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Repetition suppression in aging: A near-infrared spectroscopy study on the size-congruity effect

Silvia Erika Kober[a,b,*], Guilherme Wood[a,b]

[a] *Department of Psychology, University of Graz, Universitaetsplatz 2/III, 8010 Graz, Austria*
[b] *BioTechMed-Graz, Mozartgasse 12/II, 8010 Graz, Austria*

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ABSTRACT

Age-related changes in the hemodynamic response regarding inhibition capacity and repetition suppression were examined using a modified version of the numerical Stroop task. Young (20–38 yrs; $M = 28$ yrs; $N = 18$), middle-aged (47–59 yrs; $M = 52$ yrs; $N = 17$), and older participants (60–78 yrs; $M = 69$ yrs; $N = 19$) solved a physical and numerical version of the size-congruity task, in which trials from the same experimental condition were presented in triplets. Response times revealed a strong Stroop effect in both tasks (faster reaction times during neutral than during incongruent trials) and increased with participants' age. Reaction times decreased with item repetition. In line with previous studies, the hemodynamic response (relative concentration changes in oxygenated and deoxygenated hemoglobin) assessed with near-infrared spectroscopy was comparable across incongruent and neutral trials. Strong repetition suppression of the oxygenated hemoglobin response was observed in frontal brain regions as well as in the left parietal region in all age groups. In middle and right parietal regions, repetition suppression decreased with age and was absent among older participants. These results indicate a reduced adaptation of the hemodynamic response in middle and right parietal regions of older individuals' brains in response to repeated interference control.

1. Introduction

One of the main factors underlying age-related cognitive decline is a decrease of inhibition capacities with increasing age. Inhibition is a central component of executive functions and is associated with the ability to suppress irrelevant information and restrain inappropriate pre-potent responses (Belanger et al., 2010; Kane and Engle, 2003). To investigate age-related changes in inhibition capabilities and underlying hemodynamic responses we used a modified version of the Stroop task, namely the numerical Stroop task (Cohen Kadosh et al., 2007b, 2011; Ischebeck, 2003). While in the classic color-word Stroop task the interfering dimensions are colors and words, in the numerical Stroop task (also referred to as size-congruity task) the dimensions are numerical magnitude and physical size. The task is a comparison task, which requires individuals to compare the numerical or physical magnitude of two simultaneously presented Arabic numbers (Fig. 1). It assesses inhibitory capacities and numerical cognition. In incongruent trials, the numbers differ in physical size and numerical magnitude (e.g., 6 3). The so-called "congruity effect" describes a common finding that both accuracy and response latency deteriorate when the numerical and physical dimension are incongruent (Henik and Tzelgov, 1982; Wood et al., 2009). It reflects the difficulty to inhibit the automatic processing of magnitude of the task-irrelevant stimulus dimension (Algom et al., 1996; Tzelgov et al., 1992). In neutral trials, the numbers only differ in the relevant dimension, either in numerical magnitude or physical size (e.g., 3 3). Previous literature has shown that the congruity effect increases with age (e.g., Belanger et al., 2010; Bugg et al., 2007; Girelli et al., 2001; Milham et al., 2002; Salthouse, 2010; Spieler et al., 1996; van der Elst et al., 2006; Wood et al., 2009). These age related changes in the congruity effect indicate failure to inhibit irrelevant information in older age (> 60 years; Belanger et al., 2010; Milham et al., 2002; Salthouse, 2010; van der Elst et al., 2006). This supports the notion that with increasing age and decreasing inhibitory functions older adults get more susceptible to interference (Belanger et al., 2010). Mayas et al. (2012) described these age-related performance changes in the Stroop task as inhibitory breakdown during aging, rather than mere age-related slowing processes (Mayas et al., 2012). The majority of these prior studies used a color-word Stroop task, evidence in a numerical Stroop task is relatively rare (Girelli et al., 2001; Wood et al., 2009).

