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Number skills are maintained in healthy ageing

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ABSTRACT

Numerical skills have been extensively studied in terms of their development and pathological decline, but whether they change in healthy ageing is not well known. Longer exposure to numbers and quantity-related problems may progressively refine numerical skills, similar to what happens to other cognitive abilities like verbal memory. Alternatively, number skills may be sensitive to ageing, reflecting either a decline of number processing itself or of more auxiliary cognitive abilities that are involved in number tasks. To distinguish between these possibilities we tested 30 older and 30 younger participants on an established numerosity discrimination task requiring to judge which of two sets of items is more numerous, and on arithmetical tasks. Older participants were remarkably accurate in performing arithmetical tasks although their numerosity discrimination (also known as 'number acuity') was impaired. Further analyses indicate that this impairment was limited to numerosity trials requiring inhibiting information incongruent to numerosity (e.g., fewer but larger items), and that this also correlated with poor inhibitory processes measured by standard tests. Therefore, rather than a numerical impairment, poor numerosity discrimination is likely to reflect elderly's impoverished inhibitory processes. This conclusion is supported by simulations with a recent neuro-computational model of numerosity perception, where only the specific degradation of inhibitory processes produced a pattern that closely resembled older participants' performance. Numeracy seems therefore resilient to ageing but it is influenced by the decline of inhibitory processes

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supporting number performance, consistent with the 'Inhibitory Deficit' Theory.

1. Introduction

Does our ability to use numbers and arithmetical concepts change with ageing? Are these changes specific to numeracy or do they rather reflect decline of more general cognitive processes such as attention or inhibitory processes? Numerical skills have been extensively studied in children and young adults, both in terms of development or impairment following brain lesions (Ansari, 2008; Cappelletti, 2011). However, little is known about the impact of healthy ageing on numerical skills, and the few studies that investigated this issue focused mostly on arithmetical abilities, i.e. those required when solving problems such as 8×9 or $243 + 39$. These studies concurred to show that although older participants can learn new ways to solve arithmetical problems, they show a smaller repertoire of strategies and are less efficient than younger participants in selecting among them (e.g. Duverne & Lemaire, 2005; Lemaire & Arnaud, 2008; Geary & Lin, 1998; Salthouse & Kersten, 1993), or that they do not equally engage the same brain regions as younger participants when performing arithmetical tasks (El Yagoubi, Lemaire, & Besson, 2005). However, these tasks are typically multi-componential, requiring several processes such as the retrieval of arithmetic facts, the use of procedures and the ability to monitor the steps of the problem (Cappelletti & Cipolotti, 2011). It may therefore be difficult to isolate which specific component may be affected by ageing.

An alternative approach to test the impact of ageing on numeracy skills is to assess other simpler skills (sometimes referred to as 'biologically primary skills', Geary & Lin, 1998) which are thought to be foundational to more complex, education- and language-based numerical and arithmetical abilities. One such foundational skill is thought to be our capacity to represent approximate number, which is based on encoding numerosities as analog magnitudes (e.g. Izard, Dehaene-Lambertz, & Dehaene, 2008; Stoianov & Zorzi, 2012), and relies on an 'approximate number system' (ANS, Feigenson, Dehaene, & Spelke, 2004). The ANS is often measured in terms of the ability to discriminate numerosities (e.g. which set has more elements), also referred to as 'number acuity' (Halberda, Mazzocco, & Feigenson, 2008). Number acuity is expressed as Weber fraction (*wf*), which reflects the amount of noise in the underlying approximate number representation (Halberda et al., 2008; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004). The *wf* is highly variable across individuals (Halberda, Lya, Wilmerb, Naimana, & Germine, 2012; Halberda et al., 2008; Piazza et al., 2004), and it refines progressively from infancy to adulthood (Halberda et al., 2008; Halberda & Feigenson, 2008; Lipton & Spelke, 2003, 2012; Piazza et al., 2010). Whether it continues to improve with age is an open question: longer exposure to numbers may refine the approximate number system further, similarly to what happens to other cognitive abilities like vocabulary and semantic memory (e.g. Hedden & Gabrieli, 2004). Notably, number acuity has been found to correlate with math achievement in children (Halberda et al., 2008; Mazzocco, Feigenson, & Halberda, 2011a) and to be impaired in children with developmental dyscalculia (Mazzocco, Feigenson, & Halberda, 2011b; Piazza et al., 2010),

A few previous studies have focused on how healthy ageing participants are able to represent approximate large numerosities (i.e., more than 10 elements), which has sometimes been reported to be well maintained (e.g. Gandini, Lemaire, & Dufau, 2008; Gandini, Lemaire, & Michel, 2009; Lemaire & Lecacheur, 2007; Trick, Enns, & Brodeur, 1996; Watson, Maylor, & Bruce, 2005; Watson, Maylor, & Manson, 2002). Some of these previous results, however, are difficult to interpret. This is because in some cases the focus was mainly on the strategies used to perform the numerosity task, without reporting finer quantitative details of older participants' performance (e.g. Gandini et al., 2008). In other studies, the long presentation of the stimuli (6 s or even unlimited) may have encouraged processes different from numerosity estimation, like counting (Gandini et al., 2009; Lemaire & Lecacheur, 2007; Watson, Maylor, & Bruce, 2007). Likewise, some experimental designs did not control for continuous variables which inevitably vary when manipulating the numerosity of the display, like the total area covered by the dots, i.e. cumulative area (for discussion see Piazza et al., 2004). If these continuous variables are not taken into account, for example if in all trials an increase in numerosity always corresponds to an increase in