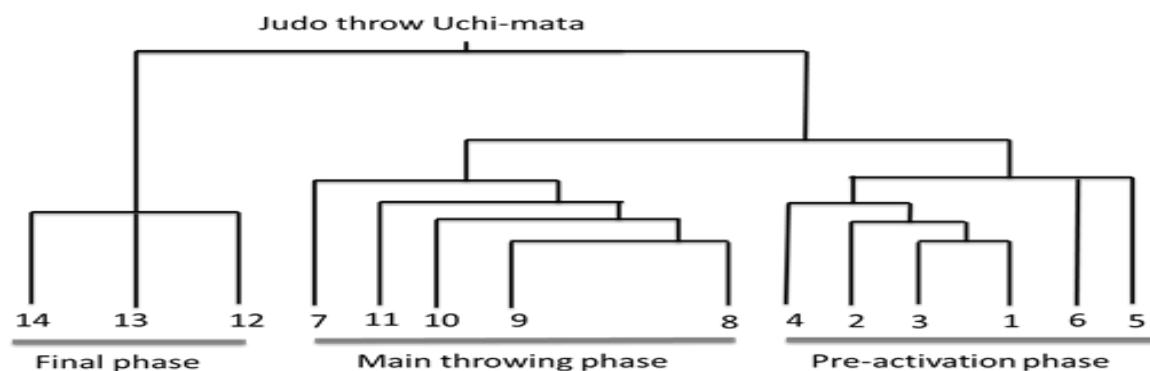


Figure 1.1 Tree like structure in the representation of the Uchi-Mata judo throwing. Figure recreated based on Weigelt, Ahlmeyer, Lex, & Schack, (2011). The start of the movement is on the right side.

In such views, mental practice was seen as an abstract, symbolic process, which operated on these mental models, allowing these models to be re-structured, sharpened and refined. For example, Richardson (1967) defined mental practice as ‘the symbolic rehearsal of a physical activity in the absence of any gross muscular movements’. In such views, the benefits of mental practice emerge because it supports cognitive (re-) structuring of the action plans, by providing ease of access to the different nodes in their hierarchical structure, or facilitating the chunking and sequencing of action units (e.g., Driskell et al., 1994; Minas, 1978; Sackett, 1934). Indeed, consistent with such cognitive views of motor skills and mental practice, several meta-analyses have revealed that mental practice has larger effects on tasks with a strong cognitive component compared to purely motor tasks (e.g., Feltz & Landers, 1983; Hird et al., 1991; Lohse, Healy, & Sherwood 2010; Ryan & Simons, 1983).

1.4. Embodied Views of Mental Practice

Recent research has challenged these symbolic views of mental practice, revealing that mental practice can directly affect not only cognitive skill representations, but also core motoric or physiological variables of performance. For example, Wohldman, Healy and Bourne (2007, 2008) have shown that mentally practicing button press sequences speeds up not only subsequent motor planning times (measured by the time it took participants to initiate a motor sequence), but also their motor execution times (measured by the time it took participants to fully execute the motor sequence). The authors argued that the latter result revealed a direct impact on motor execution, rather than planning.

Other studies revealed impacts on physiological performance measures. Page, Szaflarski, Eliassen, Pan, and Cramer (2009) provided evidence that mental practice supports the cortical re-organization of motor cortices after stroke. Roure et al. (1999) revealed that changes in heart rate during mental practice predicted subsequent improvement in volleyball. Perhaps most strikingly, mental imagery of finger and arm movements is enough to improve the physical strength of these movements, when measured later during physical training (Reiser, Büsch, & Munzert, 2011; Yue & Cole, 1992). Such results have provided converging evidence that mental practice does not – as predicted from symbolic accounts – merely affects the cognitive representation of motor skills, but affects the motor and bodily systems itself, leading to various improvements and benefits.

This has led to the development of embodied or enactive accounts of mental practice. Embodied accounts assume that mental practice is at least partially ‘enactive’ and rooted in the processes guiding actual motor execution. Accordingly, mental practice involves visual and kinaesthetic motor imagery that allows people to ‘simulate’ the sensory input that would

occur during physical execution (e.g., Decety, 1996; Jeannerod, 2001). These simulations are assumed to be based on processes that occur, in very similar form, also during the physical performance of the actions. For example, Annett (1996) assumed that the mental images during mental practice reflect the controller signals that would be sent to the motor systems during each stage of an action's execution (see also, Jeannerod, 1995; Vogt, 1996). Jeannerod and Frak (1999) proposed that they were generated by a 'subliminal activation' of the motor apparatus that plays through the mentally simulated actions. Newer accounts assume that they emerge from internal models that, during action execution, generate visual and kinaesthetic predictions of movement outcomes (e.g., Grush, 2004; Wolpert & Flanagan, 2001).

Evidence for enactive accounts comes mostly from studies investigating motor imagery outside of a mental practice context (that is, imagery of action without the explicit goal of improving subsequent performance). Several studies have provided evidence that mental imagery activates the muscular system even in the absence of physical movement (see Guillot et al., 2007; Jeannerod & Frak, 1999; Hale, 2003; Rodrigues et al., 2010). Electromyographic (EMG) studies provided a key piece of evidence. Jacobson demonstrated already in 1930 that imagery of movement is accompanied by subtle activity in those muscles that are typically used to perform the movement, consistent with Jeannerod and Frak's idea of subliminal motor system activation (see Guillot et al., 2007, for more recent findings). In a more recent example, Lebon, Rouffet, Collet and Guillot (2008) asked participants to lift or to imagine lifting a weighted dumbbell. They measured the muscle activation in three muscles, the Biceps long head, the Biceps short head and Triceps brachii. They found a significantly increased EMG activity in all muscles during motor imagery than during rest. Results such as these show that the motor system is engaged during mental practice, suggesting that it is either involved in generating the associated imagery experiences, or activated as a consequence of imagery.

Further support for motor contributions to motor imagery comes from studies showing that the timing of mental imagery closely follows the timing of the actual movements (e.g., Decety & Michel, 1989; Landauer, 1962; MacKay, 1981; but see Reed, 2002). For example, in an early study, Decety and Michel (1989) asked participants to write a sentence and to draw a cube. Their findings showed that, in writing movements, the temporal patterns in both mental and actual conditions are very similar, both when comparing between subjects and when comparing across trials in an experimental run. Studies such as these further support the notion of a motoric involvement in mental practice, and reveal close links between physical motor performance and motor imagery.

Another piece of evidence that supports embodied accounts of mental practice is that people's ability to mentally rotate body parts depends on these body parts not being engaged in a different movement (e.g., De Lange, Helmich, & Toni, 2006; Ionta, Perruchoud, Draganski & Blanke, 2012; Ionta, Fourkas, Fiorio, & Aglioti, 2007; Wohlschläger, 2001; Wohlschläger, & Wohlschläger, 1998). In a recent study, Ionta et al. (2007) studied whether changes of hands posture influence the mental rotation of hands and feet. They found that mental rotation of hands but not feet was influenced by changes in hands posture. Similarly, Wohlschläger, & Wohlschläger (1998) showed that utilizing hands in similar or different movements impairs or facilitates people ability to mentally rotate imagined objects. Such studies show that the motoric involvement in motor imagery is not only epiphenomenal, but of functional importance, such that interfering with the motor system leads to associated effects on motor imagery performance.

Finally, a host of neurophysiological studies shows that imagery of movement goes along with activity in brain regions directly involved in motor control and planning, such as the premotor and motor cortices, the supplementary motor areas, as well as the parietal lobe (e.g.,

Miller et al., 2010; Naito et al., 2002; Porro et al., 1996; for reviews, see de Lange, Roelofs, & Toni, 2008; Lotze & Halsband, 2006). Miller et al. (2010) investigated overt action and kinaesthetic imagery and measured this with EEG source localization. They had four types of body movements (shoulder, hands, tongue and speech) across three factors of performance: movement, imagery and feedback. They found that motor imagery and actual performance of a motor skill show overlapping activity in somatotopically distributed motor areas. Similar motor activations – and behavioural responses – have been observed when people watch others act, prompting the idea that similar processes of motor simulation are also engaged during action observation, and could account for both automatic and goal-directed acts of imitation (e.g., Brass, Bekkering, Wohlschläger & Prinz, 2000; Chartrand & Bargh, 1999; Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; for a review, see Iacoboni, 2009).

1.5. Problems of Embodied Accounts

Despite this broad support for enactive theories of motor imagery, the involvement of enactive processes in mental practice is still debated. As noted, one reason is that there is a scarcity of studies directly linking motor engagement to mental practice: cases where participants did not only have to imagine movement, but where this imagery was used to improve later performance. In addition, even the data on motor imagery outside of a mental practice context is far from equivocal and leaves many questions unanswered.

For example, several studies now suggest that motor activity during imagery is primarily found when participants imagine themselves from the 1st rather than the 3rd person perspective (e.g., Lorey et al., 2009), and when they are instructed to focus on the kinaesthetic sensations going along with the actions rather than just the visually perceivable effects (e.g., Stinear et al., 2006). Often, these forms of mental practice require explicit training and are not spontaneously used by participants (e.g., Lotze et al., 1999). Motor involvement during motor imagery and mental practice may therefore be far from a general phenomenon, but may be restricted to specific circumstances.

Even in cases of kinaesthetic egocentric imagery, various studies report either only very transient or complete absence of actual motor (rather than pre-motor) activation (e.g., Dechent, Merbold, Frahm, 2004; Macuga & Frey, 2012; for a review, see Lotze & Halsband, 2006), or even striking dissociations (e.g., Hanakawa, Dimyan, & Hallett, 2008; Reed, 2002). As an instructive example, amputees sometimes report the feeling of being able to control their phantom-limbs, a phenomenological experience that contrasts starkly with and appears more “real” than imagery of movement. A neuroimaging study confirmed this dissociation, with brain activity during phantom-limb movements being virtually identical with actual

movements, but strikingly different to imagined movements. More specifically, primary motor cortex was activated during actual movement of phantom limbs while premotor cortex was activated during imagined movement of phantom limbs (Raffin, Mattout, Reilly, & Giraux, 2012). This indicates that motor execution and imagery do dissociate, even when the actual movements and the kinaesthetic feedback are controlled.

Finally, even in studies that do report motor activation, it is often not clear what the role of this activation is, the evidence being subject to various interpretations. First, it has been argued that the observed motor effects during action simulation are purely epiphenomenal – a downstream consequence brought about by associations between cognitive control and motor areas – rather than the basis of mental practice processes (for discussion, see Jeannerod, 1994; Mahon & Caramazza, 2008). Second, the possibility has been raised that the reported motor activations may reflect action planning processes rather than execution processes (e.g., Hanakawa, Dimyan, & Hallett, 2008), a suggestion further supported by the more robust involvement of premotor rather than motor cortices in motor imagery (for a review, see Lotze & Halsband, 2006). And third, they may reflect the inhibition of motor output prohibited by the task rather than an excitation of the relevant motor structures, and data from a fMRI functional connectivity study indeed reveals an inhibitory influence of action planning areas onto the motor cortex (Solodkin et al., 2004).

1.6. Summary and Conclusions

Mental practice is a key research interest for the fields of motor control, sports psychology and education. However, the mechanisms underpinning it are still very much unclear. Neither symbolic nor embodied theories can fully account for the observed results. Symbolic accounts struggle with the findings that mental practice has direct effects on physiological or motoric measures. Embodied accounts, in contrast, have problems explaining why mental practice predominantly benefits skills with a strong cognitive component. In the following we will introduce a novel way of looking at mental practice – based on ideomotor theories of action planning – that combine embodied and symbolic accounts, and may therefore be able to provide a fuller explanation of the available data.

Chapter 2

Ideomotor Theories of Action Planning and their Application to Mental Practice

2.1 Ideomotor Theories of Action Planning

Ideomotor theories have been developed to account for how humans can plan and execute actions that are not passively triggered (only) by affording stimuli in the environment, but by their own intentions (i.e. volitional instead of stimulus-driven actions). At the core of these theories is therefore the question of how abstract intentions can be transformed into concrete movements that realize these goals in the current circumstances (cf. Greenwald, 1970; Hommel et al., 2001; Prinz, 1997). This is not a trivial question. To achieve such a translation of intentions to action, the brain faces several difficulties (for a review, see Wolpert & Kawato, 1998). The body has a large number of joints, which can support a wide range of movement at many angles. Even simple acts like grasping require the use of multiple muscles, some not located in the arm or hand, to be coordinated for maintaining and control through the reach. People are typically not consciously aware of the specific muscles required to perform any given action, and have only limited access as to which joints to move in precisely what way. These problems are worsened by the fact that there are typically multiple ways for humans or animals to perform a movement in order to achieve the same goal (the “degree of freedom” problem, see Wolpert & Kawato, 1998, for a review). Thus, there is no simple match between a desired outcome and the motoric solution.

The question therefore is how does the brain achieve the fluent and effortless control of action, given the complexities involved? How does a fully formed competent action emerge out of intentions that people might not even be fully aware of?

Ideomotor models solve this problem by assuming that actions are not planned motorically, and that they therefore do not require the (explicit) control this large number of degrees of freedom. Rather, in ideomotor theories, movements are assumed to be controlled on the

perceptual level: by the outcome they are intended to achieve. Actions are coded in terms of the effects they are predicted to evoke: how the action will look, sound and feel if successfully carried out. James (1890) described it as follows: “our idea of raising our arm... or crooking our finger is a sense [...] of how the raised arm or the crooked finger feels” (James, 1890, p. 499). Or later in the same text: “there need be nothing else, and that in perfectly simple voluntary acts there is nothing else, in the mind but the kinesthetic idea, thus defined, of what the act is to be.” In other words, rather than having to specify all the motoric parameters required for successful actions, humans can simply imagine them. The task of translating these action images into a fully specified motor plan is out-sourced to automatic motor control processes that happen mostly outside of consciousness.

2.2. Learning Action Planning through Self-Observation

This then raises the question how the ability to control the motor system through the anticipation of action outcome arises? Ideomotor theories propose a simple association between motor commands and perceptual effects that arises through self-observation (Prinz, 1997; Hommel et al., 2001; Elsner & Hommel, 2001). When infants first produce their first motor commands, they have no knowledge yet about the outcomes these commands will produce. However, as soon as they make their first movements – randomly, due to the lack of knowledge what outcomes his motor commands will produce –, motor commands can be associated with their typical effects. The infant may learn, for example that a certain motor command brings about horizontal movements of the arm that others lead to the opening of its grip, and so on. Over time, the infant therefore learns to associate different perceptual effects

– the opening of a grip, the varying orientations of a hand, its possible positions in space – with the motor commands required to achieve these effects.

The key insight of ideomotor models of action is that as soon as such associations are acquired, movement comes under cognitive control (Elsner & Hommel, 2001). If outcome sensory effect and motor command are associated bi-directionally, not only does activating a motor command prime associated sensory effects, but, conversely, the activation of a sensory effect can activate the associated motor commands. Sensory action images can then be used – via these sensorimotor associations – for the control of actions. As a consequence, infants can now simply “think of” or imagine the perceptual effects to trigger the associated motor behaviors. Thus, thinking of the arm in a certain orientation, with a certain grip, in a specific position in space may trigger the associated motor commands, and, in turn, real movement that matches this goal specification.

The first study to provide evidence for this notion was conducted by Elsner and Hommel (2001). In a first block, participants pressed buttons as a response to a visual stimulus. Whenever such a response was made, and contingent on which button was pressed, different tones were played to the participants (i.e. high tone for left key, low tone for right key), leading to a co-occurrence of actions with sensory outcomes. In a subsequent test phase, participants were asked to press the same buttons again. However, now the tones that previously followed their actions, were now presented just before movement selection, acting as primes. The authors reported that participants’ responses were faster when the preceding tone had previously been the consequence of this action. This supports the notion that the perception of the tone activated the corresponding motor program, in line with the idea that sensory consequences of actions learned in the first block can serve as cues for action planning after learning.

2.3. Evidence for Ideomotor Theories Stimulus Response Compatibility

In ideomotor theories, movements are planned on a perceptual level, in terms of their directly perceivable consequences (their effects). This means that the codes use to describe one's own possible actions are, at least partially, the same as the codes describing actions of other people, or, the codes describing other, inanimate stimuli in the environment. For example, the same code that represents the orientation of a bar in front of you would also be used as possible goal state for the orientation of your own hand (cf. Prinz, 1997; Hommel et al., 2001; Bach, Griffiths, Weigelt, & Tipper, 2010).

One prediction of ideomotor theories is therefore that any activation of a sensory effect, either endogenously or exogenously, may trigger the corresponding action. (Shin, Proctor & Capaldi, 2010). William James (1890) defined this type of ideomotor behaviour as follows: "We may then lay it down for certain that every representation of a movement awakens in some degree the actual movement which is the object; and awakens it in a maximum degree whenever it is not kept from so doing by an antagonistic representation present simultaneously to the mind." Thus, whenever we see or even imagine things in the environment that are similar to such an effect image we could use to control our own movements might cause these movements to be triggered automatically, or at least primed, if they are not actively inhibited.

There is ample evidence for such an automatic translation of perceptual stimuli features into motor actions. These effects are typically investigated with stimulus response compatibility experiments. A classic example is the Simon task. Participants see stimuli appearing on the left and right side of the screen. However, the stimulus position is task irrelevant; they only have to attend to the stimulus color. Participants are instructed to press a left key, for example,

if the stimulus is blue, and a right hand key if the stimulus is red. The Simon effect refers to the robust finding that reaction time will be faster when response and stimulus are in a compatible (similar) location (Simon and Rudell, 1976; Simon and Small, 1969; for review, see Hommel, 2010). Thus, participants are faster in pressing a button with the left hand, if they see a stimulus that is also on the left. When participants respond with the right hand, they are faster when they see a stimulus that is also on the right side.

Another example comes from Kunde (2001). Subjects perform either soft or forceful presses on a touch – sensitive plate. Each key press produces either a quiet or loud tone, respectively. Consistent with ideomotor theory, in blocks of trials in which the to-be-produced tone effect always matched the to-be-produced manual key press in intensity (e.g., soft press resulting in a quiet tone), response times were faster than in blocks in which the intensity of the tone effect always did not match the response intensity. Similar effects have now been reported for various stimulus features, such as orientation (Craighero et al., 1999) or shape (Bach et al., 2010).

Compatibility tasks have also been used to study how seeing somebody else do an action affects own responses. Brass, Bekkering, Wohlschläger and Prinz (2000) studied the compatibility when participants saw either an index or a middle finger being lifted on the screen, and when participants had to make the same movements themselves. They revealed that participants reacted faster to compatible trials (same finger lifted as on the screen) than to incompatible trials (different finger). Similarly, Bach, Peatfield, and Tipper (2007) studied observation of actions that were performed with different body sites: feet (kicking a soccer ball) and fingers (typing on computer keyboard). It was found that participants were significantly faster and more accurate for responding with the foot when seeing the kicking action and finger responses were faster and more accurate when seeing the typing action.

In summary, there is considerable evidence for claim of ideomotor theories that movement imagery – representations of movements coded in perceptual terms – is a key step in action planning, before executing the actual performance. Due to the perceptual coding of the movement plans, actions can be activated by various forms of imagery, such as movement intentions, but also by external stimuli, such as the spatial properties of an object or the actions of other people. This can explain the various reported mimicry phenomena. For example, when persons watch their favourite basketball team they may feel that their arms move in correspondence during a throw (e.g., Knuf, Aschersleben, & Prinz, 2001; Chartrand & Bargh, 1999).

2.4. Evidence for Ideomotor Theories: Action Effect Binding

These common codes for perceptual and motor events cause a problem. The question is how, given these distributed codes for motor actions, they become unified into action plans, and distinguished from one another. Consider that all actions involve features of several different kinds, which might be coded in different brain systems. Effective throws for example, require actors to coordinate plans for ball trajectories, hand and arm movements, and even movements of the feet, in order to enable a stable stance. Even planning a simple grasp involves the anticipation of kinesthetic feedback from the arm and hand, visual feedback from the hand as it moves through the visual field, and even more temporally distant features, such as the texture of the goal object, once it is grasped. The question is therefore how these different features that are coded in different brain systems are unified and at the same time kept apart from the potentially similar features of the simultaneously perceived visual environment. This potential for confusion is increased because actions often strongly overlap in time and we often carry out more than one action at the same time, such as when talking on

the cell phone while driving. Finally, many tasks – such as catching a ball – require the coordination of perceptual input and motor output, further increasing the need to both distinguish and integrate various sensory codes, some coding actions, some stimuli in the environment.

The Theory of Event Coding (Hommel et al., 2001) differs from previous ideomotor accounts of action planning in that it recognizes this potential problem, and provides one solution. According to this theory, one function of action planning is to “bind” all the features belonging to one action into one concrete action plan that remains active until the action is executed. This binding is assumed to keep the current plan active and maintains its relevant details, but separates it from other plans, and other competing stimuli in the environment.

Indeed, there are now various studies that confirm that planning an action with certain features (e.g., a left or a right response, or the use of feet or hands) renders this code less available for other processes, causing inhibition (for a review, see Hommel, Müsseler, Aschersleben, & Prinz, 2001). For example, planning a specific movement (i.e. button press on the left side) makes it harder to execute responses that are similar to this response but serve another goal and are therefore part of another action plan, causing response time costs (Stoet & Hommel, 1999). Similarly, Müsseler & Hommel (1997) demonstrated that codes used in a planned action are not available to visual perception, rendering stimuli that are similar to the planned action less easy to see. When the planning stage is over and the action is actually executed, these effects disappear, linking the effects directly to action planning rather than motor execution (Wühr & Müsseler, 2001). Similar effects are known from the task-switching literature. If a participant’s goal stays the same between trials, they find it easier to repeat a movement that they had just executed. If, however, their action goal changed, different movements are easier to execute (e.g., Schuch & Koch, 2004). Again, for

these response-repetition costs to be observed, it was relevant that the prior movements were merely planned, not that they were physically executed (Hübner & Druey, 2006; Schuch & Koch, 2010).