Prior behavioral studies have shown that the inhibitory conflict between relevant and irrelevant dimensions in a Stroop task can be

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[*] Corresponding author at: Department of Psychology, University of Graz, Universitaetsplatz 2/III, 8010 Graz, Austria.
E-mail addresses: silvia.kober@uni-graz.at (S.E. Kober), guilherme.wood@uni-graz.at (G. Wood).

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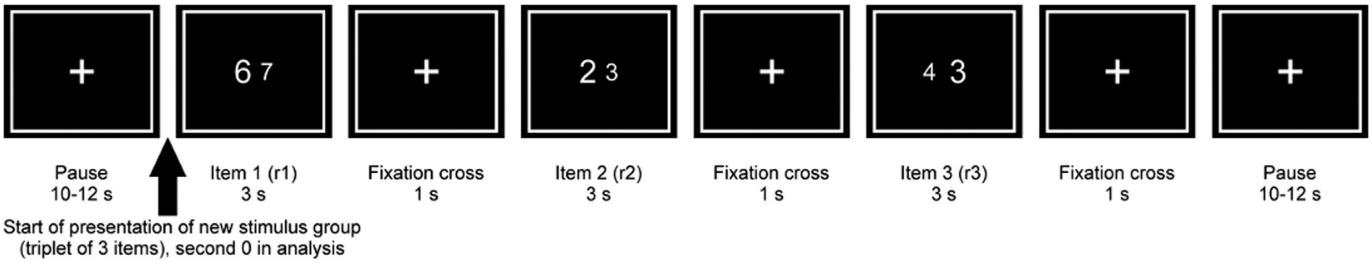

Fig. 1. Timing of a trial. Example of a single trial of the incongruent condition. Items of the same experimental condition were presented in groups of three within one trial to investigate repetition suppression effects.

reduced when items of the same task condition are repeated (Cohen Kadosh et al., 2011). Generally, repetition of stimuli (e.g., objects, words, faces) does not only show behavioral effects, it also affects neural responses. In this context, a repetition related reduction in neural activity can be observed in multiple brain areas when stimuli or some specific features thereof are repeated (Barron et al., 2016; Grill-Spector et al., 2006). This goes along with performance improvements due to repetition (e.g., faster reaction times) (Grill-Spector et al., 2006; Miyakoshi et al., 2012). This robust phenomenon is called "repetition suppression". In fMRI studies, the reduction in the magnitude of the hemodynamic response as a result of repeated stimulus presentation within functionally relevant cortical areas is also called fMRI adaptation (Grill-Spector et al., 2006; Miyakoshi et al., 2012). Current fMRI studies demonstrated age-related differences in the repetition suppression effect. Generally, older adults show reduced fMRI adaptation to repeated items during tasks such as passive viewing tasks (e.g., line drawings, pictures of natural scenes, buildings or faces), word-stem completion tasks, classification tasks of words or objects (e.g., color photographs), or auditory tasks (e.g., human non-speech sounds, animal sounds, musical sounds, machine noise) (Ballesteros et al., 2013; Bergerbest et al., 2009; Chee et al., 2006; Daselaar et al., 2005; Goh et al., 2007, 2010; Grady et al., 2011; Lee et al., 2011; Miyakoshi et al., 2012; Schmitz et al., 2010; Soldan et al., 2008). Possible explanations for reduced fMRI adaptation with age could be bottom-up, physiological changes such as cellular and vascular alteration. But it is also possible that top-down attentional control modulates fMRI adaptation (Chee et al., 2006; Miyakoshi et al., 2012; Schmitz et al., 2010). Neuroimaging studies investigating possible age differences in repetition suppression during more complex cognitive tasks requiring inhibitory control such as a Stroop interference task are lacking so far. Therefore, we used a modified version of a numerical Stroop task, in which we presented items of the same experimental condition (either neutral or incongruent stimuli) in triplets.

