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Research Report

Aging and sequential modulations of poorer strategy effects: An EEG study in arithmetic problem solving

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ABSTRACT

This study investigated age-related differences in electrophysiological signatures of sequential modulations of poorer strategy effects. Sequential modulations of poorer strategy effects refer to decreased poorer strategy effects (i.e., poorer performance when the cued strategy is not the best) on current problem following poorer strategy problems compared to after better strategy problems. Analyses on electrophysiological (EEG) data revealed important age-related changes in time, frequency, and coherence of brain activities underlying sequential modulations of poorer strategy effects. More specifically, sequential modulations of poorer strategy effects were associated with earlier and later time windows (i.e., between 200- and 550 ms and between 850- and 1250 ms). Event-related potentials (ERPs) also revealed an earlier onset in older adults, together with more anterior and less lateralized activations. Furthermore, sequential modulations of poorer strategy effects were associated with theta and alpha frequencies in young adults while these modulations were found in delta frequency and theta inter-hemispheric coherence in older adults, consistent with qualitatively distinct patterns of brain activity. These findings have important implications to further our understanding of age-related differences and similarities in sequential modulations of cognitive control processes during arithmetic strategy execution.

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1. Introduction

Aging is generally accompanied by declines in a variety of cognitive functions such as episodic memory, working-memory, or inhibitory functions (see Craik and Salhouse, 2007; Salthouse, 2010, for reviews). Previous research on cognitive aging has also showed that both young and older adults use several strategies to accomplish most cognitive tasks (see Lemaire, 2015, for an overview). Moreover, both young and older adults obtain poorer performance when the cued strategy is not the most adapted to characteristics of problems compared to when they had to execute the better strategy (i.e., which yields the best performance) on a given item (e.g., Ardiale et al., 2012; Dunlosky and Hertzog, 2000;

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Geary et al., 1993; Hertzog et al., 2012; Lemaire et al., 2004; Lemaire and Leclère, 2014; Uittenhove and Lemaire, 2012, 2013; Uittenhove et al., 2013). Such poorer strategy effects have been accounted for by assuming that, when they are asked to execute a poorer strategy on a given problem, participants have to inhibit the automatically activated strategy and activate the procedures of the required strategy before executing these procedures (e.g., Ardiale et al., 2012; Lemaire and Hinault, 2014). When they are asked to execute the better strategy, participants do not engage inhibition processes and can immediately execute procedures of the automatically activated better strategy. This makes poorer strategy effects interesting to inform how participants engage in cognitive control processes (like inhibition) during strategy execution and how these control processes evolve during aging.

Previous research has also shown that people sequentially modulate cognitive control mechanisms from one trial to the next while executing strategies. This was evidenced by several sequential effects like strategy switch costs (i.e., better performance when participants are asked to repeat the same strategy over two consecutive trials than when they are asked to use two different strategies; Ardiale et al., 2012; Luwel et al., 2009; Schillemans et al., 2009, 2011; Lemaire and Lecacheur, 2010; Lemaire and Leclère, 2014), strategy sequential difficulty effects (i.e., better performance with a strategy after executing an easy strategy compared to after executing a difficult strategy on the preceding item; Uittenhove and Lemaire, 2012, 2013; Uittenhove et al., 2013), and, the focus of this study, sequential modulations of poorer strategy effects (Lemaire and Hinault, 2014; Hinault et al., 2014).

Recently, Lemaire and Hinault (2014) reported that poorer strategy effects on current problem were larger after better strategy problems than following poorer strategy problems. It was proposed that the detection of a conflict on poorer strategy problems led the cognitive system to increase its level of control to more efficiently solve a potential conflict on the next problem, resulting in decreased poorer strategy effects. Conversely, when participants are asked to solve the previous problem with the better strategy, cognitive control processes are not prepared for a potential conflict on the next problem. This results in larger poorer strategy effects on the next problem. Regarding aging effects, Lemaire and Hinault (2014) distinguished two subgroups based on performance in a Simon task (i.e., a conflict task requiring to inhibit a spatial dimension and to focus on a target dimension, for example, the shape; Simon and Small, 1969). They revealed that high- and low-functioning older adults differed in how efficient they were in sequential modulations of cognitive control. Indeed, high-functioning older adults showed the same pattern than young adults in sequential modulations of poorer strategy effects, while lower-functioning older adults did not show such modulations. These findings suggest that efficient control mechanisms (as measured with the Simon task) allow efficient sequential modulations of poorer strategy effects.

EEG is a useful tool to investigate aging effects on cognitive processes and to reveal age-related differences when both age groups do not differ in behavioural measures. For example, in arithmetic processing, El Yagoubi et al. (2005) studied age-related differences in split effects (i.e., better performance in arithmetic verification tasks when false proposed products are far from correct products, like in 8+4=19, than when splits are small, like in 8+4=13). Split effects have been explained as reflecting the use of plausibility-checking strategy on large-split problems, and exact-calculation strategy on small-split problems (Allen et al., 1992, 1997, 2005; Ashcraft and Bataglia, 1978; De Rammelaere et al., 2001; Duverne and Lemaire, 2004, 2005; Duverne et al., 2007; El Yagoubi et al., 2003; Pesenti et al., 2000; Zbrodoff and Logan, 1990). El Yagoubi et al. (2005) found that, although both groups did not differ in behavioural split-effects, event-related potentials (ERPs) associated with large and small-split problems were similar in older adults, while a larger positivity for large-split compared to small-split problems occurring 250 ms after problem display was observed in young adults. These results are consistent with the use of a plausibility-checking strategy (i.e., determining that a proposed product cannot be true, without calculating the correct product) on large split problems in young adults, whereas older adults used an exact-calculation strategy (i.e., calculating the correct product) on both small-split and large-split problems. Hence, while behavioural measures could have led to conclude to age-invariance in split effects, ERPs revealed important qualitative differences between young and older adults.

Recently, Hinault et al. (2014) analyzed ERPs to determine the time course of sequential modulations of poorer strategy effects in young adults. They found ERP differences on current poorer strategy problems as a function of previous better or poorer strategy problems. These differences occurred both in early and late time windows, over anterior left sites of the scalp. Larger positive amplitudes on poorer strategy problems when following better strategy problems than after poorer strategy problems were associated with sequential modulations of poorer strategy effects. The first time window (i.e., 200–550 ms after stimulus presentation) suggests that control mechanisms occurred immediately after the encoding of the problem. In this latency, it was proposed that participants focused on the cue to know which strategy is required and to inhibit the automatic activation of the better strategy triggered by units of operands. The second time window (i.e., 850–1250 ms after stimulus display) has been interpreted as participants keeping the activation of the better strategy at its lower level while executing the required poorer strategy. These positive modulations are consistent with P3 (i.e., centro-parietal positive deflection peaking between 350- and 500 ms post-stimulus presentation) and conflict SP (i.e. sustained positivity starting about 500 ms following stimulus presentation) components, previously found in conflict tasks. These components have been associated with response inhibition (i.e., P3) and implementation of attentional control (i.e., conflict SP) during sequential modulations of cognitive control mechanisms (see Larson et al., 2014, for a review).

Cognitive control mechanisms were also studied by means of frequency and coherence analyses. Indeed, previous studies using these analyses revealed that cognitive and sensory processes induce modulations of electric activity over time, as well as qualitative differences in rhythmic activity (e.g.,

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