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The influence of focused-attention meditation states on the cognitive control of sequence learning☆

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ABSTRACT

Cognitive control processes influence how motor sequence information is utilised and represented. Since cognitive control processes are shared amongst goal-oriented tasks, motor sequence learning and performance might be influenced by preceding cognitive tasks such as focused-attention meditation (FAM). Prior to a serial reaction time task (SRTT), participants completed either a single-session of FAM, a single-session of FAM followed by delay (FAM+) or no meditation (CONTROL). Relative to CONTROL, FAM benefitted performance in early, random-ordered blocks. However, across subsequent sequence learning blocks, FAM+ supported the highest levels of performance improvement resulting in superior performance at the end of the SRTT. Performance following FAM+ demonstrated greater reliance on embedded sequence structures than FAM. These findings illustrate that increased top-down control immediately after FAM biases the implementation of stimulus-based planning. Introduction of a delay following FAM relaxes top-down control allowing for implementation of response-based planning resulting in sequence learning benefits.

1. Introduction

Sequential behavior prominently features in most of the daily activities we undertake throughout our lives. Fundamental to the success of our lives then is the acquisition of sequential actions and this ability, in turn, relies on how consciousness and cognitive processes shape learning, adaptation and representation (Cleeremans & Jimenez, 2002; Delevoye-Turrell & Bobineau, 2012; Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Langer, 2000). Beyond sequential actions, other forms of goal-directed behavior, including cognitive-oriented tasks, also utilise and consequently influence cognitive control mechanisms. Because of shared utilisation of cognitive control processes, it would seem reasonable to consider that sequence learning could be influenced by a preceding cognitive-oriented task such as meditation, which has been shown to influence attentional and top-down versus bottom-up regulatory processes. The present experiment was designed to test this proposal by examining the effects of meditation on subsequent sequence learning. To provide relevant theoretical background for this experiment we provide overview of current models of sequence learning and representation and meditation, the role of attentional processes in both and preliminary research investigating the effects of meditation on motor learning.

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1.1. Cognitive control processes underlying sequence learning

Cognitive control processes underlying sequence learning are needed to regulate attention, working memory, and other executive functions (e.g. response selection, conflict resolution, and task representation) are utilised to increase performance over a period of practice (Daltrozzo & Conway, 2014; Keele et al., 2003; Slagter, Davidson, & Lutz, 2011). Several models have been proposed to describe cognitive control processes and how they influence performance characteristics of sequenced actions (Abrahamse, Jimenez, Verwey, & Clegg, 2010; Abrahamse, Ruitenberg, de Kleine, & Verwey, 2013; Clegg, Digirolamo, & Keele, 1998; Daltrozzo & Conway, 2014; Keele et al., 2003; Kelly, Burton, Riedel, & Lynch, 2003; Schwarb & Schumacher, 2012; Slagter et al., 2011). A prominent feature across these models is the extent to which task features are attended and utilised during the acquisition of the sequential action. For example, control of sequence performance can either emphasise stimulus-based or response-based planning strategies (Tubau, Hommel, & Lopez-Moliner, 2007). Stimulus-based planning relies on the presentation of a signal that is associated with a specific response within the sequence as a ‘prepared-reflex’ (Hommel, 2000). Thus, the stimulus is used to signal the appropriate response in an automated way but does not afford further elaboration within the context of the sequence (Tubau et al., 2007). The notion of stimulus-based planning is very similar to the idea of unidimensional representation proposed by Keele et al. (2003) whereby a limited input source is used to predict a future response. Response-based planning, in contrast, utilises information from the action plan as a source of control, treating the response as a link within the sequence representations (Hommel, 1996; Tubau et al., 2007). Response-based planning thus emphasises associations between the representations of actions and outcomes into internalised plans that meet the goals of learning rather than just stimulus-driven responses (Elsner & Hommel, 2001; Holland, 2008; Hommel, 1996). Therefore, under response-based planning, motor responses become optimised and automated with efficient management of cognitive control processes in planning, decision-making, error-detection and memory formation (Alvarez & Emory, 2006; Chiappe, Hasher, & Siegel, 2000; Gallant, 2016; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994). Here, Keele et al. (2003) similarly refer to use of a multidimensional representation, whereby sequence elements are based on associations across a number of task features and into higher levels of goal orientation and cognition.