2.5. An Ideomotor Account of Mental Practice

In summary, according to ideomotor theories, sensory features of actions are associated to motor commands that bring these features about, such that simply imagining an action – both visually and kinaesthetically – is enough to trigger the associated actions. Actions are therefore planned on a perceptual level. Action planning describes the cognitive activity of specifying the relevant sensory features of the intended action, and integrating or “binding” them into a unique action plan. This plan can then guide automatic motor processes that convert these motor images into physical action, without requiring any explicit further involvement (cf. Hommel, et al., 2001).

We believe that such a model of action planning provides a promising framework for conceptualizing mental practice. In its most simple form, mental practice – motor/kinaesthetic imagery with the goal of improving subsequent performance – can be seen as the creation of the action plans itself, without releasing the associated motor movements. In other words, in such views, mental practice would be identical with the processes of action planning: the formation of concrete motor plans that contain all the necessary sensory features for successful performance of the action. These action plans can then be retrieved and executed in the actual performance situation.

Such a view would fit well with several observations about mental practice. First, for example, as noted, mental practice is not always decoupled in time from the performance

situation. In many cases, athletes play through their performance in their mind, immediately before initiating it. This type of “pre-performance imagery” (Morris et al., 2005) is very much identical with how action planning is typically understood, especially in ideomotor models, which conceive as action planning as primarily perceptual or imagery-related mental activity, similar to how mental practice is typically described.

Second, while mental practice has direct benefits on motor execution (Wohldmann et al., 2007; 2008) it is known that mental practice is most effective when it is applied to tasks with a strong cognitive component. If mental practice is conceptualized in terms of planning (rather than execution) processes, such a finding is plausible. Action planning similarly can be seen to be located at the intersection of cognitive and motor processes. It can be understood as the processes that transform relatively abstract intentional states into, potentially very complex, motor plans that realize these goals. It should therefore be particularly helpful where the plans are complex, and require the coordination of motor programs across different stages, consistent with meta analyses that have revealed the strongest impacts of mental practice on such tasks (e.g., Feltz & Landers, 1983).

Third and finally, such views that conceptualize mental practice in terms of action planning provide a better fit with the neurophysiological data than current models that primarily rely on execution (rather than planning related) motor processes. As noted, while some studies indeed reveal an engagement of primary motor cortices during mental practice (associated with the engagement of motor execution related processes), the more robust finding concerns an engagement of premotor areas (associated with action planning) (e.g., Dechent, Merbold, Frahm, 2004; Macuga & Frey, 2012; for a review, see Lotze & Halsband, 2006). Moreover, the emerging dissociations between motor imagery and motor execution (e.g., Hanakawa, Dimyan,

& Hallett, 2008; Reed, 2002) are consistent with such views, specifically with an overlap of planning related processes during motor imagery.

The experiments in the following sections are designed to provide a first behavioral test of whether mental practice is indeed best understood (a) in terms of execution related processes that are reactivated during imagery (e.g., Jeannerod & Frak, 1999), or whether (b) action planning related actions provide the better description.

Chapter 3

Developing a Compatibility Task

3.1. Developing a Compatibility Task to Investigate Motor Involvement in Mental Practice

The aim of Experiments 1 to 4 is to develop a robust behavioural paradigm that allows us to directly investigate the potential motor mechanisms underlying mental practice. Two main goals guide the present investigation. The first goal is to test whether mental practice generally engages general processes that are also involved in the actual planning and execution of the motor skill, as suggested by prior studies on motor imagery. Importantly, this should be demonstrated in a task that has sufficient motor complexity to benefit from mental practice, but in which participants are neither instructed nor trained to use 1st person kinaesthetic motor imagery, which is known to by itself produce a bias towards motor involvement but which is not naturally used by participants. The second goal is to resolve the functional role of this motor activation. Is it facilitatory or inhibitory? Does it reflect the simulated execution of the action, or is it better conceptualized in terms of action planning and action effect binding?

To develop such a paradigm, we adapted the well-established stimulus-response compatibility (SRC) tasks. These tasks are typically used to investigate how overt, visual stimuli affect motor output. For example, the classic Simon task tests whether seeing a stimulus on the left or right side primes responses with the left or right side, respectively (Simon and Rudell, 1976; Simon and Small, 1969; for a recent review, see Hommel, 2010). It is typically found that participants are faster when side of the response and of the stimulus are the same. Similar effects have now been observed for various stimulus and response classes, such as hand/object orientation, object/grip size, and object shape/hand trajectory (Bach, Griffiths, & Tipper, 2010; Tucker & Ellis, 1998; 2001).

SRC tasks have also been used to study how action observation automatically affects motor output. In a seminal study, Brass, Bekkering, Wohlschläger and Prinz (2000) studied how responding with middle and index fingers is affected by the simultaneous observation of index or middle movements (see also, Bertenthal, Longo & Kosobud, 2006). Again, participants responded more quickly when their own response mirrored the action they saw. Similar data come from a study by Bach, Peatfield, and Tipper (2007), which showed that such effects can be observed on a more general level, relating to the body parts – hands and feet – used in action and perception, irrespective of whether these body parts are used to carry out the same actions as the observed person (see also Gillmeister et al., 2008).

The present experiments adapt the general SRC paradigm to study how actions that are merely mentally practiced – in order to train them for later performance – affect one's own motor output. The general design of the experiments was as follows. Participants were presented with symbolic descriptions of complex rhythms (ABABB...). They were instructed to mentally practice these rhythms, in order to fluently produce them afterwards with either their hands or their feet. While they practiced the rhythms, one of two sounds was played to participants, prompting them to either make a simple key-press with either their hands or their feet. These key-presses are unrelated to the main task of mentally practicing the rhythms, but involve either the same or different body parts as those used for mentally practicing the rhythm. They therefore allow us to probe whether mental practice engages the foot- and hand-specific motor pathways that would also be utilized during physical execution. If this is the case, then the efficiency of these unrelated hand or foot responses should depend on whether participants are using the same or a different body part for mentally practicing the rhythms.

Such an effect can take one of two forms. First, as is the case for many prior studies investigating perception-behavior links (e.g., Bach et al., 2006; Brass et al., 2000; Simon & Rudell, 1976), using a body part for mental practice might *facilitate* responding with this body part to the sounds. Such a finding would support the idea that mental practice engages processes similar to the actual execution of the rhythms. In particular, it would support the idea that mental practice involves a subtle activation of the motor programs or the muscles used in the trained action, which predisposes participants for responses with these body parts (cf. Jacobsen, 1930; James, 1890; Jeannerod & Frak, 1999).

Second, however, mental practice with a body part could also *impair* the usage of the body part for other responses. Such an outcome might appear particularly likely if one assumes that mental practice relies on the processes involved in action planning rather than motor execution. As described in the previous chapter, planning an action involves specifying how the action would look and feel if it were successful. Actors may specify, for example, the body part to be used, or the speed, direction and the trajectory of the intended movement, as well as its tactile consequences. There is now evidence from various fields that the selection of those action features has direct behavioural consequences. The data indicates that the codes for those features become ‘bound’ to the action plan until it is executed, and are, in the meantime, less available to other processes, perhaps to shield the action them from interference (for a review, see Hommel, Müsseler, Aschersleben, & Prinz, 2001). It has been found, for example, that merely planning a specific movement (i.e. planning to make button press on the left side) makes it harder to execute responses – and even to perceive stimuli – that have the same features as this planned response (e.g., detecting stimuli on the left or using other body parts on the left side; Müsseler & Hommel, 1997; Stoet & Hommel, 1999). Importantly, these effects are planning and not execution-related: they are found as long as an action is planned, but disappear after it is physically executed (Wühr & Müsseler, 2001).

If mental practice is based on these action planning processes, then a similar linkage of responses to action plans should be found in the present experiments. Such an account therefore predicts negative – rather than positive – compatibility effects: mentally practicing a rhythm with the hand should impair one's use of the hands when responding to the sounds, and mentally practicing with the foot should impair responses with the foot.

3.1.1 Experiment 1 – Developing a Basic Paradigm

Experiment 1 provides a first behavioural test of whether mental practice of a motor skill relies on the same mechanisms as the actual execution of the skill. Participants were presented with different complex rhythms that they had to mentally practice (while keeping completely still) so that they could perform these rhythms later from memory, using either their hands or feet. Within the mental practice interval, we played different sounds that participants had to respond to with speeded hand and foot responses. We investigated whether participants' ability to make these hand and foot responses was affected by whether these body parts were used for mentally practicing the rhythms.

As noted, such an effect can take one of two forms. If mental practice involves a subliminal activation of motor commands or muscles used in the actual action, then positive compatibility effects should be observed: responses with the body parts that are used for mental practice should be easier than responses with a different body part. In contrast, if mental practice involves a binding of motor codes to action plans, then resource competition should occur: responses with the body part used in mental practice should be harder to make than responses with the other body part.

3.1.2 Method

Participants. Twenty students (five male, age range: 18-27) took part in the experiment. They gave informed consent approved by the School of Psychology Ethics Committee at Plymouth University. Participants were paid either at a rate of £6/hour or they received course credits. They satisfied all requirements in volunteer screening: all participants were in good health, had no history of disease or medical treatment that might influence motor or visuomotor functions. In this and all following experiments, participants were excluded from the analysis when they produced invalid rhythms in the execution interval (rhythms 50% longer/shorter than the required rhythm length) or invalid responses to the tones (responses were made before the tones were played, or responses for which the press of only one or no response key was detected) in more than 20% of the trials. Of the 20 participants tested, this was the case for four participants.

Materials and apparatus. The experiment was controlled by the experimental control software Presentation (www.neurobs.com), running on a 2.0 GHz PC running Windows XP. Foot responses were recorded with two foot pedals (33 cm apart), which were attached to the floor with black tape, and connected to the computer via the parallel port. Hand response keys were the Ctrl-key (operated by participants' left hand) and the Enter key on the number block (operated by the right hand). Sounds were played via an external loudspeaker system.

Twenty different rhythms were created for the experiment. Ten of these rhythms were to be played with the left and right hands and ten rhythms (mirror images of the first 10 rhythms) were to be played with the left and right feet. All rhythms were presented in a symbolic format consisting of 16 lines, each line corresponding to the click of an imagined metronome. The beats that participants had to produce were represented by As on the left and Bs on the

right side of each line. As on the left side represented button presses or foot pedal presses on the left hand side, while Bs on the right side represented presses with the right foot or right key (see Appendix A for a list of the rhythms). A line containing both an A and a B designated cases in which both feet or both hands should be pressed. To the left and the right of each rhythm, a symbol depicting either a hand or a foot was shown, reminding participants of the body part with which this rhythm would have to be played.

Two sounds were used as cues for the participants' responses in the memorization/mental practice interval: a high sound (sine wave of 1331 Hz) or a low sound (sine wave of 223 Hz). Both sounds lasted 100 ms. and were faded in and out at the start and end.

Procedure and design. The participants were seated in a dimly lit room, facing a computer at a distance of approximately 60 cm. The experiment contained three training sessions that lasted about 20 minutes altogether, each consisting of eight trials. The experiment proper took about 36 minutes, resulting in a total experiment time of roughly 55 minutes. The participants were tested individually and instructed by the software and the experimenter.

The first training session introduced the participants to the (difficult) task of tapping the rhythms. In each of the eight trials, participants were first presented with a cue telling them which effectors (hands or feet) they had to use to produce a rhythm. This cue remained on the screen for 2000 ms and read "Produce the following rhythm with the hands/feet!" After a short blank (300 ms), the rhythm was shown on the monitor (see Figure 1, middle frame, for an example). Pictures to its left and right reminded participants of the body part they had to use to produce it. Participants then produced this rhythm while it was on the screen. They had 11200 ms to tap the rhythm.

The second training session introduced participants to the mental training component of the task. In each trial, participants were again first presented (for 2000 ms) with a cue specifying the body parts (hands or feet) they should use to mentally train the following rhythm (Figure 3.1, left panel). After a short blank (300 ms), they were then shown one of the 20 rhythms that they had to mentally practice for 10200 ms, while not making any overt movement (Figure 3.1, middle panel). The rhythm description remained on the screen in this interval. After another blank (800 ms), a cue saying “Now produce the rhythm!” appeared. Participants now played the rhythm from memory with the body part that was previously instructed. They were reminded of this body part with small pictures appearing on the screen (see Figure 3.1, right panel), but the rhythm itself was not presented again, requiring performance from memory. They had 9200 ms. to tap the rhythm.

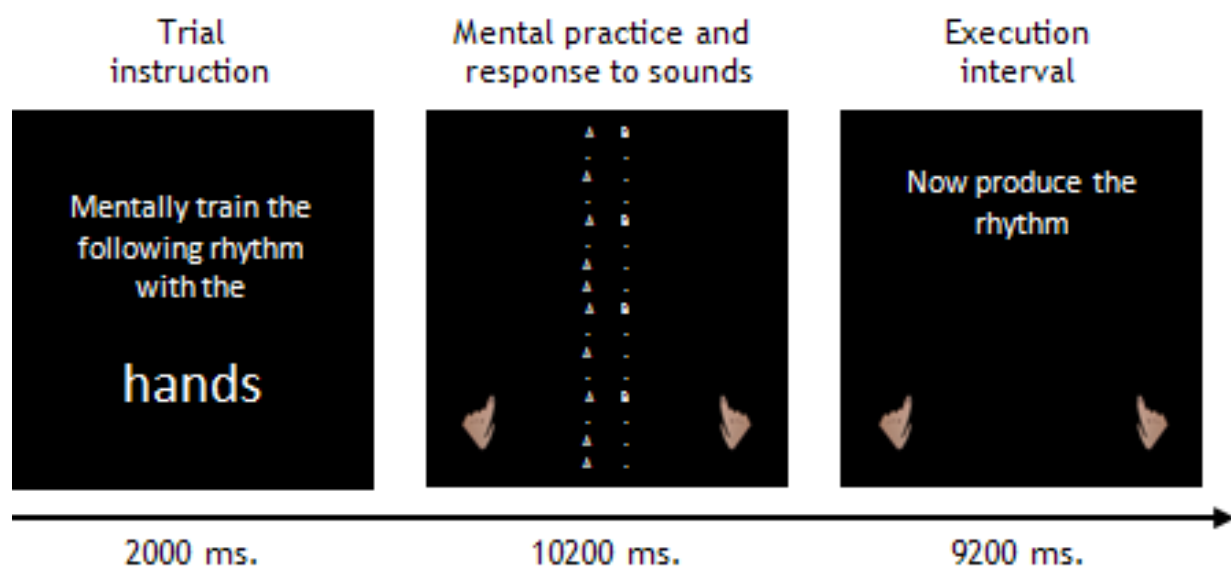


Figure 3.1 Illustration of the trial sequence in Experiment 1. The trial instruction (left panel) informed participants about the body part they had to mentally practice the rhythm with. In the mental practice interval (middle panel), participants were instructed to keep completely still while they mentally trained the rhythm. In this interval, they responded with hands or feet to sounds played after 5000, 5500, 6000, or 6500 ms after the start of this interval. In the execution interval (right panel) they executed the rhythm from memory.

The third training session introduced participants to the secondary task (responding to the sounds) and was identical to the actual experiment (see Figure 1 for a schematic). The trials in the third training session were identical to the second training session, with the exception that low and high tones were played after 5000, 5500, 6000 or 6500 ms from the start of the mental practice interval. The participants' task was to press both foot pedals as quickly as possible when hearing the low tone, and both hand keys when hearing the high tone. As before, at the end of the mental practice interval the rhythm disappeared and the cue that prompted participants to perform the rhythms appeared. As before, the rhythm itself was not presented again, requiring performance from memory.

The trials in the actual experiment were identical to the third training session. There were 80 trials altogether, separated by short breaks every 20 trials. All rhythms were shown once per block. There were equal numbers of trials in which the rhythms had to be played with the hands or the feet, and equal numbers for responding to the sounds with hands or feet. Trials were presented in a random order for each participant.

Analysis. The analysis aimed to assess whether mentally practicing with a body part affected participants' ability to use these body parts to respond to the sounds played in the mental practice interval. Error rates were calculated for each participant and condition by dividing the number of incorrect responses (participants using a wrong body part to respond to the beep) by the total number of trials. Trials were excluded if participants responded too early (i.e. before the imperative tone stimulus), or if the press of both response devices was not detected (4.8% in total). Mean response times (RTs) were calculated as the average RT of the left and right response keys, excluding trials for which the RT fell outside of three standard deviations of each participant's mean RT with the respective body part (0.8%).

3.1.3 Results

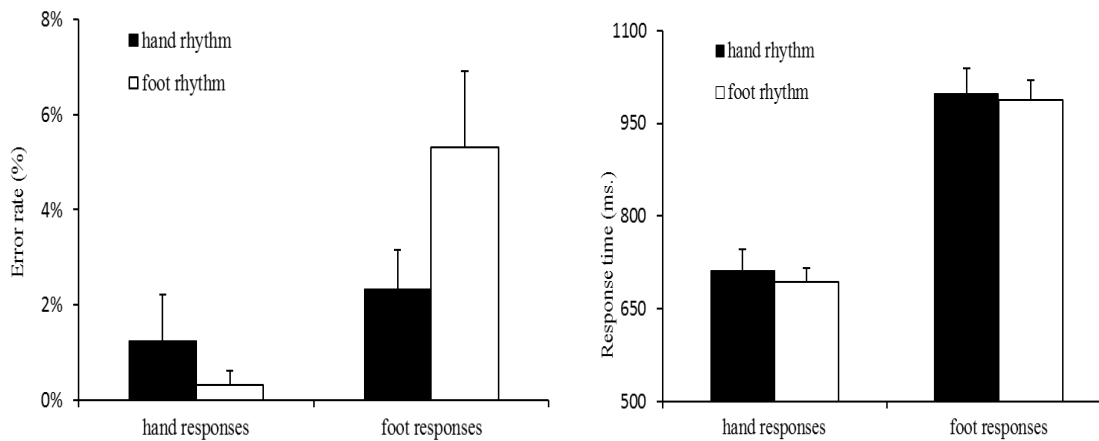


Figure 3.2 Error rates (left panel) and Response times (right panel) in Experiment 1. In each panel, the two left bars show the data for responses with the hand and the two right bars show responses with the feet. The black bars show responses while hand rhythms were mentally practiced and the white bars show responses while foot rhythms were practiced. Error bars show the standard error of the mean.

The data were analysed separately for Error Rates and RTs with repeated measures 2 x 2 ANOVA, with the factors Response Effector (foot, hand) and Imagery Effector (foot, hand). The analysis of error rates revealed no main effect of Imagery Effector, $F(1,15) = 0.93$, $p = .352$, $\eta^2_p = .06$, but a significant main effect of Response Effector, $F(1,15) = 7.07$, $p = .018$, $\eta^2_p = .32$, reflecting that participants made fewer errors when responding with the hand than with the foot. Importantly, the predicted interaction of Imagery Effector and Response Effector was significant, $F(1,15) = 4.56$, $p = .045$, $\eta^2_p = .23$, taking the form of a negative compatibility effect. Participants made more errors when responding with a body part already used for mental practice than when using a different body part.

The analysis of the RTs similarly revealed a significant main effect of Response Effector, $F(1,15) = 172.89, p < .001, \eta^2_p = .92$, with faster responses with the hand than with the foot. There was no significant main effect of Imagery Effector, $F(1,15) = 0.85, p = .370, \eta^2_p = .05$, and, in contrast to the error analysis, no interaction, $F(1,15) = 0.452, p = .511, \eta^2_p = .03$. Importantly, there was no evidence for a speed accuracy trade-off. Numerically, responses were slightly faster when different body parts were used for response and mental practice. Moreover, when correlating the size of the compatibility effects in RTs and error rates, only a (non-significant) positive correlation emerged ($r = .10$), suggesting that, if anything, those participants with negative compatibility effects in the error rates also tended to show negative effects in the RTs.

3.1.4 Discussion

Experiment 1 investigated how mental practice of hand and foot actions affects the concurrent production of unrelated responses with feet or hands. The data revealed a negative compatibility effect: participants made more errors when responding with the same body parts as those used for mental practice, compared to using different body parts. In other words, foot responses were more accurate than hand responses when participants were mentally practicing a rhythm with the hand, while the reverse was true when mentally practicing a rhythm with the foot.

This negative compatibility effect was found even though the rhythms were presented symbolically, and the task could in principle be equally solved by memorizing the sequence of button presses in an abstract, effector-independent manner. These data therefore provide the first behavioural evidence that mental practice of rhythms engages processes that are also involved in the execution of action. More specifically, the data suggest some form of resource competition, such that body parts involved in mental practice are less available for other, unrelated responses. This finding is consistent with the idea that mental practice engages action planning-related processes, which involve a binding of action features to motor plans, such that these responses are less available for other, unrelated actions (Hommel et al., 2001).

