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Intentional binding as a marker of agency across the lifespan

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ABSTRACT

The feeling of control over actions and their external effects is known as Sense of Agency (SoAg). People usually have a distinctive SoAg for events caused by their own actions. However, if the agent is a child or an older person, this feeling of being responsible for the consequences of an action may differ from what an adult would feel. The idea would be that children and elderly may have a reduced SoAg since their frontal lobes are developing or have started to loose their efficiency. The aim of this study was to elucidate whether the SoAg changes across lifespan, using the Intentional Binding (i.e., the temporal attraction between a voluntary action and its sensory consequence) as implicit measure. Data show that children and elderly are characterized by a reduced SoAg as compared to adults. These findings provide a fundamental step in the characterization of SoAg dynamics throughout individuals' lifetime.

1. Introduction

Our voluntary actions are typically accompanied by a Sense of Agency (SoAg; Haggard & Tsakiris, 2009). We feel that we can choose and control our own actions and consequently the outside world. Historically, SoAg has been a topic of interest mainly to philosophers (e.g., Gallagher, 2000; Pacherie, 2008), but over recent years it has also received attention from psychology and cognitive neuroscience researchers given its potential role in many aspects of our everyday life. In fact, SoAg is deeply entwined with our notions of freedom and is intrinsic to ethical and law questions concerning responsibility and guilt (e.g., Haggard & Chambon, 2012; Moretto, Walsh, & Haggard, 2011). Indeed, when we voluntarily perform actions, we feel responsible for them and for their consequences. The experience of agency is therefore a complex and multifaceted phenomenon, which requires not only a plan to perform a goal-directed action, but also the ability to properly identify the consequences of that behaviour in the external world, avoiding and inhibiting erroneous and maladaptive behaviours (Haggard & Tsakiris, 2009). These high-level cognitive abilities are usually part of the executive functions (EFs), supported by the functionality of frontal areas (Stuss & Levine, 2002). Even though there are no studies which have directly linked the SoAg to these cognitive functions (i.e., EFs), general scientific progress in recent years has nevertheless elucidated a clear picture of the neural bases of the SoAg, pinpointing an involvement of frontal, prefrontal and parietal areas in this phenomenon (e.g., Cavazzana, Penolazzi, Begliomini, & Bisiacchi, 2015; Khalighinejad, Di Costa, & Haggard, 2016; Khalighinejad & Haggard, 2015; Kühn, Brass, & Haggard, 2013; Moore, Ruge, Wenke, Rothwell, & Haggard, 2010; Renes, van Haren, Aarts, & Vink, 2015). As recently reported by Haggard (2017) in an elegant review, the experience of agency is mediated by the connectivity between frontal and prefrontal areas – responsible for planning and initiating actions – and parietal regions which are involved in monitoring the perceptual events. Their involvement is also supported by clinical studies which revealed that an