Abrahamse et al. (2010) and Abrahamse et al. (2013) also describe multiple strategies underlying sequence performance. Their model specifically attributes the use of performance strategies to the extent to which the sequence representation has been developed over a period practice. During early stages of sequence learning, performance follows a reaction mode, which is similar to the notion of stimulus-based (Tubau et al., 2007) or unidimensional (Keele et al., 2003) strategies or what Clegg et al. (1998) refer to as low level encoding. As practice continues, performance begins to utilise an associative mode whereby sequence automatisation increases owing to an abstract-rule formation (Abrahamse et al., 2013; Franco & Destrebecqz, 2012; Grafton, Hazeltine, & Ivry, 1998) or referred to as intermediate level associations (Clegg et al., 1998). Further practice results in increased sequence automatisation that results from sequence chunking whereby sequence elements have been abstracted into long-term memory as sub-units within the overall structure of a sequence (Abrahamse et al., 2010, 2013; Clegg et al., 1998; Jimenez, 2008; Koch & Hoffmann, 2000; Verwey & Abrahamse, 2012; Verwey & Wright, 2014). The availability of the chunking mode allows sequence production to no longer rely on stimulus-response mapping given sequence sub-units are preloaded in working memory, which allows the performer to anticipate the upcoming responses within the sequence (Jimenez, 2003, 2008). The formation of sequence chunks might conceivably support response-based planning (Tubau et al., 2007) based on high level of multidimensional associations (Keele et al., 2003) and high level abstract representation (Clegg et al., 1998) to perform speeded and accurate sequential action. Cognitive control is responsible for directing attention towards task-relevant information and inhibiting competing or irrelevant information (Gallant, 2016; Lyon & Krasnegor, 1996; Miyake et al., 2000) and as such, cognitive control would influence whether sequence learning and representation is based on stimulus-based or response-based planning.

1.2. Influence of meditation states on cognitive control

Meditation typically involves a set of guided instructions that establishes a state of cognitive control influencing attention, performance monitoring and working memory (Cahn & Polich, 2006; Debarnot, Sperduti, Di Rienzo, & Guillot, 2014; Loizzo, 2014; Moore & Malinowski, 2009; Slagter et al., 2007; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). Accordingly, a period of meditation training has been reported to improve performance on tasks that assess attention, interference control and working memory function (Gallant, 2016; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; Malinowski, 2013; Tang, Holzel, & Posner, 2015; Tang et al., 2007). To explain these effects, current theoretical models emphasise attention as the central component influenced by meditation (Moore, Gruber, Derose, & Malinowski, 2012; Moore & Malinowski, 2009). It is through its influence on attention control processes that meditation is thought to lend benefits for the function of subsequent processing stages such as working memory (Malinowski, 2013; Tang & Posner, 2009).

As meditation is thought to have a primary influence on attention, meditation styles can be described based on the manner by which the technique influences the control of attention (Lippelt, Hommel, & Colzato, 2014; Lutz, Slagter, Dunne, & Davidson, 2008). Focused attention meditation (FAM) is a meditation style that is characterised by the goal of maintaining sustained attention on a specific object (e.g., breathing) (Lippelt et al., 2014; Lutz et al., 2008; Slagter et al., 2011). Thus, FAM utilises top-down cognitive control processes that constrain attention in a narrow or convergent manner in order to sustain attention on a target object (Colzato, van der Wel, Sellaro, & Hommel, 2016; Lutz, Jha, Dunne, & Saron, 2015; van Leeuwen, Singer, & Melloni, 2012). Although FAM places an emphasis on sustaining attention on a target object, to meet this goal, other cognitive control processes are utilised as it has been reported that even experienced meditators become distracted about once every 80 s (Hasenkamp & Barsalou, 2012). Thus, sustained attention has been proposed to be but one part of a top-down oriented cognitive control cycle that is implemented in FAM

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