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Age differences in working memory updating: The role of interference, focus switching and substituting information

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ABSTRACT

Working memory updating (WMU) tasks require different elements in working memory (WM) to be maintained simultaneously, accessing one of these elements, and substituting its content. This study examined possible developmental changes from childhood to adulthood both in focus switching and substituting information in WM. In addition, possible age-related changes in interference due to representational overlap between the different elements simultaneously held in these tasks were examined. Children (8- and 11-year-olds), adolescents (14-year-olds) and younger adults (mean age = 22 years) were administered a numerical updating memory task, in which updating and focus switching were manipulated. As expected, response times decreased and recall performance increased with age. More importantly, the time needed for focus switching was longer in children than in adolescents and younger adults. On the other hand, substitution of information and interference due to representational overlap were not affected by age. These results suggest that age-related changes in focus switching might mediate developmental changes in WMU performance.

1. Introduction

Working memory (WM) is a limited capacity system that entails the active maintenance of representations necessary for the cognitive task being performed. Given the continuous flow of information to be processed and its limited capacity, a mechanism is necessary that allows WM content to be constantly updated (Morris & Jones, 1990). This mechanism is considered a fundamental executive function in cognitive architecture (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) with clear implications in a wide range of complex cognitive tasks, such as reading comprehension (e.g., Carretti, Cornoldi, De Beni, & Romano, 2005; Cornoldi, Drusi, Tencati, Giofrè, & Mirandola, 2012), arithmetic calculations and mathematical problem solving (e.g., Passolunghi & Pazzaglia, 2004, 2005; Pelegrina, Capodieci, Carretti, & Cornoldi, 2014; Swanson & Beebe-Frankenberger, 2004), and intelligence (e.g., Friedman et al., 2006).

Working memory updating (WMU) is a complex process that can involve several more basic processes. Ecker, Lewandowsky, Oberauer, and Chee (2010) have recently identified different component processes that make independent contributions to updating performance: retrieval, transformation and substitution. It is also possible to add those mechanisms responsible for inhibiting or eliminating no-longer-relevant information (Ecker, Lewandowsky, & Oberauer, 2014; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001).

The efficiency with which WM content is updated improves during childhood and adolescence as shown in different studies employing a range of updating tasks (e.g., Belacchi, Carretti, & Cornoldi, 2010; Garon, Bryson, & Smith, 2008; Huizinga, Dolan, & Van der Molen, 2006; Kwon, Reiss, & Menon, 2002; Lechuga, Moreno, Pelegrina, Gómez-Ariza, & Bajo, 2006; Schleepen & Jonkman, 2010; Vuontela et al., 2003). This developmental pattern may be due to changes in the more basic components involved in updating tasks. The present study aimed to analyze potential developmental changes during childhood and adolescence across some component processes involved in WMU. Specifically, we sought to investigate possible developmental differences in the efficiency with which information is substituted in WM. In addition, we aimed to determine possible age changes in the susceptibility to interference due to the representational overlap between the different elements simultaneously held in the updating task. Finally, we sought to identify possible age changes in focus switching that allows accessing information to be updated.

1.1. Substitution

A key element in WMU is the substitution of specific content maintained in WM for new information. Substitution is a process sensitive both to the number of to-be-substituted items (Kessler & Meiran, 2008) and to the similarity between the information involved. Lendínez, Pelegrina, and Lechuga (2011, 2014) have found that numerical updating is faster when the information involved in the substitution process is more similar in terms of numerical distance. This facilitation effect can be explained by considering substitution as a selective process that

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replaces some parts of a representation while others are left unchanged. Information in WM may be represented as groups or sets of features (Nairne, 1990; Oberauer & Kliegl, 2006). Thus, two representations would share a certain number of features depending on their similarity. When a representation is substituted by another similar, a large number of common features would be maintained and only a small number of new features must be replaced. Hence, the greater the similarity and in turn the fewer to-be-substituted features, the faster the updating.

An aim of this study was to determine whether the time needed to substitute information in WM changes throughout childhood and adolescence. A decrease in the updating cost with age could contribute to explaining the greater efficiency with which information is updated as children get older. Furthermore, it was of interest to assess possible age-related differences in the effect of similarity-based facilitation.

1.2. Similarity-based interference

WMU in addition to flexibility must provide stability to memory representations (Kessler & Meiran, 2008, see also Hazy, Frank, & O'Reilly, 2006). One factor which can threaten this stability is interference derived from different contents simultaneously held in WM. Pelegrina, Borella, Carretti, and Lechuga (2012) have found that similarity between the different elements maintained in a numerical updating task hinders performance. This similarity-based interference may also be explained by the idea that information in memory is represented as sets of features. When overlap occurs between two representations, competition arises between them owing to their shared features, and in the end one of them loses some of these features to the other (Nairne, 1990; Neath, 2000; Oberauer & Kliegl, 2006). This loss of features leads to a degradation of representations and a decrease in recall performance.