One limitation of the present experiment is that the task required participants to mentally practice in order to memorize a sequence of movements. This situation does not conform to everyday mental practice, which typically involves the improvement of an already learned sequence of movements rather than its memorization from the ground up. Indeed, the requirement to memorize the rhythms might have interfered with typical mental practice

processes, giving rise to the negative compatibility effect. Experiment 2 was conducted to replicate the original findings in a simpler task, which does not require memorization.

3.2.1 Experiment 2 – Development a New Task that does not require Memorization

The procedure of Experiment 1 differed from typical mental practice in that, in Experiment 1, mental practice had be used to completely memorize the sequence of foot or hand button presses. This requirement ensured that participants mentally practiced the rhythms, as without mental practice, only random performance would have been possible (recall that the rhythms had to be re-produced without retrieval cues). However, typically, mental practice is used to merely improve performance of an already present motor skill. Ideally, the involvement of body part specific motor planning is demonstrated in a setting that captures this typical use of mental practice. The goal of Experiment 2 was to establish that our task can be used in such a setting. We therefore attempted to first test in a validation study, before again employing a compatibility paradigm, that our mental practice task leads to tangible performance improvements, when participants are later asked to reproduce the mentally practiced rhythms as quickly and accurately as possible (compared to a rhythm that was not practiced beforehand).

As in Experiment 1, every trial began with a presentation of a complex rhythm that participants had to mentally practice with their hands or feet (while keeping completely still). In the second half of each trial, they were then given either the same or a different rhythm description, and they were required to produce this rhythm as quickly and accurately as possible. This task therefore removes the responses to the unrelated sounds, and provides a pure measure whether our task induces mental practice of the rhythm that is specific enough

to lead to performance improvements. If this is the case, then participants achieve better performance (i.e. faster and/or more accurate) for rhythms that had just been mentally practiced, compared to rhythms that have not. Prior research (e.g., Wohldmann, Healy & Bourne, 2008) has established in a similar task that required speeded typing of digit sequences that mental practice affects not only planning measures of performance (response initiation time), but also the execution itself (time to type the sequence). If our task captures the same mechanisms, similar effects on both initiation time and playing time are expected.

3.2.2 Method

Participants. Thirteen students (three male, age range: 18-25) took part in the experiment. They satisfied all requirements in volunteer screening and gave informed consent approved by the School of Psychology Ethics Committee at Plymouth University. Participants were paid either at a rate of £6/hour or they received course credits. All participants were in good health, had no history of disease or medical treatment that might influence visuomotor functions. As in the main experiments, participants were excluded when they produced invalid rhythms in the execution interval (rhythms 50% longer/shorter than the required rhythm length) in more than 20% of the trials. This was the case for two participants.

Materials and apparatus. The experiment was controlled by the experimental control software Presentation (www.neurobs.com), running on a 2.0 GHz PC running Windows XP. Foot responses were recorded with two foot pedals (33 cm apart), which were attached to the floor with black tape, and connected to the computer via the parallel port. Hand response keys were the Ctrl-key (operated by participants' left hand) and the Enter key on the number block (operated by the right hand).

Twenty different rhythms were created for the experiment. Ten of these rhythms were to be played with the left and right hands and ten rhythms (mirror images of the first 10 rhythms) were to be played with the left and right feet. All rhythms were presented in a symbolic format consisting of 16 lines, each line corresponding to the click of an imagined metronome. The taps that participants had to produce were represented by As on the left and Bs on the right side of each line (see Appendix B). As on the left side represented button presses or foot pedal presses on the left side, while Bs on the right side represented presses with the right foot or right key. A line containing both an A and a B designated taps with both feet or both hands. To the left and the right of each rhythm, a symbol depicting either a hand or a foot was shown, reminding participants of the body part with which this rhythm would have to be mentally practiced and subsequently played.

Procedure and design. The participants were seated in a dimly lit room, facing a computer at a distance of approximately 60 cm. The experiment contained two training sessions that lasted about 10 minutes altogether, each consisting of eight trials. The experiment proper took about 36 minutes, resulting in a total experiment time of roughly 55 minutes. The participants were tested individually and instructed by the software and the experimenter.

The first and second training sessions were identical to those of Experiment 1. The first training session introduced the participants to the (difficult) task of tapping the rhythms (see Appendix B for instructions). In each of the eight trials, participants were first presented with a cue telling them which effectors (hands or feet) they had to use to produce a rhythm. This cue remained on the screen for 2000 ms and read “Produce the following rhythm with the hands/feet!” After a short blank (300 ms), the rhythm was shown on the monitor (see Figure 1, middle frame). Pictures to its left and right reminded participants of the body part to be used. Participants then produced this rhythm while it was on the screen (maximum 11200 ms).

The second training session introduced participants to the mental training component of the task (see Appendix B for instructions). In each trial, participants were again first presented (for 2000 ms) with a cue specifying the body parts (hands or feet) they should use to mentally train the following rhythm. After a short blank (300 ms), they were then shown one of the 20 rhythms that they had to mentally practice for 10200 ms, while not making any overt movement. The rhythm description remained on the screen in this interval. After another blank (800 ms), a cue saying “Now produce the rhythm!” appeared, together with a description of either the same or a different rhythm than the one they had just practiced. Participants now played the rhythm as quickly and accurate as possible with the body part they had used for mental practice. They were reminded of this body part with small pictures appearing on the screen. They had 9200 ms. to tap the rhythm.

The trials in the actual experiment were identical to the second training session. There were 80 trials altogether, separated by short breaks every 20 trials. All rhythms were shown once per block. There were equal numbers of trials in which the rhythms had to be played with the hands or the feet. Trials were presented in a random order for each participant.

Analysis. We assessed the influence of mental practice on how well participants played the rhythms afterwards, in terms of three variables. The first variable, *initiation time*, measured the time it took participants to initiate the tapping in the execution interval. For each participant and each trial, we subtracted the time of the first button press from the start of the execution interval. Initiation time therefore mostly measures impact on the planning processes that take place during rhythm execution (cf. Wohldman, et al., 2007; 2008). The second variable, *play time*, measured the speed with which participants produced the rhythms. For each rhythm played by a participant, we subtracted the time of the first button press in the execution interval from the last button press. Play time is typically seen to capture primarily

execution related processes (cf. Wohldman, et al., 2007; 2008). The third variable, *deviance*, measured the accuracy of participants' performance. This was computed as the average of two sub-measures. First, we measured the difference between the number of beats that the participants produced and the number of beats that were required for this particular rhythm, as a percentage of the total rhythm length. Second, we assessed whether the participants' relative frequency of presses with the left and right buttons corresponded to the relative frequency of left and right presses required by the rhythm, again as a percentage of total rhythm length. For these analyses, trials in which the button presses of the participants deviated by 50% or more from the required button presses were excluded, as well as trials in which participants took longer than 12 seconds to play the rhythm, or in which there was a pause between two button presses longer than 2 seconds.

3.2.3 Results

Participants' performance on each of the three measures – initiation time, play time, and deviance – was compared with paired, two-sided t-tests between trained and untrained rhythms. This revealed significant improvements for trained rhythms with regard to initiation time, $t = 4.99$; $p = .001$, playing time, $t = 2.95$; $p = .015$, but not deviance, $t < 1$. The effect in play time and initiation time were negatively related ($r = -.37$, n.s.), suggesting that participants can compensate performance deficits with longer planning. Table 3.1 shows the performance for each measure.

	Trained rhythms		Untrained rhythms	
	mean	SD	mean	SD
Initiation time	756	125	838	137
Play time	2953	409	3047	379
Deviance	6.2%	3.2	5.8%	3.1

Table 3.1 Initiation Time, Play Time, and Deviance for trained and untrained rhythms.

3.2.3 Discussion

Experiment 2 verified that our task induced mental practice that was effective and specific enough to affect subsequent rhythm performance. The same rhythms and the same instructions for maximizing performance were given (but without the need to respond to the sounds), and we measured if participants were better able to tap a rhythm they had previously trained, compared to a different rhythm. We found that both time to initiate the rhythm (time from presentation of the rhythm to the first finger press) and playing time (time from first to last finger press) decreased for trained relative to untrained rhythms. This study therefore confirms, first, that the instruction to maximize performance is effective in inducing mental practice. Moreover, it shows that mental practice in our tasks does not only affect planning related measures, but also those related to motor execution, replicating prior findings (Wohldmann, et al., 2007; 2008).

3.3.1 Experiment 3 – Investigating Mental Practice with the New Task without Memorization.

Experiment 2 has demonstrated that mental practice of the rhythms does lead to tangible performance improvements, even when a symbolic description of the rhythms is given also in the mental practice interval, such that participants did not have to reproduce the rhythms from memory but merely tried to execute them as fluently as possible. Experiment 3 tests if the same negative compatibility effects as in Experiment 1 are observed, when the memory component is removed from the task.

Experiment therefore simplified the procedure by (a) replacing some of the more difficult rhythms with ones that were easier to tap, and (b) by showing participants the symbolic rhythm description also in the production interval, obviating the need for memorization, as it was the case in Experiment 2. To still encourage mental practice prior to execution, we used the same instruction as in Experiment 2. Participants were instructed that they were required to produce the rhythm as quickly and as accurately as possible in the execution interval, and that they should use the opportunity for mental practice interval to maximize their performance. Again, while participants practiced the rhythms, one of two sounds was played to them that they had to respond to with either their hands or their feet.

The predictions were as before. If mental practice relies on the same mechanisms as actual action execution, then participants' ability to respond with hand and feet should be determined by whether they are mentally practicing a movement with hands or feet. Moreover, a negative compatibility effect should be found if utilizing a body part for mental practice leads to resource competition, making this body part less available for unrelated responses.

3.3.2 Method

Participants. Twenty-three volunteers (8 male, age range: 18-24) took part in the experiment. They were paid £8/hour for their participation. All other aspects of participant selection/exclusion were identical to Experiment 1. Five participants did not meet the inclusion criterion of fewer than 20% of trials with invalid responses/rhythms and were excluded from the analysis.

Materials, apparatus and procedure. Materials and apparatus were identical to Experiment 1, with the following exceptions. First, the more difficult rhythms were exchanged with simpler rhythms. Second, participants now saw a symbolic description of the rhythm that they had to produce also in the production interval, not only during mental practice. Thus, they did not have to memorize the rhythm in the mental practice interval to be able to play it later. Third, to ensure that participants were still mentally practicing the rhythms even in this more relaxed setup, the instructions to participants now emphasized that the rhythms had to be performed as quickly and accurately as possible, and that they should use the mental practice intervals to achieve the best possible performance (see Appendix C for instructions).

Analysis. 2.9% of trials were excluded because they contained “too early” responses or because the press of both response devices was not detected. For the analysis of RTs, error trials (2.1%) as well as trials with RTs that fell outside three standard deviations of the mean RT for responses with this body part (0.2%) were additionally excluded.

3.3.3 Results

Responses to the sounds. As before, RTs and Error Rates were analysed with separate 2 x 2 ANOVAs. The analysis of the error rates (Figure 3.3, left panel) revealed neither a main effect of Imagery Effector, $F(1,17) = 1.35$, $p = .262$, $\eta^2_p = .07$, nor of Response Effector, $F(1,17) = 2.19$, $p = .157$, $\eta^2_p = .11$. However, as before, the interaction of Imagery Effector and Response Effector was significant, $F(1,17) = 7.37$, $p = .015$, $\eta^2_p = .30$. Replicating Experiment 1, this interaction took the form of a negative compatibility effect, with participants making more errors when responding with the body part used for mental practice compared to a different body part.

The analysis of the RTs (Figure 3.3, right panel) revealed a main effect of Response Effector, $F(1, 17) = 87.7$, $p < .001$, $\eta^2_p = .84$, and an effect of Imagery Effector, $F(1, 17) = 10.9$, $p = .004$, $\eta^2_p = .39$. Participants responded more quickly when mentally practicing with the hand, and when responding with the hand. However, as before, the interaction was not significant, $F(1, 17) = .71$, $p = .411$, $\eta^2_p = .04$. The size of the compatibility effects in RTs and error rates were, if anything, positively correlated ($r = .10$, n.s.), providing no evidence of a speed accuracy trade-off.

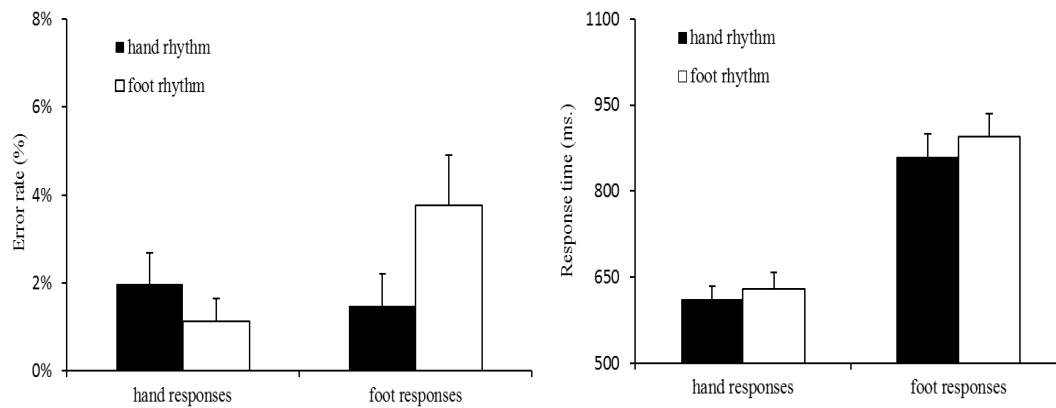


Figure 3.3 Error rates (left panel) and Response times (right panel) in Experiment 3. In each panel, the two left bars show the data for responses with the hand and the two right bars show responses with the feet. The black bars show responses while hand rhythms were mentally practiced and the white bars show responses while foot rhythms were practiced. Error bars show the standard error of the mean.

3.3.4 Discussion

Experiment 3 replicated the results of Experiment 1 in a simpler task that did not rely on memorization of the rhythms. Here, as in everyday usage, mental practice served the *improvement* of subsequent motor performance. Despite these changes to the experimental paradigm, the results of Experiment 1 were completely replicated. Participants again made more errors when responding to the sound with a body part that was already used for mentally practicing the rhythms. This replication of the negative compatibility effect of Experiment 1 therefore indicates that this negative compatibility effect is not due to the requirement to memorize the abstract rhythms. Rather, it appears to be a general consequence of mental practice, suggesting that a body part engaged in mental practice is less available for other, unrelated responses.

3.4.1 Experiment 4 – Do the Effects hold when Mental Practice and Execution are separated by another Task?

One limitation of the previous experiments was that mental practice was immediately followed by the execution of the rhythms. This type of ‘pre-performance imagery’ (Morris, Spittle, & Watt, 2005) is often used in sports, before athletes engage in a difficult performance, and can be understood as an explicit and strategic form of movement preparation (e.g., Jeannerod, 1995, 1994; Lotze & Halsband, 2006). However, it raises the question whether the negative compatibility effect truly emerges from mental practice. An alternative is that the effect emerges because participants already anticipate using the body part for the motor actions – the tapping of the rhythm – they will be making in a few seconds. In other words, the negative compatibility effects might not arise from the usage of the body part in mental practice, but the anticipation of an imminent motor response with this body part.

Experiment 4 therefore tests whether the same results will be found when mental practice and execution do not follow one another immediately. Participants did not produce the rhythms immediately after practicing them. Rather, they now mentally practiced two rhythms, one after the other, before they executed both of them (in the same order in which they practiced them). Thus, Experiment 4 separates the mental practice of a rhythm and its execution by a different task (either the mental practice of another rhythm, or the actual execution of another rhythm). If the same effects are found as before, this would show that the effects do not reflect the anticipation of an imminent motor response with this body part, but are related to mental practice. In addition, it would extend our data to another type of mental practice that involves a larger interval between practice and execution in which various other behaviours take place.

3.4.2 Method

Participants. Twenty-two volunteers (9 male, age range: 19- 40) took part in the experiment. All other aspects of the participant selection were identical to Experiment 1 and 2. Five participants did not meet the inclusion criterion of fewer than 20% of trials with invalid responses/rhythms.

Materials and apparatus. Materials and apparatus were identical to Experiment 2.

Procedure and Design. Experiment 3 differed to the previous experiment in that only 40 (instead of 80) experimental trials were presented. However, these trials now consisted of four (instead of 2) phases: mental training of the first rhythm, mental training of the second rhythm, execution of the first rhythm, and execution of the second rhythm. Both rhythms had to be executed with the same body part (see Appendix D for instructions). The timing and presentation order in the different phases corresponded to the mental practice and execution phases of the previous experiments. Again, a low or high sound was played 5000, 5500, 6000 or 6500 ms after the start of either the first or the second mental practice interval and participants responded to these sounds by either pressing both feet or both hand response keys. In the two execution intervals, participants again saw the description of the two rhythms and produced them as quickly as possible (both rhythms with the same body parts).

Analysis. 5.1% of trials were excluded because they contained “too early” responses or because the press of both response devices was not detected. For the analysis of RTs, error trials (2.1%) as well as trials with RTs that fell outside three standard deviations of the mean RT for responses with this body part (1.2%) were additionally excluded.

3.4.3 Results

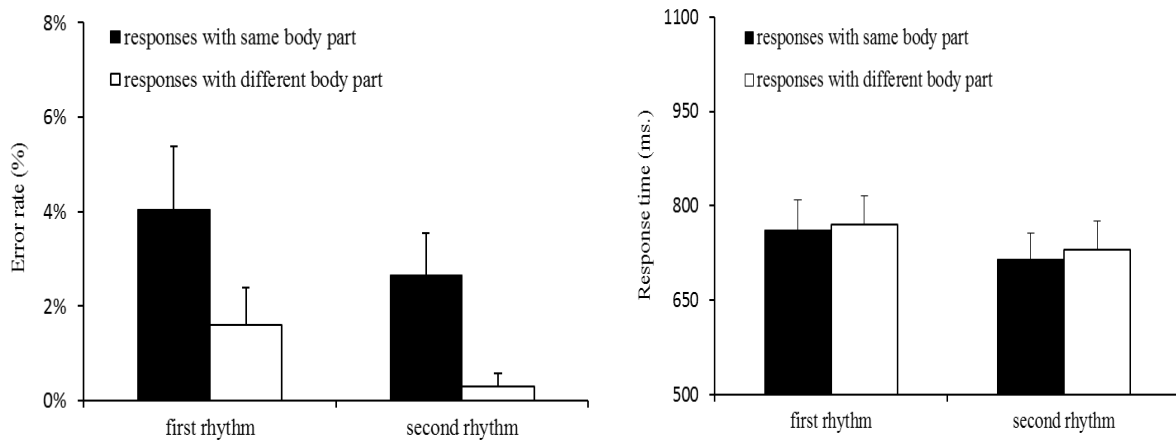


Figure 4.3 Error rates (left panel) and Response times (right panel) in Experiment 4. In each panel, the two left bars show the responses during mental practice of the first rhythm, and the bars on the right show responses during mental practice of the second rhythm. The black bars show responses with the same body part that is used for mental practice while the white bars show responses with the different body part. Error bars show the standard error of the mean.

The data were analysed with repeated measures 2 x 2 x 2 ANOVA, with the factors Response Effector (foot, hand), Imagery Effector (foot, hand), and Rhythm (first rhythm, second rhythm). The analysis of error rates (Figure 3.4, left panel) revealed neither a main effect of Imagery Effector, $F(1, 16) = 1.75, p = .204, \eta^2_p = .10$, Response Effector, $F(1, 16) = .80, p = .38, \eta^2_p = .05$, or Rhythm, $F(1, 16) = 3.77, p = .07, \eta^2_p = .19$. However, as before, there was a significant interaction of Imagery Effector and Response Effector, $F(1, 16) = 7.61, p = .014, \eta^2_p = .32$, again taking the form of a negative compatibility effect. No other effect was significant (all $F < 1$). Most importantly, there was no evidence for a three way interaction of Response Effector, Imagery Effector and Rhythm, $F(1, 19) = 0.003$. Indeed, planned comparisons confirmed that the interaction of Response Effector and Rhythm was present for both the mental practice of both the first $F(1,16) = 3.71, p = .072, \eta^2_p = .19$, and the second rhythm, $F(1,16) = 6.97, p = .018, \eta^2_p = .30$.

Again, the analysis of RTs (Figure 3.4, right panel) only revealed a main effect of Response Effector, $F(1, 17) = 19.4, p < .001, \eta^2_p = .55$, and of Rhythm, $F(1, 17) = 14.0, p = .002, \eta^2_p = .47$. No other main effect or interaction was significant (all $F < 1.5$). In particular, as in the previous experiments, the analysis of the RTs did not reveal an interaction of Imagery Effector and Response Effector, $F(1,17) = 0.49, p = .494, \eta^2_p = .03$. Moreover, the size of the compatibility effects in RTs and Error Rates were positively correlated ($r = .29, n.s.$), ruling out speed accuracy trade-offs.

3.4.4 Discussion

The data again showed that participants made fewer errors when the body parts used for responding to the sounds and for mentally practicing the rhythms were different rather than the same. This suggests that the inhibitory effects do not only emerge because participants plan to use this body part for an imminent motor response. Rather, it reveals a specific effect of utilizing a body part in mental practice, such that it is less available for other responses.

3.4.5 Experiment 1 to 4 – Summary and Conclusions

Experiments 1 to 4 developed a first behavioural test of whether mental practice of motor skills relies on body-part specific mechanisms guiding physical action execution. Participants made responses with their hands or feet while mentally practicing complex rhythms with either the same or different body parts. In three experiments, we found a direct influence of mental practice on these unrelated responses, which took the form of a negative compatibility effect. Thus, while mentally practicing a rhythm with the hand participants were more likely to accidentally respond with the foot. Conversely, mentally practicing with the foot increased the likelihood of participants accidentally responding with the hand.

