Brain and Cognition 122 (2018) 26–33

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Reduced inter-hemispheric interference in ageing: Evidence from a divided field Stroop paradigm

Jean-François Delvenne[a,*], Julie Castronovo[b]

[a] University of Leeds, United Kingdom
[b] University of Hull, United Kingdom

ARTICLE INFO

Keywords:
Ageing
Corpus callosum
Stroop
Inter-hemispheric communication

ABSTRACT

One of the most important structural changes that occur in the brain during the course of life relates to the corpus callosum, the largest neural pathway that connects the two cerebral hemispheres. It has been shown that the corpus callosum, and in particular its anterior sections, endures a process of degeneration in ageing. Hence, a primary question is whether such structural changes in the brain of older adults have functional consequences on inter-hemispheric communication. In particular, whether the atrophy of the corpus callosum in ageing may lead to a higher or lower level of *inter*-hemispheric interference is currently unknown. To investigate this question, we asked young and healthy older adults to perform modified versions of the classic Stroop paradigm in which the target and distracter were spatially separated. Across two experiments, we found that the Stroop effect was significantly reduced in older adults when the two stimuli were distributed in two different hemifields as opposed to the same single hemifield. This new finding suggests that age-related callosal thinning reduces inter-hemispheric interference by facilitating the two hemispheres to process information in parallel.

1. Introduction

The corpus callosum (CC) is the major neural pathway in the human brain that connects homologous cortical regions of the two cerebral hemispheres according to an anterior-posterior topographical organisation. Consisting of over 200 million myelinated axonal projections, it is the largest white matter structure in the brain (Aboitiz, Scheibel, Fisher, & Zaidel, 1992) and is almost exclusively responsible for the exchange of information between the two hemispheres (Gazzaniga, 2000).

In the present study, we investigated changes in *inter*-hemispheric processing that might occur in old age in the context of a Stroop task. A decline in size and micro-structural integrity of the CC in old age has been reported by a large number of MRI studies (e.g., Burke & Yeo, 1994; Davis et al., 2009; McLaughlin et al., 2007; Michielse et al., 2010; Ota et al., 2006; Sullivan, Pfefferbaum, Adalsteinsson, Swan, & Carmelli, 2002; Sullivan, Rohlfing, & Pfefferbaum, 2010), and confirmed by postmortem findings (Aboitiz et al., 1992; Hou & Pakkenberg, 2012). By the 7th and 8th decades of human life, the width of the CC would even be comparable to that of a small child (Cowell, Allen, Zalatimo, & Denenberg, 1992).

Importantly, the timeline and progression of the degeneration of the CC appear to differ across its different parts. It has increasingly been shown that white matter integrity in the ageing CC follows an anterior-posterior gradient of decline. Age-related degeneration of CC fibres occurs primarily in the anterior section known as the genu (Bastin et al., 2008, 2010; Hou & Pakkenberg, 2012; Jeeves & Moes, 1996; Madden et al., 2009; Salat et al., 2005; Schulte, Sullivan, Müller-Oehring, Adalsteinsson, & Pfefferbaum, 2005), which consists of small-diameter fibres that connect the frontal lobes. In contrast, the CC fibres in the posterior section known as the splenium, which connects the occipital lobes, appears to decline only in pathological ageing such as dementia (e.g., Frederiksen, Garde, Skimminge, Barkhof, et al., 2011; Frederiksen, Garde, Skimminge, Ryberg, et al., 2011) but not in healthy ageing (Bastin et al., 2010; Hou & Pakkenberg, 2012; Salat et al., 2005).