The hemodynamic response in frontal and parietal brain regions was assessed during the numerical Stroop task using near-infrared spectroscopy (NIRS). NIRS is a non-invasive optical neuroimaging technique that measures concentration changes of oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR) in the cerebral vessels based on their different absorption spectra for light in the near-infrared range (Kober et al., 2015b; Villringer and Chance, 1997). Generally, a fronto-parietal network is activated during performing a Stroop task (Cohen Kadosh et al., 2007b; Kaufmann et al., 2008; Wood et al., 2009). Frontal areas such as the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) are involved in conflict processing and cognitive/inhibitory control (Kaufmann et al., 2005; Leon-Carrion et al., 2008; Milham et al., 2001, 2003b, 2003a; Schroeter et al., 2002; Sun et al., 2013; van Veen and Carter, 2005; Watanabe et al., 2015; Zhang et al., 2013). Activation in the parietal cortex is also linked to conflict processing and has been suggested to be engaged in maintaining task-relevant stimulus-response mapping (Bunge et al., 2002; Kaufmann et al., 2008). Particularly, the right parietal cortex seems to play a crucial role for the congruity effect (Cohen Kadosh et al., 2007c, 2012). The involvement of a fronto-parietal network is not limited to interference control during a Stroop task, but also includes number processing. Numerical magnitudes are generally processed in the intraparietal sulcus (IPS), Brodmann Area (BA) 7 (Dehaene et al., 2003). However, the physical size of numbers is also processed in the IPS region. In the numerical Stroop task, the comparison of number magnitude and physical size is computed in parallel by separate neural substrates in the IPS (Cohen Kadosh et al., 2007b, 2007a). Frontal regions are also involved in number-related tasks (e.g., Kaufmann et al., 2008; Menon et al., 2000).

We investigated for the first time age-related changes in repetition suppression on the behavioral and neuronal level during an inhibitory control task using a modified version of the numerical Stroop task. This task required subjects to compare either the numerical size (numerical task) or the physical size (physical task) of two Arabic numbers varying along both dimensions (Tzelgov et al., 1992). Based on previous literature, one may expect a strong congruity effect in both numerical and physical tasks (Tzelgov et al., 1992). Response times should increase with age (Girelli et al., 2001; Wood et al., 2009) as well as error rates, and, accordingly, the congruity effect should also increase with age. A strong effect of repetition suppression should be observable in both tasks when items of the same condition are repeated, which might decrease in function of age (Grill-Spector et al., 2006; Miyakoshi et al., 2012; Schmitz et al., 2010). A repetition suppression effect should be observable in the hemodynamic response across all conditions and all fronto-parietal locations (Grill-Spector et al., 2006).

2. Methods

2.1. Participants

Sixty-six healthy adults aged 20–78 years took part in the present study. Twelve participants (4 young, 3 middle-aged, 5 elderly) had to be excluded from data analysis due to distorted NIRS signal (e.g., bad signal quality, high density of artefacts, and atypical/improbable NIRS amplitudes). Thus, the final sample consisted of $N = 54$ participants. The sample was divided into three age groups: young participants from 20 to 38 years ($N = 18$, 6 females, mean age 28.06 yrs., $SE = 1.52$ yrs.), middle-aged participants from 47 to 59 years ($N = 17$, 10 females, mean age 51.94 yrs., $SE = 1.01$ yrs.), and elderly participants from 60 to 78 years ($N=19$, 14 females, mean age 68.47 yrs., $SE = 1.11$ yrs.). The participants had no current or previous psychiatric, physical, or neurological disorders. All participants had normal or corrected to normal vision. To control for influence of education, participants were recruited according to their educational level, which matched the respective age group in the Austrian population (e.g., more participants with higher levels of education in the young group and more participants with lower levels of education in the elderly group). Participants older than 60 years additionally performed the Mini Mental State Examination (MMSE, Folstein et al., 1975) in order to screen for a pathological decline in cognitive functions. Older participants of the present study did not show any cognitive deficits according to the MMSE results. All participants gave written informed consent and were paid for their participation (7 Euros). The study was