This effect of mental practice on the execution of unrelated responses was robust and generalizable. It was found when participants practiced the rhythms to improve their performance (Experiments 2), and when they practiced to perform them later from memory (Experiment 1). Importantly, it was also found when mental practice and execution of the rhythms was interrupted by an intervening task (Experiment 3), suggesting that the effect does not simply reflect the anticipation of an imminent response with a body part.

This is the first behavioural study to reveal such a direct link between mental practice and overt motor behavior. On a general level, our study therefore supports theories that assume that mental practice is, at least, partially enactive and relies on processes also involved in action planning and execution (e.g., Jeannerod, 2005). Remarkably, of course, our effect was a negative compatibility effect, such that body parts used for mental practice were less rather than more available for the unrelated responses. This finding contrasts starkly with previous studies on stimulus-response compatibility. Across a variety of stimuli and experimental paradigms, positive compatibility effects are typically found: responses are faster and more accurate when they share features with a stimulus (e.g., for reviews, see Hommel, 2001; Kornblum, Hasbroucq, & Osman, 1990).

We propose that the negative compatibility effects emerge here because mental practice is not akin to the incidental observation (or imagination of stimuli), but rather involves purposeful acts of action planning where the foot and hand rhythms were integrated into concrete action plans that could guide eventual execution. Indeed, prior research has tied the negative compatibility effects directly to the formation of action plans: they are obtained whenever a task creates an overlap between a response and a simultaneously planned – but not yet executed – action (Hommel et al., 2001; Thomaschke et al. 2012). They indicate that the overlapping action features are already “bound” to this plan, and are less available for

competing plans. It has been found, for example, that planning a left or right response makes it harder to make concurrent responses in the same direction, and even to identify stimuli pointing in the same direction (Stoet & Hommel, 1997; Wühr & Müsseler, 2001; for similar effects, see Hübner & Druey, 2006; Schuch & Koch, 2004, 2010). Our data therefore indicates that mental practice may specifically capture these planning stages of action, where desired features are integrated into an action plan, until it is aligned with both the goal of the individual and the demands of the performance situation, and can effectively drive motor execution.

An interesting finding was that our compatibility effects were only found in errors, not RTs, therefore reflecting the selection of an inappropriate effector for responding to the sounds (e.g., feet instead of hands). Effects only in errors – or only in RTs, for that matter – are typically seen as the ends of a continuum, where task factors bias participants towards either an optimization of response times or accuracy. In our study, various unspecific factors may have contributed to such a bias: (1) participants did not receive feedback for either errors or too-slow responses, such that errors went unnoticed in many cases, and participants were not forced to make faster responses. (2) Even though participants were instructed to respond as quickly and accurately as possible to the sounds, the mental practice task was described as the primary task; subjects were instructed to not let this task be disrupted by the unrelated responses. (3) Due to the high demands of the primary task, response times to the sounds are unusually slow and reflect the average of two bi-manual or bi-pedal responses, further obscuring any RT effects.

In addition to these unspecific task factors, however, the effect in errors/effector selection could also be taken as further evidence for a planning-origin of our effects. Effector selection is one of the earliest stages of motor planning, and changes in effector-specific readiness

potentials are seen long before movements are initiated, and before other planning stages take part (see Bernier, Cieslak & Grafton, 2012 for recent evidence). Effector selection rates have been a measure of choice in recent action planning/binding experiments (e.g. Dutzi & Hommel, 2009). For our study, although post-hoc, the effect in error rates could therefore be taken as further indication that the overlap between physical action and mental practice happens on the level of action planning rather than physical action execution.

Chapter 4

Action Observation and Mental Practice

4.1.1 The Relationship between Mental Practice and Observation Learning

Experiment 1 to 4 provided robust evidence of negative compatibility effects of mental practice such that the body parts used for mentally practicing a rhythm are not as available for the execution of a different action as different body parts. The aim of Experiment 5 and 6 is to compare the motor activation during mental practice to motor activation during observation learning. As noted, a large body of research suggests that the observation of action goes along with a similar subliminal motor activation as motor imagery, and that this motor activation might be the foundation for the later imitation of the observed actions (for a review, see Iacoboni, 2009). An important question is therefore if both – mental practice and imitation learning – are based on the same underlying mechanisms. The demonstration of such a similarity would provide a means of conceptualizing learning from observing others (i.e. imitation) in the same way as the mental practice of action. Experiment 5 therefore adapts the previous paradigm to the situation of observation learning, that is, a situation in which we watch another person perform the rhythms and try to learn from their performance, such that we are able to execute the rhythms more effectively afterwards.

Such a change also allows us to test why the results obtained in our mental practice tasks are so different to the typical findings from action observation experiments that report facilitatory effects of seeing and performing a similar action. For example, in recent experiments, it was found that observing hand and foot responses facilitated responses with the same body parts (Bach et al., 2007; Bach & Tipper, 2007), even when observed and executed motor movements were not identical, merely relying on the same body part (Gillmeister et al., 2008).

There are two potential reasons for these differences. First, whereas in these prior studies the actions were directly presented, in ours they were imagined, based on a symbolic rhythm description. It could therefore be that the negative compatibility effects emerge from the requirement to imagine. Second, in the previous studies, the actions the participants observed were completely task irrelevant, while in the present experiment the imagined actions had to be later executed and were therefore the basis of the participants' own responses. As noted above, various theorists (e.g., Hommel et al., 2001; Schuch & Koch, 2004; Stoet & Hommel, 1997) have proposed that action codes that are part of one's own action plans are not available for other processing (leading to negative compatibility effects), in contrast to the case when the same action codes are part of an incidentally observed stimulus (leading to positive compatibility effects).

Experiment 5 and 6 therefore extends our paradigm to observation and tests these two competing accounts of the negative compatibility effects.

4.1.2 Experiment 5 – Extending the Paradigm to Observation Learning

Experiment 5 converted the mental practice paradigm used in Experiments 1 to 4 into an imitation paradigm. In the mental practice interval, participants now did not see a symbolic description of the rhythm, but watched a rhythm that was tapped by another person. As before, they had to mentally practice this rhythm in order to perform it as quickly and accurately as possible later, while they responded with hands or feet to two sounds played to them. The difference to Experiments 1 to 4 is that participants did not have to generate an imagined rhythm, but could just observe the other person's movements, similar to prior work on action observation.

If, in Experiment 1 to 4, the negative compatibility effects emerge because the eliciting stimuli were only imagined, then these effects should not be observed here and may even turn into positive effects, because the actions are explicitly presented as in other studies on action observation and stimulus response compatibility. If, however, the negative compatibility effects emerge because the body parts are part of an action plan, the same negative compatibility effects should be observed, because the same action plans have to be generated as in the previous experiments.

4.1.3 Method

Participants. Thirty-four students (9 male, age range 18-27) took part in the experiment. All other aspects of the participant selection were identical to the previous experiments. Seven participants were excluded as they produced more than 20% invalid responses/rhythms.

Materials and apparatus. The apparatus was identical to the previous experiments. In addition to the symbolical rhythm descriptions, videos of another person tapping the rhythms were shot. The rhythms played by the person were the same as the rhythms used in the symbolic rhythm descriptions in Experiment 2. Thus there were 20 videos of a person tapping the rhythms with the foot and 20 videos of a person tapping the rhythms with the hand. All movies were 9 seconds long. They showed the frontal view of the actor, cropped such that either only his hands and arms or feet were visible (see Appendix E).

Procedure and design. The procedure was based on Experiment 3. The course of each trial was identical to this experiment, with the exception that the symbolic rhythm descriptions in the mental practice interval were replaced with the movie stimuli of the same rhythms (see Figure 4.1, middle panel). Participants were instructed to watch these videos and use them to

prepare the rhythms. In the execution interval, the symbolic rhythm descriptions were shown as in Experiment 2, to obviate the need to memorize the observed rhythms.

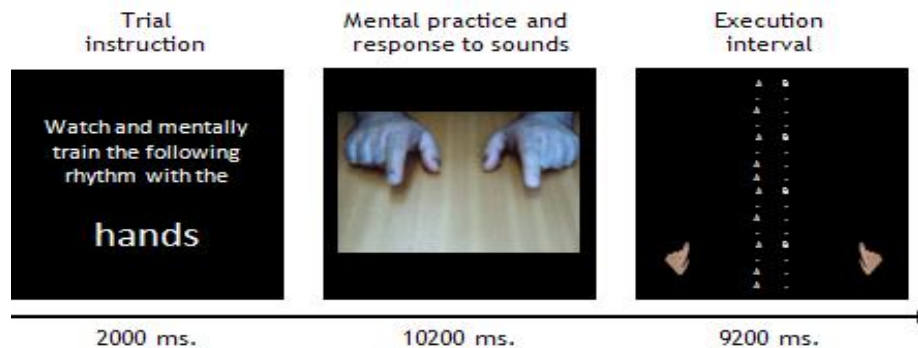


Figure 4.1 Illustration of the trial sequence in Experiment 5. The trial instruction (left panel) informed participants about the body part that would be used in the following rhythm. They then watched and mentally trained the demonstrated rhythm (middle panel) and responded with hands or feet to sounds played after 5000, 5500, 6000, or 6500 ms after the start of this interval. In the execution interval (right panel) they executed the rhythm.

Analysis. 1.4% of trials were excluded because they contained “too early” responses or because the press of both response devices was not detected. For the analysis of RTs, error trials (2.8%) as well as trials with RTs that fell outside three standard deviations of the mean RT for responses with this body part (0.5%) were additionally excluded.

4.1.4 Results

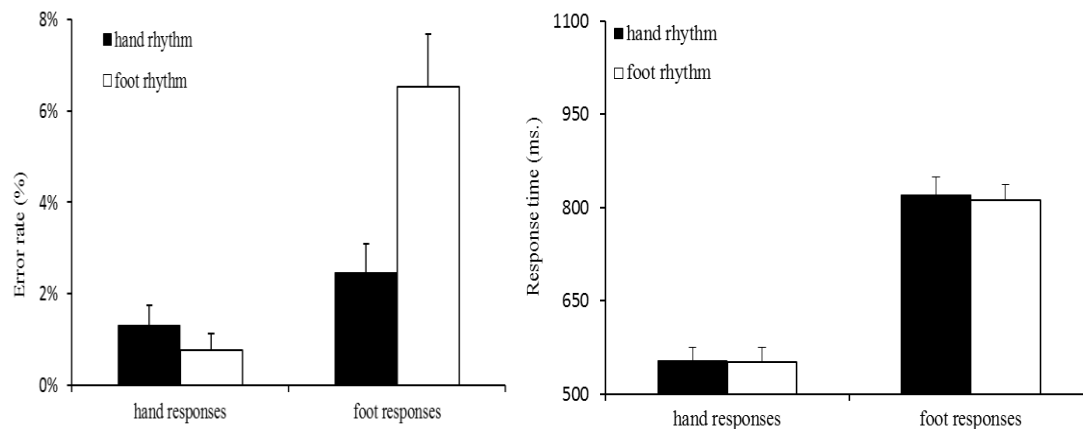


Figure 4.2 Error rates (left panel) and Response times (right panel) in Experiment 5. In each panel, the two left bars show the data for responses with the hand and the two right bars show responses with the foot. The black bars show responses while hand rhythms were mentally practiced and the white bars show responses while foot rhythms were practiced. Error bars show the standard error of the mean.

Figure 4.2 shows the results of the experiment. RTs and Error Rates were analysed with separate 2 x 2 ANOVAs with the repeated measures factors Imagery Effector (foot, hand) and Response Effector (foot, hand). The analysis of error rates revealed main effects of Imagery Effector, $F(1,26) = 7.50$, $p = .011$, $\eta^2_p = .22$, and of Response Effector, $F(1,26) = 29.57$, $p < .001$, $\eta^2_p = .53$, indicating that participants made fewer errors when responding with the hand than when responding with the foot, and when mentally practicing with the hand than the foot. Importantly, the interaction of Imagery Effector and Response Effector, $F(1,26) = 11.39$, $p = .002$, $\eta^2_p = .31$, again revealed a negative compatibility effect.

The analysis of RTs only revealed a main effect of Response Effector, $F(1,26) = 349.69$, $p < .001$, $\eta^2_p = .93$. The main effect of Imagery Effector and the interaction were not significant ($F = 1.16$ and $F < 1$, respectively). The size of the compatibility effects in response times and error rates were slightly negatively correlated ($r = -.13$, *n.s.*).

4.1.5 Discussion

While previous work has focussed on automatic imitation, this is the first study to investigate the motoric consequences of observing somebody with the purpose of later imitating their actions. The data revealed a continuity between learning from symbolic rhythm descriptions in Experiments 1 to 4 and learning from somebody else's actions in the present experiment. As in the earlier experiments, participants made fewer errors when using a body part that was not already engaged in mental practice, compared to a body part that was. This finding suggests that this effect is not due to the body part movements being merely imagined, rather than directly observed. What unifies all four experiments is that participants have to use the presented stimuli – be it videos or symbolic rhythm descriptions – to formulate a motor plan for later execution. Our finding is therefore consistent with the idea that generation of such a motor plan involves a binding of motor codes to action goals such that these codes are less available for other, unrelated responses (e.g., Hommel et al., 2001).

4.2.1 Experiment 6 – Does Eliminating the Need for Mental Practice Also Eliminate the Negative Compatibility Effect?

Experiment 1 to 5 revealed that mental practice of rhythms induces negative compatibility effects, such that participants made more errors when responding with the body part already engaged during mental practice. An important question is whether these effects are really due to the mental practice induced by our task, or due to unspecific task or stimuli aspects. One possibility is, for example, that the effects are brought about the visual presentation of hands or feet in the mental practice interval, when the model used these body parts to tap the rhythm (Experiment 4), or when they served as reminder stimulus of which body part to train the rhythm with (in Experiments 1 to 3).

Of course, even though the presentation of hands and feet by itself is known to elicit compatibility effects, these effects are usually positive, such that participants are more likely to respond with the presented body part, and not negative as was found here (Bach et al. 2006; Gillmeister, et al. 2008). Moreover, these effects are typically found directly after stimulus onset but not after prolonged exposure to the stimuli within a trial (such as the 5 to 6 seconds to the onset of the sounds as used here). Nevertheless, experiment 6 was designed to fully control for the possibility that the negative compatibility effects could be due to these or other unrelated task aspects.

Participants were exposed to exactly the same stimuli as in Experiment 5 (observation learning), but now were not instructed to mentally practice the viewed rhythms. Rather, their task was to merely memorize the rhythm tapped by the other person, so that they would be able to decide, in the second phase of each trial, whether the rhythm was the same or different to a symbolic rhythm description. Thus, rather than requiring the transformation of somebody else's action into one's own action plan, this task requires a transformation of somebody

else's action into a symbolic description. As such, Experiment 6 keeps visual stimulation and the attention to these stimuli constant, but eliminates the mental practice components of the task. If the negative compatibility effects found in Experiment 1 to 5 are due to mental practice, they should therefore be eliminated in the current experiment. If, however, the negative compatibility effects are brought about by unrelated task aspects (e.g., the presence of hands and feet in the stimuli) then the same effects should be observed here.

4.2.2 Method

Participants. 34 students (7 male, age range 18-24) took part in the experiment. As before, participants were excluded when no valid button presses were recorded in more than 20% of trials. Participants were also excluded when their performance in the same/difference task was indistinguishable from chance (<60% correct), or too few valid verbal responses were recorded (<80%). Of the 34 participants tested, this was the case for seven participants.

Materials and apparatus. The material and apparatus was identical to Experiment 4, with the exception that a microphone was additionally used to record the participants' verbal responses via Presentation's (www.neurobs.com) sound threshold detection logic.

Procedure and design. The procedure was based on Experiment 5. A movie of another person tapping a rhythm was presented in the first phase of each trial. Participants were instructed to watch this movie and to memorize the rhythm so that they would recognize it later. Participants again pressed either both foot or both hand buttons when they heard one of the two tones in this first "memorization" phase of the trials. In the second phase, participants were then shown a symbolic rhythm description (as used in the previous experiments) of either the same or a different rhythm. Their task was to merely state verbally whether this symbolic rhythm stimulus was "same" or "different" to the rhythm video they had just

observed (see Appendix F for instructions). The timing of these two phases across each trial was the same as in Experiment 4. However, as participants required less time to make their verbal same/different judgments than tapping the rhythm, we increased the number of trials (from 80 to 120), so that overall experiment times were similar. The results below are reported for the full 120 trials, but they are statistically identical when only the first 80 trials are analysed.

Analysis. As before, the analysis focussed on the responses to the task-unrelated sounds. 2.6% of trials were excluded because they contained “too early” responses or because the press of both response devices was not detected. For the analysis of RTs, error trials (2.3%) as well as trials with RTs that fell outside three standard deviations of the mean RT for responses with this body part (1.1%) were additionally excluded.

4.2.3 Results

Figure 4.3 shows the results of the experiment. As before, RTs and Error Rates were analysed with separate 2 x 2 ANOVAs with the repeated measures factors Imagery Effector (foot, hand) and Response Effector (foot, hand). The analysis of error rates revealed main effects of Response Effector, $F(1,26) = 16.46$, $p < .001$, $\eta^2_p = .39$, indicating that participants made fewer errors when responding with the hand than when responding with the foot. However, there was no effect of Response Effector, $F(1,26) = 0.17$, $p = .686$, $\eta^2_p < .01$. Moreover, in contrast to all previous experiments, the interaction of Imagery Effector and Response Effector was not significant, $F(1,26) = 0.043$, $p = .837$, $\eta^2_p < .01$. Moreover, comparing the size of compatibility effects between Experiment 5 and 6, which were identical with regard to visual stimulation, revealed a marginally significant difference, $t = 1.78$; $p = .081$. The analysis of RTs only revealed a main effect of Response Effector, $F(1,26) = 96.60$, $p < .001$,

$\eta_p^2 = .79$. The main effect of Imagery Effector and the interaction were not significant ($F < 1$, for both).

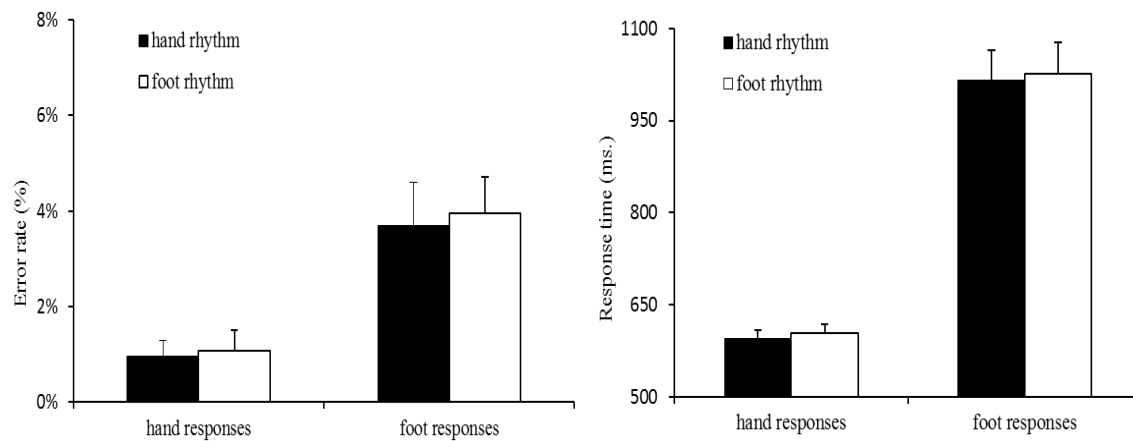


Figure 4.3 Error rates (left panel) and Response times (right panel) in Experiment 6. In each panel, the two left bars show the data for responses with the hand and the two right bars show responses with the feet. The black bars show responses while hand rhythms were mentally practiced and the white bars show responses while foot rhythms were practiced. Error bars show the standard error of the mean.

4.2.3 Discussion

Experiment 6 shows that the previously recorded negative compatibility effects are, most likely, due to the requirement to mentally practice the presented rhythms, and not just due to unrelated stimulus or task aspects (such as the presence of hands and feet in the visual stimulation). All these general task demands were kept identical in Experiment 5, while the need for mental practice was removed. We found that this also led to a complete absence of negative compatibility effects, suggesting that the negative compatibility effects are due to mental practice rather than these unrelated task aspects.

4.2.5 Experiment 5 and 6 – Summary and Conclusions

While Experiments 1 to 4 links action planning to mental practice, Experiments 5 and 6 extend this link to imitation. Imitation is a key means for transmitting knowledge, both within and between generations. It allows observers to put themselves into the other persons' shoes, vicariously experience the outcome of their actions and learn from their experience, enabling them to later reproduce their behaviours and achieve the same goals. It is often assumed that humans can imitate because watching others act does give rise to activity in motor areas of the brain, which in turn evokes a tendency for humans to automatically (non-strategically and non-consciously) copy their behaviour and body postures (Chartrand & Bargh, 1999; for reviews, see Heyes, 2011; Wang & Hamilton, 2012; van der Wel, et al., 2013). It is assumed that, for imitation proper, observers could simply “tap into” this motor activation to reproduce the desired behaviours.

