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States of focused attention and sequential action: A comparison of single session meditation and computerised attention task influences on top-down control during sequence learning☆

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ABSTRACT

Motor sequence learning is considered the result of the outflow of information following cognitive control processes that are shared by other goal-directed behaviours. Emerging evidence suggests that focused-attention meditation (FAM) establishes states of enhanced cognitive control, that then exert top-down control biases in subsequent unrelated tasks. With respect to sequence learning, a single-session of FAM has been shown to entrain stimulus-dependent forms of sequential behaviour in meditation naïve individuals. In the present experiment, we compared single-session effects of FAM and a computerised attention task (CAT) to test if FAM-induced enhanced top-down control is generally comparable to cognitive tasks that require focused attention. We also investigated if effort, arousal or pleasure associated with FAM, or CAT explained the influence of these tasks on sequence learning. Relative to a rest-only control condition, both FAM and CAT resulted in shorter reaction time (RT) in a serial reaction time task (SRTT), and this enhanced RT performance was associated with higher reliance on stimulus-based planning as opposed to sequence representation formation. However, following FAM, a greater rate of improvement in RT performance was observed in comparison to both CAT and control conditions. Neither effort, arousal nor pleasure associated with FAM or CAT explained SRTT performance. These findings were interpreted to suggest that the effect of FAM states on increased top-down control during sequence learning is based on the focused attention control feature of this meditation. FAM states might be associated with enhanced cognitive control to promote the development of more efficient stimulus-response processing in comparison to states induced by other attentional tasks.

1. Introduction

Motor sequences are an integral part of everyday life. Activities of daily living such as driving to work, typing up documents, or preparing a meal, allow us to navigate and interact with the environment successfully. Although these motor sequences are performed with automaticity, cognitive research has yet to provide clear theoretical perspectives on information processing and sequence learning strategies. Recently, cognitive processes utilised in goal-directed behaviours are thought to play a crucial role in sequence learning which leads to the idea that movement sequences can be executed using different learning strategies (Verwey, Shea, & Wright, 2015). For example, cognitive control is a key component in sequence learning and governs how attention is utilised in goal-directed behaviours. This raises the possibility that factors which influence cognitive control may also impact motor sequence learning. Of recent interest is the influence of meditation on cognitive control and especially attention, for subsequent cognitive processes utilised in various goal-directed behaviours. While different forms of meditation exist (Nash & Newberg, 2013), focused attention meditation (FAM) in particular appears to influence attentional control processes (Lutz, Slagter, Dunne, & Davidson, 2008). FAM is characterised by maintaining sustained attention on a specific instructed object (e.g. breath or body awareness) (Lutz et al., 2008; Slagter, Davidson, & Lutz, 2011). It has been shown to constrain attention in a narrow manner which, in turn, bias cognitive control to function in a convergent style for subsequent cognitive tasks (Colzato, Sellaro, Samara, Baas, & Hommel, 2015; Colzato, Sellaro, Samara, & Hommel, 2015). The cognitive control effects of FAM have recently been shown

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to extend to complex sequence learning (Chan, Immink, & Lushington, 2017; Immink, Colzato, Stolte, & Hommel, 2017). Theoretical models of FAM (Malinowski, 2013; Tang, Holzel, & Posner, 2015) have proposed that as an outcome of practice, core regulatory processes such as effort (Immink et al., 2017; Lumma, Kok, & Singer, 2015), arousal (Amihai & Kozhevnikov, 2015), and pleasure may have an influence on cognitive control but remain poorly understood. We provide a brief review of evidence for FAM on cognitive control and models of sequence learning control strategies.

1.1. Cognitive control in sequence learning

Motor sequence learning research has provided several cognitive control paradigms that explain the acquisition and representation of sequential action (Abrahamse & Noordzij, 2011; Verwey et al., 2015; Verwey & Wright, 2014). Common amongst these are the interactions between attention, memory, executive functions, and the development of models for task representation, information processing and error resolution for learning improvements over time (Abrahamse, Jimenez, Verwey, & Clegg, 2010; Abrahamse & Noordzij, 2011; Daltrozzo & Conway, 2014; Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Verwey et al., 2015). These models converge onto the evidence for two different learning strategies that stem from cognitive control (Verwey & Wright, 2014), namely responding to stimuli in an external stimulus-based control or using sequence-specific representations via an internal plan-based control to engage in sequence learning (Tubau, Hommel, & Lopez-Moliner, 2007; Verwey et al., 2015; Verwey & Clegg, 2005). Importantly, these two strategies demonstrate that movement sequences can be executed with different processing strategies, which signifies that sequence learning is a cognitive task that relies on both central and perceptual processes (Verwey et al., 2015). This highlights the crucial role of cognitive control during learning (Tubau et al., 2007), where factors prior to and during learning can often bias cognitive control and therefore learning strategy.