Nevertheless, although the atrophy of the CC in the healthy older population has been shown to be associated with general cognitive decline, such as slower processing and psychomotor speed, poorer performance at tests of working memory and executive function (e.g., Fling et al., 2011; Jokinen, Ryberg, & Halska, 2007; Ryberg et al., 2011; Sullivan et al., 2010; Zahr, Rohlfing, Pfefferbaum, & Sullivan, 2009), the specific effects of an ageing CC on *inter*-hemispheric communication are currently unclear. Given that the size of the CC is related to the amount of myelinated and non-myelinated transcallosal fibres needed for transmission of neuronal impulses between hemispheres (Aboitiz et al., 1992), it is plausible to suggest that *inter*-hemispheric

---

* Corresponding author at: School of Psychology, University of Leeds, Leeds LS2 9JT, United Kingdom.
E-mail address: j.f.delvenne@leeds.ac.uk (J.-F. Delvenne).

https://doi.org/10.1016/j.bandc.2018.01.008
Received 1 December 2016; Received in revised form 26 October 2017; Accepted 25 January 2018

communication would be somewhat disrupted in older age as compared to younger adulthood.

Here, we designed a paradigm that allowed us to explore whether and how communication between the cerebral hemispheres changes in old age as compared to young adulthood. We used a divided field Stroop paradigm in which the target and distracter are spatially separated from each other and tachistoscopically displayed either both within a single hemifield (*unilateral display*) or each in a different hemifield (*bilateral display*). When both presented within the same hemifield, the target and distracter are initially processed by the contralateral hemisphere as a result of the well-known contralateral organisation of the visual system. In that case, no *inter*-hemispheric communication is required for a Stroop effect (i.e., a slower response to the target in the presence of an incongruent distracter) to occur. In contrast, when the stimuli are displayed in different hemifields, they are initially processed by a different hemisphere and an *inter*-hemispheric exchange is therefore required for a Stroop effect to emerge. Given that the anterior part of the CC connects the left and right cingulate cortex (Locke & Yakovlev, 1965), that increased activations within the anterior cingulate cortex during a Stroop effect have been reported (Brown et al., 1998; Bush et al., 1998; Peterson et al., 1999; Whalen et al., 1998), and that the Stroop effect has been found to be correlated with white matter integrity of the genu (Schulte, Müller-Oehring, Javitz, Pfefferbaum, & Sullivan, 2008), the divided field Stroop paradigm is ideal to test behavioural consequences of age-related atrophy of the anterior section of the CC.

With this paradigm, three potential outcomes must be considered. Firstly, the level of *inter*-hemispheric interference in older adults may be comparable to that of younger adults. Such a result could either mean that our paradigm is not sensitive enough to reveal behavioural consequences of callosal atrophy in healthy ageing, or that the *inter*-hemispheric interference in the context of a Stroop task is not affected in older adults. Secondly, a higher level of *inter*-hemispheric interference in older adults may be observed when compared to younger adults. Here, this could suggest that the ageing CC is less efficient in maintaining independent processing between the two hemispheres. Indeed, one function of the CC (i.e., *inhibitory* function) is to act as a barrier preventing information from being unnecessarily transferred from one hemisphere to the other (Bloom & Hynd, 2005; van der Knaap & van der Ham, 2011). In the context of a divided field Stroop task, a less efficient CC (due to an age-related atrophy for instance) might struggle to prevent the incongruent stimulus to interfere with the target in a bilateral condition. Finally, a lower level of *inter*-hemispheric interference may be observed in older adults when compared to younger adults. This finding would suggest that the ageing CC is less efficient in facilitating the sharing and integration of information between hemispheres, a function of the CC known as the *excitatory* function (Bloom & Hynd, 2005; van der Knaap & van der Ham, 2011).

Therefore, the present study has two main objectives: (1) to investigate whether *inter*-hemispheric communication is affected in older age in the context of a Stroop task, and (2) to examine the nature of that potential disruption.