Experiment 5 challenges these ideas by revealing that the general motor resonance evoked by incidentally observing others is absent when people watch others with the express purpose to imitate them later. Instead, the to-be-imitated action features were less – rather than more – available for unrelated responses. Experiment 5 therefore suggests that watching somebody to imitate is more akin to mental practice than automatic imitation and gives rise to the same binding effects. Both cases may therefore involve the purposeful selection of intended action features and “binding” them into an action plan. The only difference is that in mental practice these features were self-generated, while in imitation they could be extracted directly from the other person's action.

Chapter 5

Additional Analyses of Experiment 1 to 6

5.1 Additional Analyses of Experiment 1 to 6

Experiments 1 to 6 revealed robust evidence that mental practice and observation learning draws upon body part specific processes involved in physical action execution, particularly pointing to planning related processes that bind features to intended action plans. Here we report additional analyses that further support the conclusions drawn, that provide insights into aspects of the data that were not in the focus of the main experiment, and that allow us to test hypotheses that require power supplied by across-experiment analyses.

5.2 Analysis 1 – Do Spontaneous Motor Responses Reflect the Establishment of an Action Plan?

We observed that participants sometimes produced overt motor responses before the imperative sound cues were played. These “too early” trials were excluded from the main analysis, but can be seen as a potential further indicator of the engagement of body-part specific motor systems when mentally practicing the rhythms. To test whether these responses indeed reflect the spontaneous outflow of body-part specific motor activation, we tested whether these responses were more likely to be made with the body part with which the rhythm had to be mentally practiced. As only few participants made these responses in each experiment (see Table 1), the comparison was run across all participants that produced “too early” responses across all experiments in order to increase power. As expected, across experiments, participants were more likely to make “too early” responses with the body part used for mental practice compared with the other body part, $t(25) = 1.86, p = .037$. As can be seen in Table 1, the pattern held numerically for each of the four experiments, and was marginally significant for Experiment 3 and 4 when tested separately. The data from the “too

early” responses therefore support the notion that mental practice relies on a covert motoric simulation of the rhythms, which can sometimes accidentally drive overt motor behavior.

Experiment	same body part	diff. body part	n	<i>t</i>	<i>p</i>
1 (from memory)	1.4%	0.3%	5	1.69	.166
3 (speeded production)	1.5%	0.2%	7	2.30	.061
4 (delayed production)	2.0%	1.1%	6	2.07	.093
5 (imitation)	1.6%	0.6%	8	1.10	.308

Tables 5.1 Spontaneous Motor Response in Mental Practice Interval across Experiment.

5.3 Analysis 2 – Does the Negative Compatibility Effects Reflect Response Inhibition or Action Effect Binding?

An important question is what process the negative compatibility effects reflect. We interpreted these effects in terms of resource competition. Accordingly, action planning requires the binding of action features to an action plan or goal (e.g., Hommel et al., 2001). Action features that are bound in this way are less available to be incorporated into another, unrelated action that subserves a different goal. In our case, body parts used to mentally practice a rhythm may therefore be bound to the plan to produce this rhythm, and are therefore less available to respond to the unrelated sounds. However, an alternative view is that the negative compatibility effects reflect inhibitory processes that prevent the formulated motor plans from activating overt motor responses, until required by the task. Indeed, if motor imagery is equivalent to actual motor output then there need to be processes that inhibit the spontaneous outflow of motor activity during mental practice (e.g., James, 1890; Vogt, 1996), and a recent fMRI study has provided evidence for such inhibition (Solodkin et al., 2004).

One way to distinguish between these possibilities is to relate the negative compatibility effects to the spontaneous motor outflow during the mental practice interval (the “too early” responses analysed above). The resource competition and motor inhibition accounts make different predictions of how these spontaneous motor outputs should be related to the negative compatibility effects. According to the motor inhibition view, those participants that show the strongest negative compatibility effects when responding to the sounds should be the *least likely* to produce an overt motor response in the mental practice interval. The reason is that if the negative compatibility effects reflect an inhibition of spontaneous motor responses, then those participants that inhibit more should produce less motor output. The reverse is the case for the resource competition view. On this view, those participants with the strongest negative compatibility effects are seen as the participants that have formulated the strongest motor plans in the mental practice interval. They should therefore be the *most likely* to mistakenly execute this action plan, and show “too early” responses with the body part used for mental practice.

The results favour the resource competition view. We computed the correlation between each participant’s negative compatibility effect with their tendency to produce a motor response before the sounds were played with the body part used for mental practice (as opposed to responses with the opposite body part not engaged in mental practice). As before, to increase power, this correlation was computed across all 26 participants in Experiment 1 to 4, who produced button presses before the sounds were played (after standardizing the effects for each experiment). Indeed, a highly significant negative correlation emerged ($r = -.63$, $p < .001$), indicating that those participants with the strongest negative compatibility effects were more – rather than less – likely to make an anticipative motor response with the body part used for mental practice. Negative correlations were also observed when each experiment was analysed separately (Exp. 1 (memory), $r = -.91$, Exp. 3 (fast responses), $r = -$

.47, Exp. 4 (delayed responses), $r = -.30$, Exp. 5 (imitation), $r = -.86$). This correlational analysis therefore supports the view that the negative compatibility effects do not reflect the attempt to inhibit spontaneous motor outflow, but the formulation of an action plan that requires the “binding” of an effector to the action plan so that it is less available for other, unrelated responses.

5.4 Analysis 3 – Does Responding with the Same or Different Body Part Affect the Ability to Mentally Practice the Rhythms?

The effects described so far reflect the effect of mental practice on the concurrent execution of unrelated responses. However, to the extent that mental practice and overt responses rely on the same underlying motor representations, then the opposite influence might be present as well: the hand and foot responses participants make to the sounds could affect how well they are able to mentally practice the foot and hand rhythms. In other words, mental practice of the rhythms might be easier or harder depending on whether it was interrupted by a response made with the same or with a different body part. Although not the primary focus of this investigation, such reverse effects of action on cognition have been demonstrated before (e.g., Tipper & Bach, 2008; Bach & Tipper, 2007; Müsseler & Hommel, 1997; Symes et al., 2008, 2009, 2010; Topolinski, 2012). They are often less robust and less often investigated than the typical compatibility effects of a stimulus on a response, but are typically seen as providing evidence that the engagement of the motor representations reflects a use of these representations in the interrupted task, rather than mere epiphenomenal activations (Hommel et al., 2002).

To assess the influence of overt responses on the ability to mentally practice the rhythms, we assessed how well participants played the rhythms afterwards. Two variables were created to assess the participants' performance. The first variable, *play time*, measured the speed with which participants produced the rhythms. For each rhythm played by a participant, we subtracted the time of the first button press in the execution interval from the last button press. The second variable, *deviance*, measured the accuracy of participants' performance. This was computed as the average of two sub-measures. First, we measured the absolute difference between the number of beats that the participants produced and the number of beats that were required for this particular rhythm, as a percentage of the total rhythm length. Second, we assessed whether the participants' relative frequency of presses with the left and right buttons corresponded to the relative frequency of left and right presses required by the rhythm, again as a percentage of total rhythm length. For these analyses, trials in which the button presses of the participants deviated by 50% or more from the required button presses were excluded, as well as trials in which participants took longer than 12 seconds to play the rhythm, or in which there was a pause between two button presses longer than 2 seconds.

Experiment	Deviance		Play time	
	same	different	same	different
1 (from memory)	5.2%	5.8%	4677	4674
3 (speeded production)	3.1%	4.0%	3247	3247
4 (delayed production)	6.3%	6.9%	3227	3181
5 (imitation)	1.4%	1.8%	5107	5104

Tables 5.2 Deviance and play time depending on whether mental practice was interrupted by a response with same or a different body part used in mental practice.

Computing the performance of participants on these two measures revealed a consistent numerical pattern across experiments for the deviance measure. As can be seen in Table 5.2, in all four experiments, participants tapped the rhythms more accurately when they had utilized the same body parts for responding to the sounds and for mental practice, compared to trials in which they used a different body part. This difference was highly significant when data was pooled across experiments to increase power ($t(77) = 2.66, p = .009$). When performance was compared for each experiment separately, a significant difference was apparent for Experiment 3, $t(17) = 2.67, p = .016$, and a marginally significant difference for Experiment 5, $t(26) = 1.61, p = .059$, but not for Experiment 1, $t(15) = 1.41, p = .150$, and Experiment 4, $t(16) = 0.71, p = .487$.

As can be seen in Table 2, the play time measure did not reveal a consistent pattern across experiments. There was no significant difference, either when performance in both conditions was compared across experiments to increase power ($t(77) = 0.68, p = .500$), or in any of the single experiments (Experiment 1, $t(15) = 0.056, p = .956$; Experiment 3, $t(17) = 0.00, p = .998$; Experiment 3, $t(26) = 1.34, p = .20$; Experiment 5, $t(26) = .01, p = .994$).

Thus, the analysis of the rhythm performance reveals a consistent positive compatibility effect, at least when the data are pooled across experiments. Participants tapped the rhythms more accurately when their prior mental practice was interrupted by a button press that corresponded to the body part used in their motor plan, compared to a different body part.

5.5 Post- hoc Analysis 4 – Does the Data Pattern hold Across Response Modalities?

The effects in Experiments 1 to 5 were driven more strongly by the trials requiring a foot response compared to hand responses. Indeed, while the difference for foot response was significant for most experiments (see Table 5.3), too few errors were generally made for hand responses to demonstrate similar statistical differences. It is therefore crucial to demonstrate that our effects are not just an unspecific effect on foot responses, but a general tendency to respond with the effector not used in mental practice, irrespective of whether a hand or foot response is required. First, the consistency of results across experiments supports the presence of such a crossover interaction. In all experiments, error rates were reduced for foot as well hand responses when a different effector was used for mental practice. Second, and more importantly, this consistency was also supported statistically, when the data was pooled (and standardized) across Experiments 1 to 5 to increase power. Pairwise tests, run separately for trials requiring hand responses and foot responses, revealed significant reductions of error rates when different body parts were used for mental practice and responding to the sounds for both foot responses ($t = 4.82; p < .001$) and hand responses ($t = 2.37; p = .020$). This verified that the negative compatibility effects indeed affect both response modalities: for both feet and hand responses, participants are more likely to utilize a different body part, when the required body part is already in use for mentally practicing the rhythms.

Experiment	Foot responses		Hand responses	
	t	p	t	p
1 (from memory)	1.65	.112	1.00	.333
3 (speeded production)	2.71	.015	0.90	.380
4 (delayed production)	2.01	.062	1.46	.164
5 (imitation)	3.23	.003	1.33	.196
Pooled (Exp 1, 3 to 5)	4.82	.001	2.37	.020

Tables 5.3 Significance tests for compatibility effects across Experiment 1 to 5 and data is pooled across experiments, separately for trials requiring foot or hand responses.

5.5 Summary and Conclusion

The data from Experiments 1 to 6 suggest that mental practice is based on planning-related motor processes. These processes allow actors to establish concrete plans for motor execution, by “binding” the different features an action needs to be successful – speed, direction of motion, or, here, the sequence of button presses with a certain body part – into unified plans for action. During mental practice, these planning processes may allow actors to develop complex plans for action that are aligned with both their goals and the (anticipated) demands of the performance situation.

The additional analysis reported here supported such an involvement of planning related processes in mental practice. One feature of planning accounts is that the integration of features into action plans, while preventing their use for other responses, will benefit the execution of current plans. Such an effect was revealed by the analysis of the spontaneous motor responses participants sometimes made during mental practice. We found that those participants with the strongest negative compatibility effects were the most likely to

accidentally press a response key during mental practice. Importantly, these responses were made with the body part concurrently used for mental practice, consistent with the idea that they reflect action plans that participants “forgot” to inhibit. Although post-hoc, these data therefore confirm that mental practice indeed has two coupled effects on overt motor behavior: it prevents the use of the relevant action features in unrelated responses, and, at the same time, facilitates the execution of the current plan (cf. Hommel et al., 2001).

Chapter 6

Transfer of Learning and Mental practice

6.1.1 Exploring Effector Specificity of Mental Practice with a Transfer of Learning Task

Experiments 1 to 6 provided robust evidence that mental practice and observation learning draw upon body part specific processes involved in physical action execution, particularly pointing to planning-related processes that integrate intended action features – in our case, the sequence of left and right button presses to be executed with a specific body part – to potential action plans.

A key feature of such planning accounts is that planning can occur across multiple levels, some more proximally and some more distally related to the actual body movements (cf. Hommel, et al., 2001). For example, the simple act of turning on the light might be planned on the level of low-level motor consequences one wants to achieve – extending one’s arms towards the light switch and pressing it – but also on the level of more distal action consequences: the faint clicking sound that accompanies a successful press of the switch, and the turning on of the light (cf. Hommel, et al., 2001). Depending on expertise, goals and task requirement, people can switch between these distal and proximal modes of action planning, with a general preference given to more high-level, goal oriented planning (Wulf, 2007).

The data of Experiments 1 to 6, however, suggests that the action plans established during mental practice are relatively low level and concrete. They involved body part specific motor processes, even in cases where such an involvement was not explicitly required, and the task could simply be accomplished by learning a sequence of left and right button presses. There are two potential reasons for such an effect. First, during mental practice and action planning, it may be mandatory to specify the involvement of body parts, even if participants do not explicitly take them into account. This may be supported by the finding that effector-selection is one of the earliest stages of action planning, preceding the specification of other action

features, such as force, velocity or trajectory (see Bernier, Cieslak & Grafton, 2012 for recent evidence). Second, it is possible that the task itself encouraged participants to engage in a relative concrete mode of action planning that involves the specific body parts. The reason is that in all tasks in the previous experiments, participants knew in advance that the body part they used for mental practice would also be the body part required for executing the response. Participants were therefore very much motivated to establish an effector specific representation of the rhythm sequences.

Experiments 7 and 8 were designed to explore whether mental practice is flexible enough to operate on relatively high level that is independent from the body parts involved, if this is encouraged by the task situation (for example, because participants are not sure if the body part used for execution will be the same as the one used during mental practice). The previous design does not allow us to resolve this question, as the establishment of flexible, body-part independent rhythm representation would give rise to a null effect: no negative compatibility effects would be expected for participants that mentally practice in such an abstract manner, and, for example, only establish a mental representation of the left and right button presses, independent of the body part involved. Experiment 7 and 8 therefore utilize a transfer task to test the potential abstract-ness of action plans that are established through mental practice.

Transfer of learning is defined to occur when learning in one context or with one set of materials impacts on performance in another context or with other related materials. It is defined as the influence of previous experiences on performance of a new skill or on the learning of a new skill (Magill, 2007). For example learning to swim freestyle helps a person later to learn more quickly to swim many kinds such as breaststroke, backstroke and butterfly. Transfer is typically distinguished as near, intermediate and far, which describes

the amount of correspondence between the new and the old skill, with increasing learning speed the closer the new skill is to the already existing skill. For example the skills needed for dribbling hand and basketball are near, while transfer of skills between tennis and table tennis may be intermediate or far. Thorndike (1923) argued that transfer depended on identical elements in two performances and that most performance were simply too different from one another for much transfer to be expected. In contrast, some recent authors argue that all skill learning is, in fact, a sort of transfer, as all new skills build, to some extent, on what has been acquired earlier (e.g., Rosalie & Muller, 2013).

An intriguing finding is that – like we have suggested for mental practice – transfer of motor skills seems to happen mostly on the level of action planning (Lohse, Healy & Sherwood, 2010). For example, various studies have investigated intermanual transfer: from one body part to the other, typically from the dominant hand to the other hand, or vice versa (e.g., Hicks, Frank, & Kinsbourne, 1982; Thut et al., 1997). These studies have consistently found that motor skills can be transferred, with some losses, from one body part to the other, arguing that a large part of motor skill are indeed represented in an effector independent manner (e.g., Parlow & Kinsbourne, 1989; Thut et al., 1997). Similarly, studies have found that the amount of transfer is influenced by factors affecting performance on the task or planning level (e.g., trajectories in allocentric space), but not by factors affecting performance on low-level effector level (e.g., trajectories on body-part centric coordinate systems, Lohse, et al., 2010), again supporting a relatively abstract representation of motor skills established during mental practice.

This suggests that transfer might operate on similar planning-level representations as mental practice, and that motor skills established through mental practice may lend itself excellently for subsequent transfer. Indeed, other authors have similarly theorized that while physical

practice is typically more effective in skill acquisition, mental practice may play a key role in enabling later transfer of a skill (Wohldman, Healy & Bourne, 2008). Indeed, a recent study, using a combined behavioral and near infrared spectography (NIRS) approach supported this idea. Amemiya, Ishizu, Ayabe, & Kojima, (2010) compared transfer of a finger tapping motor skill to the contralateral hand after mental practice and physical practice. They found that while mental practice improved subsequent performance of both the ipsilateral and the contralateral finger, physical practice improved only ipsilateral performance.

These results suggest that mental practice of the rhythms will go along with relatively large transfer. What is relatively unknown is, however, to what imitated movement sequences – motor skills learned by observing others – can be transferred to another body part. Prior research suggests that observed actions are directly matched to an action plan in the observers' motor repertoire (e.g., Rizzolatti & Craighero, 2004). If it is the case, then these plans might, by virtue of the body part observed, be body part specific as well. In other words, while mental practice should potentially be able to generate highly abstract – and therefore transferrable motor skills –, the same may not be the case for imitation. Here, the derived motor skills should be very much bound to the body parts they were produced with in the observed action.

To test these questions, Experiment 7 and 8 adapted the prior task to a transfer of learning paradigm. In each trial of these experiments, participants first mentally practiced – from a symbolic rhythm description in Experiment 7 and from watching somebody else produce the rhythm in Experiment 8 – a complex rhythm, to be played with either their hands or their feet. They were then expected to reproduce the same or a different, not previously practiced rhythm, with either the same or a different body part. The difference in performance between

practiced and non-practiced rhythms gives us a measure of the benefits of mental practice (see Experiment 2). The extent to which these benefits are reduced when switching to a different body part provide a measure for the amount of transfer.

We hypothesized that, if participants establish relative high-level, abstract rhythm representations during mental practice, then we should find that rhythms sequences learned with one body part (for example: the hand) can be effectively transferred to another body part (for example: the foot). The extent to which performance improvements are lost will provide information about how body-part specific the motor plans generated by mental practice are. For example, if mental practice of a foot rhythm still benefits execution with a different body part, then the data would argue for a relative high-level abstract sequence representation that has been established.

Note that, in both experiments, the motivation to generate relatively abstract, body-part independent motor plans was high. Participants were well aware that the body part used for mental practice might not be the same as the one used for the performance of the rhythm. This allowed us to compare, across Experiments, to what extent mental practice and imitation learning enables the generation of such abstract motor plans, and to what extent the potentially generated motor plans are restricted.

6.1.2 Experiment 7 – Transfer of Symbolic Mental Practice

Experiment 7 tests the transfer of motor skills to another body part, when the motor skills were acquired (or at least improved) through mental practice, based on a symbolic rhythm description used in Experiment 1 to 4. As in the previous experiments, participants were instructed to mentally practice different complex rhythms with either hands or feet, in order to later perform as quickly and accurately as possible. In every trial, participants would first see a symbolic description of the rhythm that they mentally practiced. They then had to produce it. We varied, first, whether the rhythm they later had to produce was the same or a different rhythm. Second, we varied whether this rhythm had to be performed with the same or a different body part than that used for mental practice.

This experiment allows us to test, first, if mental practice of the rhythms improves performance. If this is the case, participants should make fewer errors when performing the same rhythm that they had just practiced, compared to performing a different rhythm. Second, if mental practice is body part specific, then these benefits of executing the same rhythm (compared to a different one) should only be found when participants are using the same body part for mental practice and actual performance.

Note that participants were very much aware that the body part used for mental practice might not be the body part they would ultimately use to produce the rhythm. The motivation to engage in an body-part independent mode of mental practice – deriving distal and abstract, outcome related motor plans in terms of the sequence of left and right button presses – was therefore encouraged, in contrast to the previous experiments. The crucial question is whether this manipulation is enough to prompt the formation of body-part independent motor plans, and whether this is also the case when the rhythms are learned by observing others in Experiment 8. Any differences in the effects between experiments therefore provides new

insights to what extent mental practice and imitation learning enables the generation of abstract non-motor related action plans.

6.1.3 Method

Participants: Nineteen students (16 women, 3 men, age range 18-23 years) took part in the experiment. Participants satisfied all requirements in volunteer screening and gave informed consent approved by the school of Psychology at the University of Plymouth. All participants were in good health, had no history of disease or medical treatment that might influence motor performance and visual-motor functions. The study was approved by the Plymouth University Ethics Committee.

Material & Apparatus. The experiment was manipulated by the program Presentation running on a 3.0 GHz PC running Windows XP. Hand response keys were the Ctrl-key (operated by participants' left hand) and Enter key on the number block (operated by the right hand). Foot responses were recorded with two foot pedals, which were attached to the floor black tape. The distance between the two pedals was 33 cm. Twenty different rhythms were used. Ten of these rhythms were to be played with left and right hands and ten were to be played with the left and right feet (see Appendix G).

All rhythms were visually presented in the same format. Each rhythm had 16 lines. As in the previous experiments, participants were told that each line corresponded to the click of an imagined metronome. Beats that participants had to produce were represented by 'A's and 'B's in each line. 'A's represented button presses or foot pedal presses on the left hand side. 'B's represented beats to be played with the right foot or right key. A line containing both an 'A' on the left side and a 'B' on the right designated cases in which both feet and both hands should be pressed. Left and right of each rhythm, a symbol depicting either a hand or a foot

was shown that indicated with which body part had to be used for mental practice (see Figure 6.1).

