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Differences in updating processes between musicians and non-musicians from late childhood to adolescence

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ABSTRACT

The main purpose of our study was to examine whether musical training is associated with improvements in updating executive function development between late childhood and adolescence, as well as to analyse which updating sub-processes — inhibition or maintenance — are more affected by musical experience. Sixty-nine musicians (37 children aged between 10–11 years and 32 adolescents between 15–16 years) and 69 non-musicians (37 children aged between 10–11 years and 32 adolescents between 15–16 years) participated in the study and were matched in academic level and fluid intelligence. Updating function was measured by the updating task developed by De Beni and Palladino (2004), which allowed differentiating scores for maintenance and inhibition processes. The results showed that musicians outperformed non-musicians both in maintenance and inhibitory processes, specifically in resistance to proactive interference.

1. Introduction

Music performance is a complex activity that involves the integration of auditory and visual stimuli, kinaesthetic control, pattern recognition, and memory processes (Barrett, Ashley, Strait, & Kraus, 2013). For this reason, music performance has been considered to require high levels of attentional control, including selective attention, inhibition, shifting, updating, and monitoring processes (Bialystok & DePape, 2009). These processes have been linked to executive control, which essentially involves cognitive flexibility, updating information in working memory (WM), and inhibition (Miyake et al., 2000).

There is a broad number of studies that have reported improvements associated with musical training in various executive functions, such as cognitive flexibility (Zuk, Benjamin, Kenyon, & Gaab, 2014), updating information in WM (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Franklin et al., 2008; George & Coch, 2011; Hou et al., 2014; Lee, Lu, & Ko, 2007; Ramachandra, Meighan, & Gradzki, 2012; Roden, Grube, Bongard, & Kreutz, 2014), and inhibition (Bialystok & DePape, 2009; Dowsett & Livesey, 2000; Holochwost et al., 2017; Hou et al., 2014; Moreno, Bialystok, Schellenberg, Cepeda, & Chau, 2011).

The purpose of this study was to explore the relationship between musical training and one of the main executive functions: the updating of information in WM, defined as 'the act of modifying the current status of representation of schema in memory to accommodate new input' (Morris & Jones, 1990, p. 112).

WM has been characterised as a limited-capacity mechanism for the temporary maintenance and processing of information. Although several WM models have been described in the literature, it is generally assumed that WM is involved in complex cognitive tasks and highly related to controlled attention and fluid intelligence (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Engle, Kane, & Tuholski, 1999; Fry & Hale, 2000). According to one of the most prominent models (Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974), WM is a mechanism that involves four main components: the phonological loop, the visuo-spatial sketchpad, and the episodic buffer (which are for temporary information storage), and the central executive, which is responsible for the control and regulation of attention. Specifically, Baddeley (1996) described four main functions of the central executive: the coordination of simultaneous tasks and the shift from one task to another, the supervision of coding and retrieving strategies, the regulation of selective attention and inhibitory processes, and the retrieval and processing of information stored in long-term memory (LTM). Given that WM has a limited capacity, these functions would be carried out with a limited amount of cognitive resources.

The limited amount of mental resources for the simultaneous storage and processing of information in WM has been conceptualised as a key factor in cognitive development (e.g. Bjorklund & Harnishfeger, 1990; Case, Kurland, & Goldberg, 1982) and language comprehension (Just & Carpenter, 1992). Both theories emphasise the trade-off

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between storing and processing information.

Developmental efficiency theories (Bjorklund & Harnishfeger, 1990; Case et al., 1982) suggest that available resources to store and process information in WM do not increase through development but improve their efficiency (Case et al., 1982), therefore increasing the availability of mental resources to execute cognitive processes, which could be described as the speed of activation/suppression of information (Harnishfeger, 1995). Furthermore, Just and Carpenter's (1992) computational theory of language comprehension suggests that both storage and processing rely on the amount of global activation available. These authors considered the suppression of irrelevant information as a way to release activation for maintenance, increasing WM efficiency.

On their behalf, Engle (2002) conceptualised WM as executive attention and specified that working memory capacity 'is not about memory, but about using attention to maintain and suppress information' (p. 20). In this theory, executive attention processes are responsible for the temporary maintenance of retrieved LTM traces that should be actively maintained or kept accessible in the limited focus of attention, while blocking interference, distraction, or conflict sources (Kane, Conway, Hambrick, & Engle, 2007). From this perspective, WM capacity (WMC) has been defined as 'the capability of the executive attention component of the WM system' (Kane & Engle, 2002, p. 638); they are the attentional processes available to actively maintain or accurately retrieve the relevant task information under interference conditions (Kane et al., 2007). Thus, as Kane and Engle (2000) pointed out, proactive interference could have a prominent role in WM efficiency.

WMC has been traditionally measured through complex span tasks such as the reading span task (Daneman & Carpenter, 1980), the counting span task (Case et al., 1982), and the operation span task (Turner & Engle, 1989). These tasks were created to measure the trade-off between capacity and processing resources. All of them require a secondary processing task that interferes with the primary storage task. Attentional processes would be necessary to keep memory information accessible (Conway et al., 2005). When new information or task demands appear, WM content must be updated, suppressing no-longer-relevant information and maintaining activation of information relevant to task goals (Belacchi, Carretti, & Cornoldi, 2010).