Although both stimulus- and plan-based control strategies predict sequence learning improvements with practice, the processes underlying performance improvement differ. This can be demonstrated using the motor learning paradigm known as the Serial Reaction Timed Task (SRTT: Nissen & Bullemer, 1987). In the SRTT, a stimulus appears at one of several locations on a screen and participants must respond by pressing the corresponding key according to the stimulus location on the screen. Unbeknownst to them, the order of the stimuli follows a structured sequence that repeats over cycles. Typically after several blocks of training, a transfer block with either a new or random sequence is presented and participants' exhibit increased reaction times due to learning of the original sequence that has occurred over the training blocks. The SRTT can be used to discern which strategy was utilised during learning. For example if an individual is using stimulus-based control, response latency decreases can be explained by the reinforcement of stimulus-response associations due to enhanced top-down cognitive control resulting in the prioritisation of attention at the target stimuli. In this case, the stimulus is used as the main source of information to signal the response without further elaboration in the context of the sequence (Tubau et al., 2007). Here, performance improvement is evident even when the task is lacking a sequence and can be described as general learning effects (Abrahamse & Noordzij, 2011). By contrast, performance improvement from plan-based control is associated with sequence-specific representations, which means that response efficiencies observed in latency reductions are based on reducing stimulus reliance and instead rely on responses and feedback (Abrahamse & Noordzij, 2011; Robertson, 2007; Willingham, 1999). The efficiencies developed are specific to an internalised structure of the practiced sequence, and so performance gains established by plan-based control are lost when there is deviance from the learnt sequence structure.

It is important to note that although stimulus- and plan-based control modes support learning, the learner is not exclusively utilising one control mode over the other during learning. For example, both control modes can simultaneously support the reduction of reaction time in sequence learning, but when no sequence regularity is evident, then the control system relies more on perceptual processes to support learning (Robertson, 2007). Recently, it has been noted that this switch of control modes can occur dynamically and almost instantaneously in learners which indicates that control changes are not just expected between learning blocks but also within block dynamics (Verwey et al., 2015). This switching of control modes mainly serves the purpose of maximising performance efficiency during sequence learning (Abrahamse, Braem, Notebaert, & Verguts, 2016), to which different frontal regions of the cortex may play a role in regulating cognitive contributions for performance (Koechlin & Summerfield, 2007).

One of the main determinants for the switching of stimulus- or plan-based control, is the manner by which cognitive control facilitates attention towards task-relevant stimuli and/or inhibition of irrelevant information (Friedman & Miyake, 2004; Gallant, 2016). Indeed, it is posited that cognitive control is contextually driven and works dynamically in a double-edged manner (Amer, Campbell, & Hasher, 2016; Amer & Hasher, 2014). When top-down cognitive control is enhanced, a resultant convergent control style prioritises speed and accuracy for responding to the stimulus (Colzato, Ozturk, & Hommel, 2012). In contrast, a weakened top-down control facilitates a divergent control style that searches for different plans to the problem (Colzato et al., 2012) through the exploration of stimulus-stimulus or response-response associations in the SRTT (Abrahamse et al., 2010; Verwey et al., 2015). Several factors such as individual differences and age can affect the modulation of top down cognitive control. For example, Biss, Ngo, Hasher, Campbell, and Rowe (2013) compared the performance of a task that required remembering a list of words between a group of older and younger adults and used part of the words disguised as distractors during presentation. It was found that older adults rarely forgot words that were presented as distractors while younger adults forgot words in both the original list and as distractors. Younger adults utilised an enhanced top-down control approach to focus attention and suppress distractors, while older adults were more creatively using the so-called "irrelevant distractors" for rehearsal (Amer et al., 2016; Amer & Hasher, 2014; Biss et al., 2013). More specifically, enhanced/weakened top-down cognitive control is considered to support two different systems in the form of information processing and storage, and problem solving during sequence learning. Specifically, it was found that early stages of sequence learning were not age-dependent and meditated by problem solving (weakening of top-down) while early and late sequence learning are mediated by more basic cognitive control functions such as processing speed, attention and working memory (enhanced top-down) (Krüger, Hinder, Puri, & Summers, 2017). More recent work has found that cognitive tasks like meditation is able to bias cognitive control and attention in either convergent (enhanced top-down) or divergent (weakened top-down) control styles (Colzato et al., 2012; Colzato, Szapora, Lippelt, & Hommel, 2017), which in turn can affect whether stimulus- or plan-based control is prioritised when it precedes learning (Chan et al., 2017; Immink et al., 2017).

1.2. Sequence learning following a single-session of focused attention meditation

Recent investigations of single-session FAM practice supported that cognitive control was biased in a convergent control style during performance of subsequent goal-directed cognitive tasks (Colzato, van der Wel, Sellaro, & Hommel, 2016; Lippelt, Hommel, & Colzato, 2014; Lutz, Jha, Dunne, & Saron, 2015; van Leeuwen, Singer, & Melloni, 2012). For direct applications in sequence learning, when FAM immediately preceded learning, stimulus-based control was responsible for reduction in response times and improvement in general learning performance, attributed to an enhanced top-down and convergent control style (Chan