Procedure. The participants were seated, facing a computer at a distance of approximately 90 cm. The experiment contained three training and instruction sessions that lasted 18 minutes altogether. The actual experiment took about 38 minutes, so the total experiment duration was roughly 56 min. The participants were tested individually and participants were instructed by the software during training and the actual experiment.

The first training session consisted of eight trials and served to familiarize participants with the execution of the rhythms. In each trial, participants were first presented with a cue telling them which body parts (hands or feet) they had to use to produce the following rhythm. This cue remained on the screen for 2000 ms and read “Produce the following rhythm with the hands!” or “Produce the following rhythm with feet” After a short blank (300ms), the rhythm was shown on the monitor, with pictures to its left and right reminding participants of then produced this rhythm while it was on screen. They had 10200ms to complete the rhythm.

The second training session also consisted of eight trials. Participants were now introduced to the mental training component of the task. In each trial, participants were again first presented with the cue telling them the body parts (hands or feet) they should use to mentally train the rhythm (for 2000 ms). After a short blank (300 ms), they were then shown one of the 20 rhythms for 10200 ms and were instructed to mentally practice the rhythm, while not making any movement. After that a cue said “Now produce the rhythm with hands/feet”. After this, the rhythm participants had to play was presented again with small pictures indicating hands or feet on the left or right (see Figure .6.1).

The participants were instructed to initiate and execute the rhythm as quickly as possible. The third training session contained 8 trials and was identical to the experiment proper. The

course of each trial was identical to the second training session. However, now, the rhythms shown in the production interval could either be the same or a different rhythm than the one they just practiced. Similarly, they could be instructed to play these same or different rhythms with either the same or a different body part. Figure 2 shows a schematic of the trials in the actual experiment.

As before, they had 10500 ms to play the rhythms. There were 80 trials altogether, separated by short breaks every 20 trials. All rhythms were shown twice per block, in a different randomization for each participant. Across trials, 25% of the rhythms were identical to the rhythm that was mentally and had to be performed with the same body part. In another 25% of trials, the rhythms were identical to the rhythm that was mentally but had to be performed with a different body part. In another 25% of trials, a different rhythm than the one that was mentally practiced had to be executed with the same body part. Finally, in 25% of trials a different rhythm had to be played with a different body part.

Measures. We assessed the influence of mental practice on how well participants played the rhythms afterwards in terms of two variables. The first dependent variable, *total play time*, reflected the total time participants needed to reproduce a rhythm, from the onset of the prompt to start producing the rhythm to the last button press. It was the sum of two subordinate measures. *Initiation time* measured the time it took participants to initiate the tapping in the execution interval. For each participant and each trial, we subtracted the time of the first button press from the start of the execution interval. Initiation time therefore mostly measures impact on the planning processes that take place during rhythm execution (cf. Wohldman, et al., 2007; 2008). The second variable, *play time*, measured the speed with which participants produced the rhythms. For each rhythm played by a participant, we subtracted the time of the first button press in the execution interval from the last button press.

Play time is typically seen to capture primarily execution related processes (cf. Wohldman, et al., 2007; 2008).

The second dependent variable, *deviance*, measured the accuracy of participants' performance. Again, this was computed as the average of two sub-measures. First, we measured the difference between the number of beats that the participants produced and the number of beats that were required for this particular rhythm, as a percentage of the total rhythm length. Second, we assessed whether the participants' relative frequency of presses with the left and right buttons corresponded to the relative frequency of left and right presses required by the rhythm, again as a percentage of total rhythm length.

For these analyses, trials in which the button presses of the participants deviated by 50% or more from the required button presses were excluded, as well as trials in which participants took longer than 12 seconds to play the rhythm, or in which there was a pause between two button presses longer than 2 seconds.

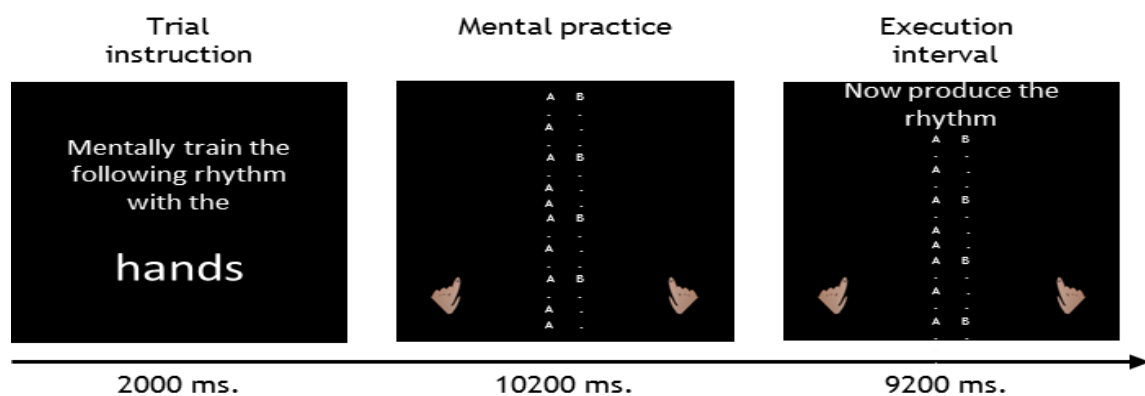


Figure 6.1 Illustration of the trial sequence in Experiment 7. The trial instruction (left panel) informed participants about the body part they had to mentally practice the rhythm with. They then mentally trained the rhythm in the mental practice interval (middle panel). In the execution interval (right panel) they executed the rhythm. The rhythm to be executed could either be the same or a different rhythm than the one they had practiced, and would need to be executed with the same or different body part.

6.1.4 Results

The data were analysed separately for *Deviance* and *Total Play Time* with repeated measures 2 x 2 ANOVAs, with two factors. The first factor Body Part (same, different) and Rhythm (same, different). Of the 19 participants tested, one participant was excluded, due to problems with the response device, which did not store responses. Three participants were excluded because they did not make valid responses in more than 20% of the trials.

The analysis of *total play time* revealed a main effect of factor of Rhythm, $F(1,15) = 71.98, p < 0.001, \eta^2_p = .84$, with faster play time for rhythms that had been trained in the same trial, compared to rhythms that had not been trained. The main effect of Body Part was not significant $F(1,15) = .56, p = 0.468, \eta^2_p = .038$, and neither was the interaction, $F(1,15) = 1.419, p = 0.253, \eta^2_p = .092$, revealing no evidence for any losses of the benefits of mental practice due to switching body parts. Indeed, the difference for better performance for trained rhythms was present for both rhythms to be executed with the same, $t = 4.24, p < .001$, and with a different body part, $t = 7.23, p < .001$, being, if anything, larger for different body parts (See figure 6.2). The pattern of results was statistically identical, if initiation times or playing times were analysed separately, revealing similar main effects on both sub-measures (initiation time, $F(1,15) = 36.48, p < .001, \eta^2_p = .723$; play time, $F(1,15) = 61.69, p < .001, \eta^2_p = .815$), but no interactions or main effects of body part.

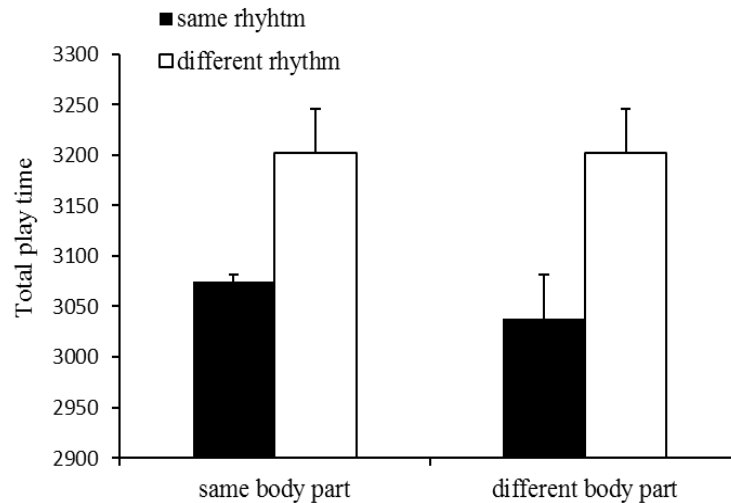


Figure 6.2 Total Play time in Experiment 7. The two left bars show the data for rhythms that had to be executed with the same body as used during mental practice of the rhythm, and the two right bars when they had to be executed with a different body part. The black bars show the data from trials in which the same rhythm had to be executed as the one that was just mentally practiced. The white bars show the data when a different rhythm had to be executed. Error bars show the standard error of the mean.

The analysis of total deviance revealed no main effect of the factor Body Parts (same, different), $F(1,15) = .104$, $p = 0.752$, $\eta_p^2 = .007$. Also main effect factor of the factor Rhythm (same, different) was not significant, $F(1,15) = .052$, $p = 0.823$, $\eta_p^2 = .004$, and neither was the interaction, $F(1,15) = 1.336$, $p = 0.267$, $\eta_p^2 = .087$, (See Fig, 6.3). Thus, in sum, the measure of deviance was not sensitive to either the mental practice or transfer manipulation.

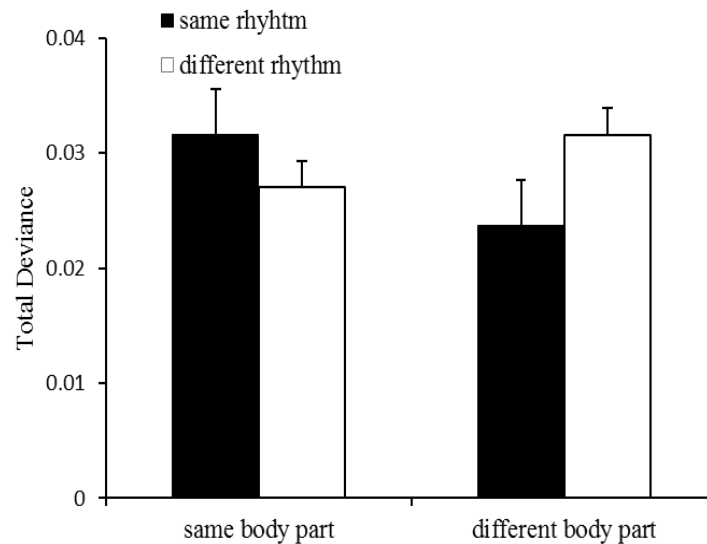


Figure 6.3 Total Deviance in Experiment 7. The two left bars show the data for rhythms that had to be executed with the same body as used during mental practice of the rhythm, and the two right bars when they had to be executed with a different body part. The black bars show the data from trials in which the same rhythm had to be executed as the one that was just mentally practiced. The white bars show the data when a different rhythm had to be executed. Error bars show the standard error of the mean.

6.1.5 Discussion

While Experiment 1 to 6 suggested that mental practice involves activating body part specific motor planning processes, Experiment 7 now explored whether the associated performance improvements can be transferred to another body part. As in Experiment 2, we found that prior mental practice of the rhythms was effective in improving subsequent rhythm production time. We found that this affected both the time to initiate the rhythms – according to Wohldman et al. (2007, 2008) reflecting an impact on subsequent planning processes –, but also playing time, indicator of efficiency of lower level execution processes. Importantly, however, this benefit of mental practice could be transferred to a different body part without any detectable loss of performance improvements. In other words, if participants mentally practiced a foot rhythm, they were afterwards as effective in producing this rhythm with the

hand than with the foot. Similarly, when having mentally practiced a hand rhythm, they gained as much performance improvements when later having to execute this rhythm with the foot than with the hand.

This finding shows that participants experienced near perfect transfer of a trained rhythm to another body part, suggesting a highly abstract mode of representing the skill. At first, this might seem like a trivial finding. After all, participants could have simply memorized the sequence of left and right button presses, without mentally practicing them. Consider, however, that mental practice did not only affect response time, but also playing time as well. According to prior research (Wohldman, Healy, & Bourne, 2007; 2008), playing time of such button sequences is directly associated with motor execution processes. This suggests that, even though that the action plans during mental practice were abstract enough to be transferred to another body part, they were nevertheless concrete enough to affect the execution of the rhythms itself (playing time), not only the time to plan them (initiation time) before execution.

At first glance, the present results of near-perfect transfer might also seem at odds with the involvement of planning related but body part specific motor processes (as suggested in Experiments 1 to 6). It is, however, in line with the idea that action planning can occur on various levels, some being “proximally” related to the actual motor movements, others more “distal” (Hommel et al., 2002), affecting specifically high-level, outcome related representations of the intended actions. In our case, for example, planning might have occurred on the level of left-right button presses, and the sequence of these presses, but decoupled from the body parts involved.

The finding of near-perfect transfer is also in line with the idea that motor skills established through mental practice may lend itself excellently for subsequent transfer (Wohldman,

Healy & Bourne, 2008). As noted, Amemiya, Ishizu, Ayabe, & Kojima, (2010) found that mental practice improved subsequent performance of both the ipsilateral and the contralateral finger, physical practice improved only ipsilateral performance. If one assumes that transfer of motor skills happens particularly on the level of planning (e.g., Lohse, Healy & Sherwood, 2010), this would suggest that action plans established for immediate execution rely strongly on body-part related processes, while action plans established for mental practice can be more abstract, and may involve representations that can guide action production even though they are decoupled from the low-level motor processes that guide the movement of the specific body parts (cf. Hommel, et al., 2001).

6.2.1 Experiment 8 - Transfer of Imitation and Mental Practice

Experiment 7 demonstrated near perfect transfer of a motor skill learned with one body part (e.g., the hands) to another body part (e.g., the feet), suggesting that the action plans established during mental practice are relatively abstract and decoupled from low level motor processes. Experiment 8 now tests if a similar high-level mode of planning can be achieved also when actions are observed.

There are reasons to suspect that the body part independence observed in Experiment 7 might be not as pronounced here. The symbolic mode of presentation in Experiment 7 might have enabled focusing on abstract sequences of left-right button presses, independently of the required body parts. In Experiment 8, the body parts are part of the rhythms produced by the other person. If it is the case that observed actions are “directly matched” on motor plans in the observers’ repertoires (Rizzolatti & Craighero, 2004), these plans should now be body part specific; participants should be less able to generate body-part independent representations of the observed motor sequences.

In Experiment 2, we therefore varied the mode in which the rhythms were presented. As before, participants were instructed to mentally practice different complex rhythms with either hands or feet, in order to perform them later as quickly and accurately as possible. However, now, the rhythms were not presented symbolically, but in the form of a video of somebody else performing the rhythm. Again, we varied, first, whether this rhythm they had to produce was the same or a different rhythm. Second; we varied whether this rhythm had to be performed with the same or different body part than that used for mental practice.

The predictions were as before. If mental practices of the rhythms improve performance, participants should make fewer errors when performing the same rhythm that they had just practiced, compared to performing a different rhythm. Second, if mental practice is body part specific, then these benefits of executing the same rhythm (compared to a different one) should only be found when participants are using the same body part for mental practice and actual performance.

6.2.2 Method

Participants: twenty four students (21 women, 3 men, age range 18-23 years) took part in the experiment. Participants satisfied all requirements in volunteer screening and gave informed consent approved by the school of Psychology at the University of Plymouth. All participants were in good health, had no history of disease or medical treatment that might influence motor performance and visual-motor functions. The study was approved by the Plymouth University Ethics Committee.

Material, apparatus and procedure. Materials and apparatus were identical to experiment 7, with the following exceptions. Participants now did not see a symbolic rhythm description, but watched another person produce the same rhythms, as in Experiments 5 and 6 (see figure, 6.4), and (Appendix H).

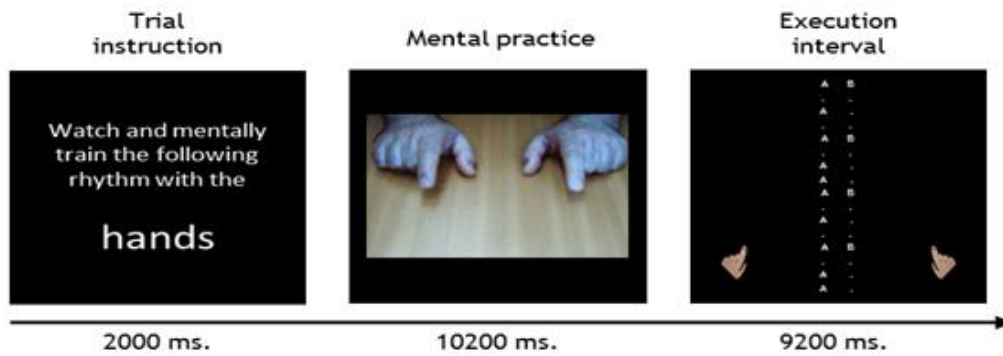


Figure 6.4 Illustration of Trial in Experiment 8. The trial instruction (left panel) informed participants about the body part they had to mentally practice the rhythm with. They then mentally trained the rhythm in the mental practice interval (middle panel) by observing another person execute the rhythm. In the execution interval (right panel) they executed the rhythm. The rhythm to be executed could either be the same or a different rhythm than the one they had practiced, and would need to be executed with the same or different body part.

6.2.3 Results

The analysis investigated the transfer of learning of rhythms played by another person to another body part. As in Experiment 7, we analysed Total Play Time and Total Deviance. Of the 24 participants tested, two participants were excluded due to problems with the response device, which did not store responses properly. Five participants were excluded because they did not make valid responses in more than 20% of the trials.

Participants' responses to the rhythms were analysed separately for Total Deviance and Total Play Time with a repeated measures 2 x 2 ANOVA, with the two factors Body Part (same, different) and Rhythm (same, different). The analysis of Total Play Time revealed no main effect of Body Part, $F(1,16) = 2.39$, $p = .141$, $\eta^2_p = .130$, but a highly significant main effect of Rhythm, $F(1, 16) = 11.129$, $p = .004$, $\eta^2_p = .410$, with on average faster rhythm production times for rhythms observed in this trial, compared to not-observed rhythms. Importantly, the interaction of the two factors was significant, $F(1, 16) = 4.82$, $p = .043$, $\eta^2_p = .232$, revealing larger benefits of prior rhythms observations for rhythms that had to be executed with the same compared to a different body part. In fact, when analysing the difference between trained and untrained rhythms separately for same and different body parts, significant difference were only apparent for the trials in which the body part did not change, $t = 6.07$, $p < .001$, but not for trials in which the body part did was different to the previously observed rhythm, $t = .96$, $p = .35$.

The pattern was numerically identical when initiation time and play time were analysed separately, even though the interaction just failed to reach significance in both cases (play time, $F(1, 16) = 2.446$, $p = .136$, $\eta^2_p = .180$; initiation time, $F(1, 16) = 2.887$, $p = .109$, $\eta^2_p = .153$). Moreover, for both sub-measures the benefit of prior observation was statistically present for rhythms to be executed with the same body part (play time, $t = 3.44$, $p = .003$; initiation time, $t = 5.19$, $p < .001$), but not for rhythms to be executed with a different body part (play time, $t = 2.05$, $p = .057$; initiation time, $t = .11$, $p = .91$).

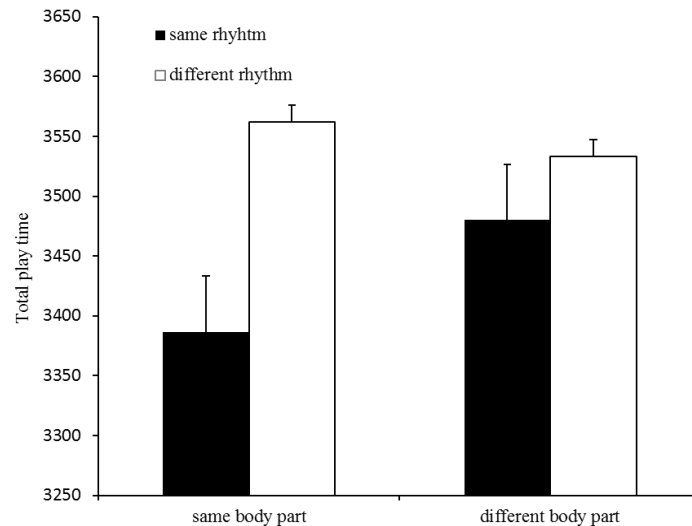


Figure 6.5 Total Play Time in Experiment 8. The two left bars show the data for rhythms that had to be executed with the same body as used during mental practice of the rhythm, and the two right bars when they had to be executed with a different body part. The black bars show the data from trials in which the same rhythm had to be executed as the one that was just mentally practiced. The white bars show the data when a different rhythm had to be executed. Error bars show the standard error of the mean.

The analysis of total deviance revealed no main effects of the factor Body Part (same, different), $F(1,16) = .271, p = .610, \eta^2_p = .017$, and no main effect of the factor Rhythm (same, different), $F(1,16) = .022, p = .884, \eta^2_p = .001$. As in the analysis of total play time, the interaction same and different body part and same and different rhythm was significant, $F(1, 16) = 4.371, p = .04, \eta^2_p = .237$. As in total play time, the benefit of mental practice for playing the rhythm more accurately was larger when the rhythm had to be executed with the same compared to a different body part. See (Figure 6.6). However, when analysed separately, the difference between same and different rhythms was neither significant for when participants used the same body part, $F(1,16) = .97, p = .34$, nor when they used a different body part, $F(1,16) = 1.56, p = .13$.