Some authors have underlined that WMC is highly related to updating executive function (e.g. Schmiedek, Hildebrandt, Lovdén, Wilhelm, & Lindenberger, 2009), based on the high correlation found between updating measures and WM complex span tasks (Conway, 1996; Engle, Tuholski, Laughlin, & Conway, 1999; Lehto, 1996; Miyake et al., 2000; Schmiedek et al., 2009; St Clair-Thompson & Gathercole, 2006; Towse, Hitch, & Hutton, 1998). However, as Ecker, Lewandowsky, Oberauer, and Chee (2010) pointed out, WMC and updating differ as a function of their underlying processes. Through structural equation models, these authors described three underlying processes: (a) retrieval of relevant information from LTM, (b) transformation of information in WM, and (c) substitution of information in WM.

Whereas the processes of retrieval and transformation could represent a common source of variance shared by WMC and updating, substitution could be the only sub-process specific to updating, and thus the basis for differentiating between updating and WMC. Moreover, the updating sub-processes could also differentiate at a developmental level. The sub-processes more related to WMC (retrieval and transformation) seem to develop from late childhood to adolescence, followed by stabilisation (Carriedo, Corral, Montoro, Herrero, & Rucián, 2016; Conklin, Luciana, Hooper, & Yarger, 2007; Gathercole, Pickering, Knight, & Stegmann, 2004), while the sub-process of substitution seems to develop up until young adulthood (Carriedo et al., 2016).

More recently, Ecker, Lewandowsky, and Oberauer (2014) focused on the substitution sub-process. These authors specified that the removal of no-longer-relevant information could be an active attentional process, and that an efficient substitution could require the ability to shift between no-longer-relevant information and the encoding of new information in its place.

Therefore, as Passolunghi and Pazzaglia (2005) pointed out, updating is a complex process that would require different levels of activation to continuously reject no-longer-relevant information and maintain activation of relevant information (see also Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012; Shipstead, Lindsey, Marshall, & Engle, 2014; Unsworth & Engle, 2007; Unsworth, Fukuda, Awh, & Vogel, 2014).

Some previous studies have examined the relation between WMC and musical training using complex span tasks. For example, George and Coch (2011) and Ramachandra et al. (2012) carried out two separate studies to explore WM individual differences associated with musical training in young adult musicians and non-musicians. In both cases, the results showed that musicians significantly outperformed non-musicians at the behavioral level. Moreover, George and Coch (2011) found a shorter latency in the P300 component in musicians, which has been interpreted as an improved ability to update WM content (Steiner, Barry, & Gonsalvez, 2013). Both George and Coch (2011) and Ramachandra et al. (2012) concluded that musical training is associated with improvements in basic processes related to WM and attention—in the ability to simultaneously store and process information, in mental binding, and in the suppression of irrelevant information (i.e. less susceptibility to interference) (Franklin et al., 2008; Hou et al., 2014; Ramachandra et al., 2012). This relationship between musical training and WM was also found when controlling for general intelligence (e.g. Franklin et al., 2008; Roden et al., 2014).

Other authors (Hou et al., 2014), using complex memory span tasks and the classic n-back updating paradigm, also found improvements in updating executive function associated with musical training. Hou et al. (2014) concluded that the continuous updating of musical information stored in LTM could be a fundamental process during music performance to select adequate responses.

This empirical evidence has been supported by neuroimaging studies that reported brain structure changes associated with musical training, both in children (Habibi et al., 2014; Schlaug, Norton, Overy, & Winner, 2005) and in adults (Gaser & Schlaug, 2003; Grahn & Rowe, 2009). Moreover, neuroplasticity differences between musicians and non-musicians have been found in auditory (Bangert & Schlaug, 2006; Gaser & Schlaug, 2003; Herholz & Zatorre, 2012; Jäncke, 2009) and sensorimotor areas (Gaser & Schlaug, 2003; Jäncke, 2009), and structural differences have been found that seem to extend to other brain regions such as the inferior frontal area (Sluming et al., 2002), which is associated with executive control functions (Aron, Robbins, & Poldrack, 2004).

In conclusion, previous research has shown the existence of individual differences in WMC and updating associated with musical training, even when controlling for general intelligence (e.g. Franklin et al., 2008; Roden et al., 2014). However, to our knowledge, the vast majority of these studies have explored this association without differentiating among the processes involved—that is, between the retrieval/transformation and substitution processes. Moreover, previous research on cognitive advantages associated with musical training has been mainly focused on children (Lee et al., 2007; Roden et al., 2014; Schellenberg, 2004; Schellenberg, 2011), or on adults (Bialystok & DePape, 2009; Franklin et al., 2008; George & Coch, 2011; Ramachandra et al., 2012; Talamini, Carretti, & Grassi, 2016), but has not yet explored advantages throughout development, specifically from late childhood to adolescence, which is a period crucial for developmental changes in executive functions (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Carriedo et al., 2016; Diamond & Goldman-Rakic, 1989; Fischer, Biscaldi, & Gezeck, 1997; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Zald & Iacono, 1998). Thus, it could be possible that musical training is associated with individual differences in retrieval/transformation and substitution processes, and that this association could vary through development.