2. Experiment 1

2.1. Method

2.1.1. Participants

We tested 15 older adults (13 females), aged 66–76 (mean age = 70.5 ± 3.2 years) and 15 young adults (14 females), aged 18–20 (mean age = 19.2 ± 0.8 years). Older adults were recruited from the community and were screened for possible underlying neurological disturbances with the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). A high cut-off score was applied (i.e., 27) and all the older adults recruited here achieved at least that score. Young adults were psychology students at the University of Leeds and participated for course credits. All participants were unaware of the purpose of the experiment. They self-reported no history of neurological problems, correct colour vision, normal or corrected-to-normal visual acuity, and a right-hand preference.[1] They also provided a written informed consent. All participants were tested at the University. The experimental protocol was approved by the School of Psychology Research Ethics Committee, from the University of Leeds.

2.1.2. Stimuli and procedure

Stimuli were displayed on a 17 in. screen (1280 × 1024 resolution) of a 3.20 GHz PC, with responses measured on an external QWERTY keyboard connected to the PC. There were two response keys ("2" and "3") that were positioned approximately 9 in. to the right of the midline, so that participants could use their right hand comfortably to respond, with the index finger placed on key "2" and the middle finger placed on key "3". Stimuli were generated using the E-Prime 2.0 computer software (Psychology Software Tools, Inc., www.pstnet.com). Participants viewed the PC screen at an approximate distance of 60 cm. All stimuli were presented on a grey screen background (200 of red, blue and green phosphors). Red (255 of red phosphor and 0 of blue and green phosphors) and Blue (255 of blue phosphor and 0 of red and green phosphors) rectangular outlines (with a thickness of approximately 0.35°) were used as target stimuli and the words "RED" and "BLUE" written in white Arial font were used as distracters. The stimuli were displayed either horizontally in half of the trials and subtended 1.33° × 2.66°, or vertically in the other half of the trials and subtended 2.66° × 1.33° (see Fig. 1). The use of these two different orientations was to control for the distance between the stimuli and the centre of the visual field. Each stimulus was positioned within one of the four 'invisible' quadrants (i.e., upper-left, upper-right, down-left and down-right) so that the stimulus edge was always 2° from the horizontal and vertical meridian.

All participants were tested individually in a quiet room. Each trial commenced by the presentation of a central black fixation cross (0.3° × 0.3°) at the centre of the screen for 500 ms. Participants were encouraged to keep their eyes fixated on the centre of the screen. After a blank interval of variable duration (400–700 ms), one coloured rectangular outline and one word were presented simultaneously in two separate quadrants for 180 ms, a time generally considered as brief enough to prevent saccadic eye movements (Bourne, 2006; Carpenter, 1988). In half of the trials, the coloured rectangular outline and the word were displayed horizontally whereas in the other half of the trials, they were presented vertically. In half of the trials, the coloured rectangular outline and the word were displayed in horizontally opposite visual quadrants (*bilateral display*) (upper-left/upper-right or lower-left/lower-right), thus in two different hemifields. In the other half of the trials, the coloured rectangular outline and the word were displayed in vertically opposite visual quadrants (*unilateral display*) (upper-left/lower-left or upper-right/lower-right), thus within the same single hemifield. The two types of stimuli could be either *congruent* (i.e., the colour of the rectangular outline matched the name of the colour denoted by the word) or *incongruent* (i.e., the colour of the rectangular outline and that denoted by the word were different) (Fig. 1). Participants were instructed to ignore the word and to focus merely on the rectangular outline. They had to decide as quickly as possible whether the colour of the rectangular outline was red or blue. Responses had to be made within 2000 ms of the onset of the stimuli by pressing the appropriate numerical key on the computer keyboard ("2" = blue; "3" = red). The next trial began 1000 ms after a response had been made or

---

[1] In both experiments of the present study, handedness was assessed in the following way: participants were asked how often they use their left or right hand (i.e., always left, usually left, neutral, usually right or always right) for the following task: writing, throwing, using scissors, tooth brush, knife without a fork, spoon, and computer mouse. All of our participants responded either 'usually right' or 'always right' in all their answers.