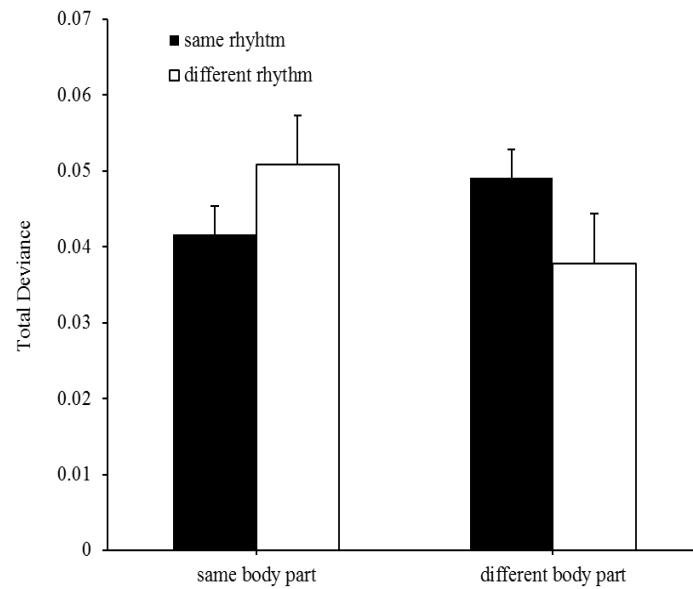


Figure 6.6 Total Deviance in Experiment 8. The two left bars show the data for rhythms that had to be executed with the same body part as used during mental practice of the rhythm, and the two right bars when they had to be executed with a different body part. The black bars show the data from trials in which the same rhythm had to be executed as the one that was just mentally practiced. The white bars show the data when a different rhythm had to be executed. Error bars show the standard error of the mean.

6.2.4 Discussion

While Experiment 7 demonstrated near perfect transfer of motor skills learned through mental practice with one body part to another body part, Experiment 8 shows that this is not the case when learning a motor skill through imitation. While prior mental practice enhanced performance of rhythms observed to be executed with the same body part, the same benefits could not be transferred – and were virtually absent –, when participants had to execute a rhythm that they had observed another person perform with a different body part. This difference occurred even though in both Experiment 7 and Experiment 8, participants knew in advance that they were just as likely to execute the mentally practiced rhythm with the same as with another body part. As such, the different findings suggest that mental practice allows relatively abstract action representations to be established, which still can effectively guide action execution, but not action observation. Action representation established through action execution appear to mandatorily be bound up with low-level motor properties – here the body part involved – and can not easily be abstracted away from these properties.

Chapter 7

General Discussion

7.1 General Discussion - Overview

Due to its role in novice and expert motor performance, mental practice is an important research focus in sports psychology and education. However, not much progress has been made in specifying the underlying processes, which are still either conceptualized as purely symbolic (Driskell et al., 1994; Minas, 1978; Sackett, 1934), or as deeply rooted in execution-related processes: emerging from a subliminal activation of the motor apparatus that allows actors to play through the sensations going along with the actions (Jacobson, 1930; Jeannerod & Frak, 1999). The present work instead proposes to conceptualize mental practice in terms of the action planning processes that precede motor execution, but which are nevertheless closely linked to them. The eight experiments reported here tested some first predictions of such an account.

In the following, I will first review the main results of these experiments, and will then discuss in detail how mental practice and imitation learning can be conceptualized in terms of action planning processes, as well as the discuss the implications of such an approach for outstanding question in sports psychology.

7.2 Summary of the Results of Experiment 1 to 6

Experiment 1 to 6 utilized a classical compatibility paradigm to test whether mental practice of motor skills relies on body-part specific motor processes involved in physical action execution. Participants mentally practiced complex rhythms with their feet or hands while using either the same or different body parts to respond to unrelated sounds played while they mentally practiced. Across experiments, we found a direct influence of mental practice on these unrelated responses. It took the form of a negative compatibility effect, making it harder

for participants to respond with the body part concurrently used in mental practice. Thus, while mentally practicing a rhythm with the hand participants were more likely to make accidental responses with the foot. Conversely, while mentally practicing with the foot, they were more likely to accidentally respond with the hand.

This effect of mental practice on the execution of an unrelated response was robust and generalizable. It was found when participants were mentally practicing the rhythms in order to perform them later from memory (Experiment 1) and when they merely practiced to improve their subsequent performance (Experiment 3). It was found when mental practice and execution of the rhythms was interrupted by the mental practice/execution of a different rhythm (Experiment 4), suggesting that the effect does not simply reflect the anticipation of an imminent response with this body part, and can be found when mental practice and execution are separated by an intervening task. It was found when participants practiced by watching somebody else perform the rhythms (Experiment 5), ruling out that the effects originate from the translation of a symbolic rhythm into motor codes, and extending our data to the case of observation learning or imitation. The effect was only eliminated when the need for mental practice was eliminated as well, while visual stimulation and task relevance of the rhythms was kept identical (Experiment 6), tying the negative compatibility effects directly to the mental practice of the rhythms, rather than to other, unrelated task-aspects.

This direct effect of mental practice on overt motor behavior supports the view that mental practice is, at least partially, enactive and draws upon body part specific motor processes. In addition, it provides new insights about the nature about this motor involvement. The negative compatibility effects observed here are not consistent with the view that mental practice gives rise to the same sub-threshold activation of low-level motor systems as the passive observation of action. Across studies and experimental paradigms, positive

compatibility effects are typically observed, where viewing of action-related stimuli facilitates – rather than impairs – the execution of motorically similar responses (for reviews, see Hommel, 2001; Kornblum, et al., 1990). Viewing hand and foot actions, for example, facilitates unrelated responses with the same body parts (Bach et al., 2007; 2008).

Rather, the negative compatibility effects were in line with the view that our mental practice task specifically draws upon the higher-level planning processes (cf. Hommel et al., 2001; Thomaschke, 2012). These processes allow actors to establish concrete plans for motor execution, by “binding” the different features an action needs to be successful – speed, direction of motion, or, here, the sequence of button presses with a certain body part – into unified plans for action. This binding allows even complex movements to be coordinated across effector systems, but, at the same time, renders the involved features less accessible for other responses. For example, it has been found that simply planning a left or right response makes it harder to make responses in the same direction, and planning to use a body part impairs the use of the same body part for another response (Stoet & Hommel, 1997; for similar effects, see Hübner & Druet, 2006; Schuch & Koch, 2004, 2010).

Our data therefore suggest that mental practice is based on these planning-related motor processes. During mental practice, they may allow actors to develop complex plans for action that are aligned with both their goals and the (anticipated) demands of the performance situation. Several additional aspects of our results supported such an involvement of planning related processes in mental practice. First, if the negative compatibility effects indeed reflect the formation of action plans, then they should be obtained only as long as the task requires participants to develop concrete plans for eventual execution. Indeed, across experiments, negative compatibility effects were found as long as the presented rhythms were the basis of subsequent motor performance, irrespective of whether this happened immediately after

practice (Experiment 1, 3 and 5) or only after an intervening task (Experiment 4). However, as soon as the rhythms were not the basis of a future action of the participants – the condition under which positive compatibility effects are typically observed in other stimulus response compatibility paradigms – these effects were completely eliminated (Experiment 6).

Second, another feature of planning accounts is that the integration of features into action plans, while preventing their use for other responses, will benefit the execution of current plans. Such an effect was revealed, first, in Experiment 2, which confirmed that mentally practicing the rhythms does indeed not only improve subsequent motor planning processes (as measured by time to initiate the rhythms), but motoric execution itself (measured by the time to execute the complete rhythm), replicating prior work on mental practice (Wohldman et al., 2007; 2008).

Second, and more importantly, such an effect was revealed by analysis of the spontaneous motor responses participants sometimes made during mental practice. We found that those participants with the strongest negative compatibility effects were the most likely to accidentally press a response key during mental practice. Importantly, these responses were made with the body part concurrently used for mental practice, consistent with the idea that they reflect action plans that participants “forgot” to inhibit. Although post-hoc, these data therefore confirm that mental practice indeed has two coupled effects on overt motor behavior: it prevents the use of the relevant action features in unrelated responses, and, at the same time, facilitates the execution of the current plan (cf. Hommel et al., 2001).

7.2 Summary of the Results of Experiments 7 and 8

Experiments 7 and 8 took a complementary approach to testing planning accounts of mental practice. Recent ideomotor models of action planning (Prinz, 1997; Hommel et al., 2001) assume that actions can be planned on multiple levels, some more proximally related to the motor commands sent to the muscle, some more distally. In other words, a hierarchy of action goals is typically assumed, with higher level goals directly related to the ultimate outcomes of the actions (“the goals”), and lower level goals (“the means”) that specify the motor actions required to achieve these goals (Ondobaka & Bekkering, 2012). Depending on one’s skill and its automatization, it may suffice to explicitly only specify the overall goals of a skill to trigger the subordinate release of motor movements. Such a relatively high level encoding of action goals may achieve relatively fluent encoding of actions, even in changing environments, where different motor actions are required for goal achievement. For example, when driving somewhere, experienced drivers explicitly only specify their target location and trust their lower level motor representations to safely guide them towards the goal, without requiring effortful cognitive involvement (Bargh and Wyer 1997).

Considering the prevalence of relatively abstract codes guiding action execution, it may be surprising that Experiment 1 to 6 revealed robust involvement of low-level motor features (i.e. the body part to be used) in mental practice, especially as the task could be solved by merely memorizing a sequence of left and right button presses in a non-effector specific manner. There are two potential reasons for this effect. The first is that participants were simply not skilled enough at producing the rhythms to engage in such a high level encoding of the rhythms. In other words, participants might have felt that imagery of the complete movements was required for effective performance. The second reason is, of course, that the task itself favoured such a body-part centric encoding of the mentally practiced actions. The

reason is that participants could be absolutely sure that the body part they used for mental practice was also the body part they would later use to reproduce the rhythm. This task aspect might have discouraged establishing relatively abstract action plans, and favoured plans specifying the involvement of body parts.

Experiment 7 and 8 therefore tested whether participants could also generate more abstract action plans during mental practice. We used a classical transfer task, in which participants were not sure about whether the same body part would be used during mental practice and execution, and where therefore more abstract action plans were favoured by the task. Participants first mentally practiced a rhythm, as before, but later had to execute this rhythm – or a different, non-practiced rhythm – with either the same or a different body part.

The results of Experiment 7 revealed that, indeed, participants were able to generate very abstract action plans. As in Experiment 2, we found that previous practice of a rhythm benefitted subsequent performance, affecting both time to initiate the rhythm as the time to fully execute it (cf. Wohldman, Healy, & Bourne, 2007, 2008). Importantly, however, the same benefits were achieved when execution involved a different body part than mental practice. This suggests that in this setting, where participants were not sure about the body part required for ultimate rhythm execution, participants were able to generate very abstract rhythm representations that could be transferred – without detectable impairments – to another body part. This excellent transfer of mentally practiced actions is in agreement with previous research and theorizing (e.g., Wohldman et al., 2008; Amemiya et al., 2010; Lohse et al., 2010).

A striking finding was that this perfect transfer only held when rhythms were practiced based on a symbolic rhythm description in Experiment 7. In Experiment 8, participants practiced

exactly the same rhythms by observing others. They watched as another person tapped the rhythm – with either their hands or their feet – and attempted to learn their own subsequent performance by watching this performance. In this setup, mental practice only benefitted rhythms played with the same body part as used in mental practice. This difference suggests that whereas relatively abstract action plans can be established during mental practice from a symbolic rhythm description, as soon as visual input is available that directly links the motor skill to a body part – as during action observation – any generated action plans are very much concrete and body part specific. It is consistent with the finding that imitation relies on systems that directly match an observed action to an action plan in the observer's motor repertoire (e.g., Iacoboni, 2009). De-coupling the body part from this representation might have required additional effort that participants did not engage in, considering the overall difficulty of the task.

7.3 Towards an Action Planning Account of Mental Practice

The results of the present study have direct implications on our knowledge of the processes underlying mental practice. Previous research has conceptualized these processes still as either conceptualized as purely symbolic (Driskell et al., 1994; Minas, 1978; Sackett, 1934), or as deeply rooted in execution-related processes: emerging from a subliminal activation of the motor apparatus that allows actors to play through the sensations going along with the actions (Jacobson, 1930; Jeannerod & Frak, 1999). By linking mental practice to the planning processes that form the interface between higher-level “cognitive” and lower-level motor processes, the present work suggests a unification of these approaches.

In such views, mental practice can be conceptualized as the planning activity itself, with physical execution either being indefinitely delayed or decoupled (cf. Koch, Keller, & Prinz,

2004). As it is the case for action planning, it involves a linkage of intended action features to a concrete action plan: actors specify how the action would look and feel if it were successfully carried out, so that it matches both the goals of the individual and the external demands. Subsequent rehearsal allows these “movement images” to be sharpened and refined, so that they can drive motor execution more effectively and are aligned with both the goals of the individual and the demands of the performance situation.

Because such planning views incorporate aspects of both symbolic and enactive accounts of mental practice, they allow us to integrate several conflicting findings in the literature and resolve several debates.

7.4 Implications for Research in Sport Psychology

Current accounts of mental practice struggle with the finding that mental practice primarily benefits skills with cognitive components (e.g., Feltz & Landers, 1983; Hird et al., 1991; Ryan & Simons, 1983), but also has direct effects on motor execution and physiological variables (e.g., Wohldmann et al., 2007; 2008; Yue & Cole, 1992). While enactive theories struggle to account for the cognitive benefits, symbolic accounts have problems explaining motor or physiological benefits (cf. Moran, Campbell, Holmes, & MacIntyre, 2012). Action planning accounts, however, can account for both. The cognitive benefits are in line with the notion that action planning is particularly beneficial if several sets of complex action sequences have to be coordinated, or integrated with complex environmental demands. Physiological or execution-related benefits, in contrast, can be explained because the purpose of action planning is effective execution. If mental practice allows existing movement plans to be sharpened and refined, they will become effective drivers of later lower-level motor processes. Indeed, the reported manual strength gains after mental practice, for example, are not due to changes to the actual muscles, but due to more effective signals reaching them (Yue & Cole, 1992; Ranganathan, Siemionow, Liu, Sahgal, Yue, 2004). Moreover, the strength gains are tied to the vividness of imagery during mental practice, consistent with the idea that sharper mental images generated during mental practice are better drivers of intended motor output (Reiser et al., 2011).

A second debate concerns the factors influencing the benefits of mental practice on performance. Motor theories naturally account for the larger benefits of 1st person (rather than 3rd person) and kinesthetic imagery, where people imagine the actions as if they would be carrying them out (Lorey et al., 2009; Stinear et al., 2006). After all, this type of imagery most closely mirrors the sensory feedback that would emerge from a subliminal activation of

the motor system. However, those theories struggle to account for effects of imagery that are not motor-related. It is known, for example, that mental practice has stronger benefits when imagery also captures the environmental, cognitive and emotional aspects of the performance situation (for a review, see Holmes & Collins, 2001). As the purpose of action planning is precisely the mediation between the higher-level goals, environmental influences and the action possibilities of the individual, planning-related theories can account for the influences of such extraneous (“distal”) variables, ensuring that the resulting action plans properly take into account the demands of the performance situation (for an extensive review of the role of distal variables in action planning, see Hommel et al., 2001; for use affective action features in action planning, see Eder, Müsseler, & Hommel, 2012).

7.5 Implications for Neuroscientific Investigations into Motor Imagery

Understanding mental practice in terms of action planning-related processes allows us to integrate conflicting findings from neuroimaging studies. First, while neuroimaging studies are generally consistent with the idea that action-related structures are engaged in motor imagery, there is considerable debate whether this activation reflects execution-related processes. For example, when amputees report the feeling of being able to move their amputated hand, both the phenomenological experience and brain activation corresponds more closely to actual movement execution than to movement imagery, even though kinaesthetic feedback is controlled (Raffin et al., 2012). Such dissociations are no surprise for planning accounts, which assume that any overlap should be found for planning but not execution related structures. Indeed, primary motor cortex activation – closely linked to physical motor execution – is not consistently found across studies on motor imagery. In contrast, pre-motor cortex activation, much more closely aligned to action planning, is consistently observed (for a review, see Lotze & Halsband, 2006). Moreover, a recent fMRI

study has directly compared imagery-related brain activity with both preparatory and execution related activity. As predicted from the present findings, motoric activation during imagery was aligned with planning, not execution (Hanakawa et al., 2006).

Second, our data may have something to say on why these motoric activations during motor imagery are sometimes inhibitory (rather than facilitatory). These inhibitory effects are typically discussed in terms of a prevention of spontaneous motor outflow (e.g., Solodkin et al., 2004; Tipper & Bach, 2011). Our present data suggest that they may be better interpreted as a more natural consequence of an action planning process that involves a binding of motor features to a not-yet executed motor plan such that these features are not available for unrelated responses. Indeed, the areas involved for these suppressive effects on motor output during imagery – the supplementary motor area and the parietal visuomotor areas (Solodkin et al., 2004) – are also crucial nodes in action planning networks (e.g., Hanakawa et al., 2006). Moreover, the supplementary motor area in particular has been implicated in action-effect learning and may therefore represent specifically the intended features of an action plan (Elsner et al., 2002; Melcher et al., 2008).

Finally, our data shed light on whether the pre-motoric activation is merely an epiphenomenon rather than a crucial component of motor imagery (for discussion, see Jeannerod, 1994; Mahon & Caramazza, 2008). Our data argue against this possibility. First, the fact that the inhibitory effects are linked to the execution of an action plan, suggest not a mere motor outflow process but a goal-directed linkage to action goals. Second, and more importantly, our paradigm also revealed effects of motor execution on mental practice, such that subsequent execution was facilitated when mental practice was interrupted by a response with the same body part. Such effects are seen to be strong evidence for an involvement of motor structures in cognition, as they reflect a “backwards” influence, where activation in the

motor system influences task performance. They would not be expected if motor systems would not play a crucial role in the task. For our study, they therefore suggest that the motoric activations during mental practice play a fundamental role in mental practice and are functionally linked to the improvement of the trained motor skill. Of course, the effects observed here need to be interpreted with caution, as they were not as robust as the negative compatibility effects and our paradigm was not designed to investigate these action-mental practice effects. Nevertheless, the presence of these action-to-imagery effects provides direct evidence that motor structures are required for mental practice.

It is an open question why these action-to-practice effects were in the opposite direction as the compatibility effects found in the responses to the sounds. Along with certain models of motor imagery (Jeannerod, 1995) and mental practice (Beisteiner, Höllinger, Lindinger, Lang, & Berthoz, 1995), we speculate that whereas response initiation requires that the required action codes are not already used for another goal, imagery can benefit from concurrent kinesthetic feedback that strengthens the underlying movement representations. Although testing these ideas is beyond the scope of the present article, it is important to note that identical dissociations had been observed in the original studies on action effect binding (Stoet & Hommel, 1999). While planning a response inhibits the use of similar motoric features in other responses, executing an action provides additional activation to – and facilitates the execution of – movement plans that are currently held active, and share some of the action's features. As such, while having to be clarified by further research, these effects of motor execution on mental practice nevertheless (1) highlight the functional role of action related processes for successful mental practice, and (2) further support the proposed link to prior research on the processes of action planning.

7.6 Linking Mental Practice and Imitation Learning

While Experiments 1 to 4 link action planning to mental practice, Experiment 5 extended this link to imitation, a research focus of anthropology and developmental psychology. Imitation is a key means for transmitting knowledge, both within and between generations. It allows observers to put themselves into the other people's shoes, vicariously experience the outcome of their actions and learn from their experience, enabling them to later reproduce the behaviours and achieve the same goals. It is often assumed that humans can imitate because watching others does give rise to a subtle 'resonance' of the motor apparatus, which manifests as a tendency to non-strategically and non-consciously copy others' behaviour and body postures (Chartrand & Bargh, 1999; for reviews, see Heyes, 2011; Wang & Hamilton, 2012; van der Wel et al., 2013). It is assumed that, during imitation proper, observers would similarly "tap into" this motor activation to reproduce the desired behaviors.

Experiment 5 challenges this idea by revealing that the general motor resonance evoked by incidentally observing others is absent when people watch others with the express purpose to imitate. Instead, the to-be-imitated action features were less – rather than more – available for unrelated responses. Experiment 4 therefore suggests that watching somebody to imitate is more akin to mental practice than automatic imitation and gives rise to the same binding effects. Imitating an observed action may therefore similarly involve the purposeful selection of intended action features and "binding" them into an action plan. The only difference is that in mental practice these features were self-generated, while in imitation they could be extracted directly from the other person's action.

The implied difference between imitation proper and more automatic forms of imitation is consistent with recent theoretical developments in infant research. There, imitation is

similarly distinguished from its more automatic counterparts, and understood as a goal-directed process, which serves the acquisition of knowledge about which sequences of motor behaviours achieve a particular outcome (Csibra, 2008; Heyes, 1993). For example, when intending to imitate, infants do not – as motor resonance accounts would imply – merely copy the observed movements, but link them to a goal: they faithfully reproduce the seen motor behavior only, when they believe it to be crucial for goal achievement (e.g. Gergely, Bekkering, & Király, 2002; Bekkering, Wohlschlaeger & Gattis, 2000). Moreover, these forms of imitation are not automatic. They emerge from an intentional stance for learning, which is triggered either by the motivation to attain desired action consequences (for a review, see Elsner, 2007), or by “natural pedagogy”, the various cues adults give to signal to the infant that there is something to learn (for an overview, see Csibra & Gergely, 2009).