There are several situations where the overlap between representations increases, and hence the interference between the items held in WM. On the one hand, interference is related to memory load. When the number of simultaneously stored items increases, so too does the number of shared features, thus leading to representational overlap. On the other hand, the more similar the information maintained, the higher the number of shared features, which would also lead to greater interference.

The study of similarity-based interference during childhood is of particular relevance given that some authors have specifically suggested that interference may be related to age differences in WMU. Thus, Schleepen and Jonkman (2010) have attributed age differences in n-back task performance to an improvement in interference control. As children get older they could better manage the interference, especially in the higher WM load conditions. However, other studies have found no evidence that susceptibility to interference related to the increase in WM load changes throughout childhood. Göthe, Esser, Gendt, and Kliegl (2012) administered verbal and visuospatial updating tasks to 7- and 11-year-old children in order to assess the extent to which a specific interference model of WM (Oberauer & Kliegl, 2006) fitted to the performance of the different age groups. One of the estimated parameters was feature overwriting, which was related to memory load. It was assumed that a greater load produces a higher degree of overlap and consequently more interference by overwriting. Göthe et al. (2012) did not find age differences in this parameter among children aged 7 and 11 years. Rodríguez-Villagra, Göthe, Oberauer, and Kliegl (2013) obtained an analogous result with a visuospatial updating task, where no differences were found among 10-year-old children and adults in the feature overwriting parameter.

The present study aimed to further address this question by using another manipulation that affects representational overlap and in turn interference. Thus, instead of manipulating the memory load (or the number of maintained items), similarity between the two representations that should be simultaneously stored in WM was directly manipulated. Findings from a previous study with older adults revealed that this manipulation resulted in age-related differences. Specifically, similarity affected older participants' recall more than younger individuals' recall (Pelegrina et al., 2012). The present study employed the same task to determine whether susceptibility to similarity-based interference decreases throughout childhood.

1.3. Focus switching

Another process involved in WMU tasks is focus switching. Normally, in updating tasks there are different items that have to be maintained simultaneously in WM and that are susceptible of being replaced at some point of the task. This requires a mechanism to access each of the to-be-updated elements. Garavan (1998) showed that there was a cost for selecting one of the items maintained in WM for immediate processing. In his study, Garavan used a continuous counting paradigm whereby participants had to keep two counters in memory for two different figures (a triangle and a rectangle). Participants updated the appropriate mental count adding one unit when the corresponding figure was presented. Garavan's main finding was that the time to update the information was about 300 to 500 ms slower when there was a switch from a counter to the other, that is, when the counter to be updated was different to the counter previously updated (e.g., triangle after a rectangle). This switching cost showed that not all the items in WM are equally accessible.

The focus-switching mechanism acquires special significance in WM embedded-processes models, where WM is considered a temporarily activated subset of long-term memory representations (e.g., Cowan, 1995, 1999). Oberauer (2002) has suggested that of all the elements in WM, one of them has a privileged status by being held in the focus of attention, meaning that this representation is immediately available for processing (see also McElree, 2001; McElree & Dosher, 1989). On a second level, referred to as the direct-access region, a limited number of representations would be held in a state of availability to be retrieved in the focus of attention. The focus-switching mechanism is responsible for selecting and accessing items maintained in the direct-access region, activating them in the focus of attention. Only information activated in the focus of attention can be selected as the object of a cognitive operation.

Some studies carried out on young and older adults have observed age-related changes in focus switching. In fact, Verhaeghen and colleagues view focus switching as an executive process that contributes to WM performance deficits in older adults (Vaughan, Basak, Hartman, & Verhaeghen, 2008; Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007). Similarly, efficiency in accessing information in the focus of attention could change throughout childhood and adolescence. This improvement may help to explain the overall changes obtained in updating tasks. In fact, focus-switching accuracy seems to predict verbal working memory in typically developing children (Magimairaj & Montgomery, 2012). Therefore, an aim of this study was to determine to what extent focus-switching efficacy changes throughout childhood and adolescence.

1.4. The present study

This study aimed to determine to what extent information substitution and focus switching in WM change during childhood and adolescence. It is possible that improvement in updating performance across childhood and adolescence is, to a certain degree, due to greater efficiency in the substitution and focus-switching processes.

This study employed a numerical updating task where participants had to maintain and update the values associated with two different items (Lendínez et al., 2011, 2014). During the updating trials, one of the values required modification according to a criterion, while the other would remain unchanged. There were also non-updating trials where both values were to continue unmodified. The inclusion of both types of trials makes it possible to determine the updating cost. The criterion for updating was the result of a numerical comparison