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impaired functionality of such areas is associated with pathologies characterized by a lack of agency (e.g., corticobasal syndrome: Wolpe et al., 2013; schizophrenia: Renes et al., 2016). Another example of inefficiency of these regions might be represented by both healthy children and elderly people. It is well known that the frontal cortex is subjected to dramatic age-related modifications (for a review, see: West, 1996): it is the last cortical area to mature in children and among the first to be impaired in aging (e.g., Casey, Tottenham, Liston, & Durston, 2005; Raz, 2000). Usually, these changes in brain structure and functionality inevitably impact on cognitive abilities as well, in particular on EFs, which are mediated by frontal lobes' integrity and activity. A considerable body of research convincingly shows that there are systematic, age-related improvements in EFs during childhood and adolescence, coinciding with growth spurts in the maturation of the frontal lobes (e.g., Zelazo & Müller, 2002). Likewise, a decrease of EFs during normal aging, even in the absence of pathologies, has been demonstrated (e.g., Zelazo, Craik, & Booth, 2004). In light of these assumptions, one might expect changes in the processing of agency in these two populations. However, how this capacity changes across the lifespan has not yet been addressed and it constitutes an open, pertinent issue, given the impact of SoAg in social and legal aspects of life. As mentioned above, SoAg implies individual responsibility for the consequences of one's own actions (Frith, 2014; Moll et al., 2007) and in many countries, the law requires that the individual be fully responsible and aware of the consequences of his/her actions (Frith, 2014; Haggard & Chambon, 2012; Moretto et al., 2011). A first attempt to study whether SoAg differs in children and elderly people in respect to young adults was conducted by Metcalfe, Eich, and Castel (2010). The Authors tried to resolve this issue investigating the different level of metacognitive awareness of agency across the lifespan. They used an explicit computer task previously adopted to study the metacognition of agency in young adults (Metcalfe & Greene, 2007). Participants had to move the mouse to get the cursor to touch X's and avoid the O's which streamed from the top of a computer screen. Afterwards, they were asked to make *judgments of agency* (i.e., how in control he/she felt) and *judgments of performance*. Objective control was either undistorted (i.e., participant had perfect control of the mouse), or distorted by (i) 'turbulence' (i.e., random noise was added to the position of the mouse to produce the position of the cursor on the screen, limiting participant's control), (ii) 'lag' between the mouse and cursor movements (of 250 or 500 ms), or (iii) 'magic,' (i.e., an increased radius around the X's such that the person would be credited with touching an X even if they had not touched it). Authors observed that young adults were the most sensitive to discrepancies in control over their own actions compared to both children (8–10 years old) and older adults (mean age 75). This finding suggest that SoAg could evolve across the lifespan, changing our skills to link our actions with their consequences. More recently, van Elk, Rutjens, and van der Pligt (2015) investigated the possible role of SoAg in the development of illusory control (i.e., the erroneous belief that one's actions can cause a certain outcome, even if that outcome is uncontrollable and determined by chance) in 7–12-year-old children and in young adults. Participants were asked to play a computerized card guessing game in which they were required to select a face-down card from a deck of two rapidly flashing cards on a computer screen. Following their selection of a card, a randomized outcome was presented and participants were required to indicate to what extent they believed the card was selected by themselves or by the computer. The authors manipulated the congruence of the outcome with participants' initial choice (i.e. congruent or incongruent) and the valence of the presented outcome (i.e. positive or negative). The analysis focused on perceived control throughout the card guessing game as a measure of 'illusory control', and on perceived control as a function of action outcome, as a measure of the SoAg. They observed that the illusion of control throughout the card guessing game was more enhanced for younger (< 8 years old) compared to older children (> 8 years old) and more pronounced for children compared to adults. Regarding SoAg, both adults' and children' agency ratings were similarly affected by the congruence between performed and observed outcomes (e.g., when a temporal delay or spatial deviation was introduced) in line with adult studies (e.g., Aarts, Custers, & Marien, 2009; Daprati et al., 1997). However, this latter study did not consider older participants. Although the studies by Metcalfe et al. (2010) and van Elk et al. (2015) represent the first attempts to investigate age-related differences in the SoAg, only explicit agency measures were considered. However, explicit measures of agency are usually very prone to be influenced by individual differences related to cognitive capacities or personality, and to a lack of subjectivity insights (e.g., Gawronski, LeBel, & Peters, 2007). In addition, this sort of measure reflects very little about the SoAg, since it does not capture the feeling of agency that accompanies normal voluntary actions. Recently, our group adopted implicit measuring of the SoAg with children (Cavazzana, Begliomini, & Bisiacchi, 2014). The classical Intentional Binding effect (IB – Haggard, Clark, & Kalogeras, 2002) was considered: the IB refers to the temporal compression between a voluntary action and its ensuing sensory effect. In other words, when a voluntary action is followed by a sensory effect (e.g., a sound), people tend to perceive the onset of the voluntary action later in time, towards its effect as compared to a baseline condition in which only the voluntary action is present (i.e., action binding). On the other hand, the sound triggered by the voluntary action is perceived earlier in time towards its voluntary action, as compared to a baseline condition in which only the sound is present. This bias to perceive actions and effects closer in time than they actually are has been observed only when the action is intentional. Indeed, it does not happen when the first event is unrelated to the participants' will. For this reason, IB has been considered a reliable implicit measure of agency. By taking advantage of the implicit nature of this measure, differences in the processing of agency in children as compared to young adults were demonstrated (Cavazzana et al., 2014). In particular, we found that children showed a reduced temporal compression (i.e., IB) as compared to young adults. Starting from these results, we decided to extend the investigation to elderly people. The general purpose of the present work was therefore to explore how IB, as an implicit measure of SoAg, can evolve across the lifespan, avoiding the limits of verbal reports that characterize the explicit level of SoAg. Based on previous studies (e.g., Cavazzana et al., 2014; Metcalfe et al., 2010; Moore, 2016), we expected the IB effect to show different features in children and elderly people as compared to young adults. More precisely, we expected the IB effect to be weaker in children and elderly as compared to young adults.