Experiment 5 therefore suggests that this distinction between automatic and intentional imitation is mirrored on the motor level. Whereas incidentally watching somebody generally primes the motor apparatus for similar movements, in goal-directed imitation, these activations are linked to a goal. Only motor behaviours that subservise this goal will be facilitated, while others – even when motorically similar – are inhibited. This hypothesis could be tested in typical mimicry experiments, where it is found that observation of another person elicits a tendency to perform similar movements (e.g. Chartrand & Bargh, 1999). We predict that, when the other person is just incidentally watched, their movements (e.g. face rubbing) should evoke not only automatic imitation of the specific movements, but also a more general tendency to use the same body part, even for unrelated movements (e.g., finger tapping). In contrast, when the goal is to watch the other person for later imitation, such a general activation of the body parts should be absent. Any movements that are observed should capture specifically the to-be-imitated behaviour.

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Appendices

Appendix (A) Experiment one:

Training one

"Dear participant!

Thank you for taking part in this experiment. Your task will be to practice different rhythms in your mind and later to re-produce them as quickly as possible.

At the start of each trial you will first be informed about the body parts you will have to use to re-produce the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove your shoes if you like.

Then, the rhythm will appear. Press any button to see an example."

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot pedal. A *B* marks a beat with the right Enter key or the right foot pedal.

Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on the screen with the designated keys (foot or hand)."

Training two:

"In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first watch and practice the rhythm in your mind, and then reproduce it a few seconds later. Again, you will be informed at the start of each trial which body part you will have to use to tap the rhythm: either the hands (using the left Ctrl and right Enter keys), or the feet (using the red and green foot pedals). Then, the rhythm you will have to practice in your mind will appear.

Press any button to see an example."

"A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

A .

A B

. .

A .

. .

Don't do anything as long as the rhythm is on the screen --- Use your imagination!

Wait till the rhythm disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the rhythm. Please try to produce the rhythm with the highest possible speed while still being accurate.

Pressing any button starts a short training phase..."

Training three sessions:

"There is one more complication. We are interested in how much you will benefit from mentally practicing the different rhythms. The rhythms that you will have to produce can either be the same or different to the rhythms that you have trained. Two differences are possible:

1. The rhythms might need to be performed with a different body part than how you originally trained them. For example, you might need to mentally practice a rhythm with the foot and then tap it with the hands.

2. The rhythms that you need to perform might themselves be different than the ones you practiced. For example, you might practice a rhythm starting with AABAAB while you may have to perform a rhythm starting with BABABA,

You will be informed before you produce the rhythms of both the body part that you will need to use and which rhythm you will have to tap.

Press any key for a short training phase."

Actual experiment:

Appendix (B) Experiement two

Training session one:

"Dear participant!

thank you for taking part in this experiment. Your task will be to practice different rhythms in your mind and later to re-produce them as quickly as possible.

At the start of each trial you will first be informed about the body parts you will have to use to re-produce the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove your shoes if you like.

Then, the rhythm will appear. Press any button to see an example."

"A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot

pedal. A *B* marks a beat with the right Enter key or the right foot pedal.

Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on

the screen with the designated keys (foot or hand)."

Training session two:

"In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first watch and practice the rhythm in your mind, and then reproduce it a few seconds later.

Again, you will be informed at the start of each trial which body part you will have to use to tap the rhythm: either the hands (using the left Ctrl and right Enter keys), or the feet (using the red and green foot pedals).

Then, the rhythm you will have to practice in your mind will appear.

Press any button to see an example."

"A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

A .

A B

. .

A .

. .

Don't do anything as long as the rhythm is on the screen --- Use your imagination!

Wait till the rhythm disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the rhythm. Please try to produce the rhythm with the highest possible speed while still being accurate.

Pressing any button starts a short training phase..."

Trianing session3:

"There is one more complication. We are interested in how much you will benefit from mentally practicing the different rhythms.

The rhythms that you will have to produce will therefore be either the same or different to the rhythms that you have trained. For example, you might practice a rhythm starting with AABAAB while you may have to perform a rhythm starting with BABABA,

So please try to mentally practice the presented rhythms as effectively as you can.

Howevewer, even if the rhythm you need to produce is not the same as the one you practiced, please try nevertheless to tap it as accurately and as quickly as possible.

Press any key for a short training phase."

"Pressing any button starts a short training phase..."

Actual Experiment:

"Dear participant!

Pressing the enter-button starts the actual experiment. Remember; please respond as quickly and accurately as possible. Thank you for taking part in our experiment!

The experimenter will be happy to answer any questions you might have

1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A B
A .	. .	. .	A .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A B
. .	. .	. .	. .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	A B
. B	. .	. .	. B	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. B	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	A B
. .	. .	. .	. .	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. .	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

Appendix (C) Experiment three:

Training session one: First instruction screen:

Dear participant!

Thank you for taking part in this experiment. Your task will be to tap different rhythms with hands or feet. At the start of each trial you will first be informed about the body parts you will have to use to tap the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove your shoes if you like. Then, the rhythm will appear. Press any button to see an example."

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot pedal. A *B* marks a beat with the right Ctrl key or the right foot pedal.

Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on the screen with the designated keys (foot or hand)."

Training session 2

First instruction screen:

"In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first mentally train the rhythm by watching another person perform it on the computer screen. Then you will have to reproduce the rhythm yourself.

Again, you will be informed at the start of each trial which body part you will have to use (by yourself and the other person) to tap the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the foot pedals).

Then, the a video showing the other person tap the rhythm will appear. Please watch closely, and use this video to mentally practice the rhythm.

Press any button to see an example." "Don't do anything as long as the video is playing --- Use your imagination and mentally practice the rhythm that you see the other person perform! Wait till the movie disappears and an instruction saying *Now produce the rhythm* appears. You will then have around 8 seconds to reproduce the rhythm.

Pressing any button starts a short training phase..."

Training session 3

First instruction screen:

"There is one more complication. We are interested in how much you will benefit from mentally practicing

the different rhythms. The rhythms that you will have to produce can either be the same or different to the rhythms that you have trained. Two differences are possible:

1. The rhythms might need to be performed with a different body part than how you originally trained them. For example, you might need to mentally practice a rhythm with the foot and then tap it with the hands.
2. The rhythms that you need to perform might themselves be different than the ones you practiced. For example, you might practice a rhythm starting with AABAAB while you may have to perform a rhythm starting with BABABA, You will be informed before you produce the rhythms of both the body part that you will need to use and which rhythm you will have to tap.

Press any key for a short training phase."

Actual experiment:

Pressing the enter-button starts the actual experiment. Remember; please respond as quickly and accurately as possible. Thank you for taking part in our experiment!

The experimenter will be happy to answer any questions you might have

1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A .
A .	. .	. .	A .	. .	A .	. .	A .	. .	A .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	. .	. .	. .	. B	. B	. B	. .	. .	. .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A .
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A .
. .	. .	. .	. .	. .	A .	. .	A .	. .	A .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	. .	. .	. .	. B	. B	. B	. .	. .	. .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A .
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	A .
. B	. .	. .	. B	. .	. B	. .	. B	. .	A .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. .
A .	A B	. B	. B	. B	. B	. B	. B	A B	A .
. B	. .	. .	. B	. B	. B	. .	. .	. .	A .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	A .
. .	. .	. .	. .	. .	. B	. .	. B	. .	A .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. .
A .	A B	. B	. B	. B	. B	. B	. B	A B	A .
. B	. .	. .	. .	. B	. B	. .	. .	. .	A .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

Appendix (D) Experiment four:

Training session 1 First instruction screen:

Dear participant!

Thank you for taking part in this experiment. Your task will be to memorize different rhythms and later to re-produce them. At the start of each trial you will first be informed about the body parts you will have to use to re-produce the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove

your shoes if you like. Then, the rhythm will appear. Press any button to see an example.

Second instruction screen:

A B

..

A .

..

A B

..

A .

..

A B

..

A .

..

A B

..

A .

..

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot pedal. A *B* marks a beat with the right Enter key or the right foot pedal. Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on the screen with the designated keys (foot or hand).

Training session 2 First instruction screen:

In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first watch and memorize the rhythm, and then reproduce it a few seconds later. Again,

you will be informed at the start of each trial which body part you will have to use to reproduce the rhythm: either the hands (using the left Ctrl and right Enter keys), or the feet (using the red and green foot pedals). Then, the rhythm you will have to memorize will appear.

Press any button to see an example. Second instruction screen:

A B

..

A .

..

A B

..

A .

..

A B

..

A .

A .

A B

..

A .

..

don't do anything as long as the rhythm is on the screen, though, wait till the rhythm

disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the rhythm. Pressing any button starts a short training phase...

Training session 3 / First instruction screen:

There is one more complication. We will try to interrupt your memorization. We will be playing two different sounds - a low and a high beep - to you during the intervals in which

you try to memorize the rhythms. If you hear a low beep, please press both foot pedals as quickly as possible. If you hear a high beep, please press both finger keys as quickly as possible. This task is designed to disrupt your concentration. Please try to not be interrupted. Respond to the beeps as fast as you can, but don't let your concentration be disrupted. Press any key to hear the different sounds.

Actual experiment

Pressing the enter-button starts the actual experiment. Remember; please respond as quickly and accurately as possible..

1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A B
A .	. .	. .	A .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A B
. .	. .	. .	. .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	A B
. B	. .	. .	. B	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. B	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	A B
. .	. .	. .	. .	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. .	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

Thank you for taking part in our experiment! The experimenter will be happy to answer any questions you might have.

Appendix (E) Experiment Five

Training session one:

Dear participant!

Thank you for taking part in this experiment. Your task will be to practice different rhythms in your mind and later to re-produce them as quickly as possible.

At the start of each trial you will first be informed about the body parts you will have to use to re-produce the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove your shoes if you like. Then, the rhythm will appear. Press any button to see an example.

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot pedal. A *B* marks a beat with the right Ctrl key or the right foot pedal.

Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on the screen with the designated keys (foot or hand).

Training session two:

"In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first watch and practice the rhythm in your mind, and then reproduce it a few seconds later. Again, you will be informed at the start of each trial which body part you will have to use to tap the rhythm: either the hands (using the left Ctrl and right Ctrl keys), or the feet (using the red and green foot pedals). Then, the rhythm you will have to practice in your mind will appear.

Press any button to see an example."

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

A .

A B

. .

A .

. .

Don't do anything as long as the rhythm is on the screen --- Use your imagination!

Wait till the rhythm disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the rhythm. Please try to produce the rhythm with the highest possible speed while still being accurate.

Pressing any button starts a short training phase.

Training three:

"There is one more complication. We will try to interrupt your mental practice. We will be playing two different sounds - a low and a high beep - to you during the intervals in which you try to practice the rhythms in your mind. If you hear a low beep, please press both foot pedals as quickly as possible. If you hear a high beep, please press both finger keys as quickly as possible. This task is designed to disrupt your concentration. Please try to not be interrupted. Respond to the beeps as fast as you can, but don't let your concentration be disrupted.

Press any key to hear the different sounds.

Pressing any button starts a short training phase.

Training complete!

Actual experiment:

Pressing the enter-button starts the actual experiment. Remember; please respond as quickly and accurately as possible.

1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A B
A .	. .	. .	A .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A B
. .	. .	. .	. .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	A B
. B	. .	. .	. B	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. B	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	A B
. .	. .	. .	. .	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. .	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

Thank you for taking part in our experiment! The experimenter will be happy to answer any questions you might have.

Appendix (F) Experiment Six

Training one:

"Dear participant!

Thank you for taking part in this experiment.

Your task will be to watch different rhythms that another person's taps with hands or feet and then to check whether they correspond with a rhythm that is subsequently displayed in a more abstract format.

Press any button to see an example of a rhythm movie. While you watch it, try to memorize the sequence of movements."

Watch the rhythm

"These movies can also show rhythms performed with the feet.

Press any button to see the same rhythm done with the feet..."

Watch the rhythm

"As said, your task will be to check whether this movie corresponded to a rhythm that is displayed in a more abstract format.

Press any button to see the same rhythm presented abstractly..."

"A .

. B

. .

. .

A .

. B

. .

. .

A B

. .
 . .
 . .
 A .
 . B

Imagine a metronome ticking in each line. An *A* marks a beat with the left foot or hand. A *B* marks a beat with the right foot or hand.

Pressing any button starts a short training phase that shows rhythms that can either match or not match the abstract description. "

Watch the rhythm

Tap the rhythm

Training two:

In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first watch and practice two rhythms in your mind, and then reproduce them later.

Again, you will be informed at the start of each trial which body part you will have to use to tap the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals).

Then, the rhythm you will have to practice in your mind will appear.

Press any button to see an example."

A B
 . .
 A .
 . .
 A B
 . .
 A .
 . .

A B

. .

A .

A .

A B

. .

A .

. .

In any trial, you will have to mentally practice two different rhythms in sequence,

both with the same body part (feet or hands). Don't do anything as long as the rhythm is on the screen --- Use your imagination!

Wait till the rhythm disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the two rhythms in sequence, first one, and then the other. Please try to produce the rhythm with the highest possible speed while still being accurate.

Pressing any button starts a short training phase.

Training complete!

Training three:

"There is one further complication. We will try to interrupt your memorization. We will be playing two different sounds - a low and a high beep - to you while you are watching and memorizing the rhythms. If you hear a low beep, please press both foot pedals as quickly as possible Press the left and right ctrl keys if you hear the high sound as quickly as possible.

Pressing V indicates a rhythm that matches the abstract description, and pressing N indicates a different rhythm.. Pressing any button starts a short training phase.

"A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An A marks a beat with the left key (\) or the left foot pedal. A B marks a beat with the right key (/) or the right foot pedal. Don't do anything as long as the rhythm is on the screen, though, wait till the rhythm disappears and an instruction saying

Now produce the rhythm appears. You will then have around 8 seconds to reproduce the rhythm.

Pressing any button starts a short training phase..."

Actual experiment

"Pressing a button starts the experiment... Pressing V indicates a rhythm that matches the abstract description, and pressing N indicates a different rhythm.

Watch the rhythm

Respond to sound

Say Yes or No

1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A B
A .	. .	. .	A .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A B
. .	. .	. .	. .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	A B
. B	. .	. .	. B	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. B	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	A B
. .	. .	. .	. .	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. .	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

Appendix (G) Experiment Seven

Training one:

"Dear participant!

Thank you for taking part in this experiment. Your task will be to practice different rhythms in your mind and later to re-produce them as quickly as possible. At the start of each trial you will first be informed about the body parts you will have to use to re-produce the rhythm:

either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove your shoes if you like.

Then, the rhythm will appear. Press any button to see an example."

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot pedal. A *B* marks a beat with the right Enter key or the right foot pedal.

Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on the screen with the designated keys (foot or hand)."

----Thank you----

Training two:

"In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first watch and practice the rhythm in your mind, and then reproduce it a few seconds later. Again, you will be informed at the start of each trial which body part you will have to use to tap the rhythm: either the hands (using the left Ctrl and right Enter keys), or the feet (using the red and green foot pedals). Then, the rhythm you will have to practice in your mind will appear. Press any button to see an example."

Watch the rhythm

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

A .

A B

. .

A .

. .

Don't do anything as long as the rhythm is on the screen --- Use your imagination!

Wait till the rhythm disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the rhythm. Please try to produce the rhythm with the highest possible speed while still being accurate.

Pressing any button starts a short training phase..."

Watch Rhythm

Tap the rhythm

Training three:

"There is one more complication. We are interested in how much you will benefit from mentally practicing the different rhythms. The rhythms that you will have to produce can either be the same or different to the rhythms that you have trained. Two differences are possible:

1. The rhythms might need to be performed with a different body part than how you originally trained them. For example, you might need to mentally practice a rhythm with the foot and then tap it with the hands.
2. The rhythms that you need to perform might themselves be different than the ones you practiced. For example, you might practice a rhythm starting with AABAAB while you may have to perform a rhythm starting with BABABA,

You will be informed before you produce the rhythms of both the body part that you will need to use and which rhythm you will have to tap.

Press any key for a short training phase."

Watch Rhythm

Corresponding by
mental practice

Tap the rhythm

Actual experiment

"Please rest your hands on the two ctrl-keys and the feet on the two foot pedals. Press any of these buttons to start the experiment.

Watch Rhythm

Corresponding by
mental practice

Tap the rhythm

1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A B
A .	. .	. .	A .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A B
. .	. .	. .	. .	. .	A .	. .	A .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	A .
. .	. .	. .	. .	. B	. B	. B	. .	. .	A .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A B
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. .
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	A B
. B	. .	. .	. B	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. B	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	A B
. .	. .	. .	. .	. .	. B	. .	. B	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. B
. .	. .	. .	. .	A .	A .	A .	. .	. .	. B
A .	A B	. B	. B	. B	. B	. B	. B	A B	A B
. B	. .	. .	. .	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	. .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

Thank you for taking part in our experiment! The experimenter will be happy to answer any questions you might have.

Appendix (H) Experiment Eight

Training session one:

"Dear participant!

Thank you for taking part in this experiment. Your task will be to tap different rhythms with hands or feet. At the start of each trial you will first be informed about the body parts you will have to **use** to tap the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the red and green foot pedals). You can remove your shoes if you like. Then, the rhythm will appear. Press any button to see an example."

"A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Imagine a metronome ticking in each line. An *A* marks a beat with the left Ctrl key or the left foot pedal. A *B* marks a beat with the right Ctrl key or the right foot pedal.

Pressing any button starts a short training phase. Try to reproduce each rhythm that appears on the screen with the designated keys (foot or hand)."

Training two:

"In the actual experiment you will not produce the rhythms right away. Rather, your task will be to first mentally train the rhythm by watching another person perform it on the computer screen. Then you will have to reproduce the rhythm yourself. Again, you will be informed at the start of each trial which body part you will have to use (by yourself and the other person) to tap the rhythm: either the hands (using the left and right Ctrl keys), or the feet (using the foot pedals). Then, the video showing the other person tap the rhythm will appear. Please watch closely and use this video to mentally practice the rhythm.

Press any button to see an example."

Watch the video

"Don't do anything as long as the video is playing --- Use your imagination and mentally practice the rhythm that you see the other person perform!

Wait till the movie disappears and an instruction saying *Now produce the rhythm* appears.

You will then have around 8 seconds to reproduce the rhythm.

Pressing any button starts a short training phase..."

Watch the video

"A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

A B

. .

A .

. .

Training three:

"There is one more complication. We are interested in how much you will benefit from mentally practicing the different rhythms. The rhythms that you will have to produce can either be the same or different to the rhythms that you have trained. Two differences are possible:

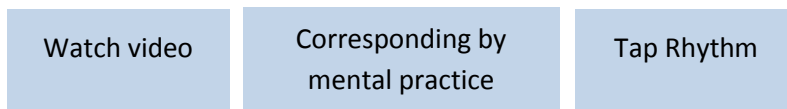
1. The rhythms might need to be performed with a different body part than how you originally trained them.

For example, you might need to mentally practice a rhythm with the foot and then tap it with the hands.

2. The rhythms that you need to perform might themselves be different than the ones you practiced. For example, you might practice a rhythm starting with AABAAB while you may have to perform a rhythm starting with BABABA,

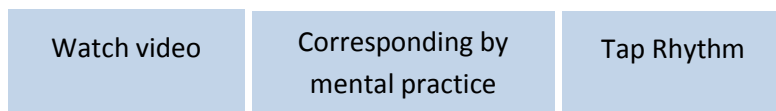
You will be informed before you produce the rhythms of both the body part that you will need to use and which rhythm you will have to tap.

Press any key for a short training phase."



Actual experiment

"Please rest your hands on the two ctrl-keys and the feet on the two foot pedals. Press any of these buttons to start the experiment.



1	2	3	4	5	6	7	8	9	10
. B	A B	A .	A .	A .	A .	A B	A .	A B	A .
A .	. .	. .	A .	. .	A .	. .	A .	. .	A .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	. .	. .	. .	. B	. B	. B	. .	. .	. .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A .
A .	. .	. .	A .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
A B	A B	A .	A .	A .	A .	A B	A .	A B	A .
. .	. .	. .	. .	. .	A .	. .	A .	. .	A .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	. .	. .	. .	. B	. B	. B	. .	. .	. .
. B	A B	A .	A .	A .	A .	A .	A .	A B	A .
A .	. .	. .	. .	A .	A .	. .	. .	. .	. .
. .	A .	. B	A B	. B	. B	. .	A B	A .	. B
. .	A .	. B	. .	. .	. .	. .	. .	. .	. .
11	12	13	14	15	16	17	18	19	20
A .	A B	. B	. B	. B	. B	A B	. B	A B	. B
. B	. .	. .	. B	. .	. B	. .	. B	. .	. B
. .	. B	A .	A B	A .	A .	. .	A B	. B	A .
. .	. .	. .	. .	A .	A .	A .	. .	. .	. .
A .	A B	. B	. B	. B	. B	. B	. B	A B	. B
. B	. .	. .	. B	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	A .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .
A B	A B	. B	. B	. B	. B	A B	. B	A B	. B
. .	. .	. .	. .	. .	. B	. .	. B	. .	. B
. .	. B	A .	A B	A .	A .	. .	A B	. B	A .
. .	. .	. .	. .	A .	A .	A .	. .	. .	. .
A .	A B	. B	. B	. B	. B	. B	. B	A B	. B
. B	. .	. .	. .	. B	. B	. .	. .	. .	. .
. .	. B	A .	A B	A .	A .	. .	A B	. B	A .
. .	. B	A .	. .	. .	. .	. .	. .	. .	. .

. Thank you for taking part in our experiment!

The experimenter will be happy to answer any questions you might have.