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Subjective, behavioral, and physiological responses to the rubber hand illusion do not vary with age in the adult phase

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ABSTRACT

The Rubber Hand Illusion (RHI) is a perceptual illusion that enables integration of artificial limbs into the body representation through combined multisensory integration. Most previous studies investigating the RHI have involved young healthy adults within a very narrow age range (typically 20–30 years old). The purpose of this paper was to determine the influence of age on the RHI. The RHI was performed on 93 healthy adults classified into three groups of age (20–35 years old, N = 41; 36–60 years old, N = 28; and 61–80 years old, N = 24), and its effects were measured with subjective (Embodiment of Rubber Hand Questionnaire), behavioral (proprioceptive drift), and physiological (changes in skin temperature and conductance) measures. There were neither significant differences among groups in any response, nor significant covariability or correlation between age and other measures (but for skin temperature), which suggests that the RHI elicits similar responses across different age groups in the adult phase.

1. Introduction

The Rubber Hand Illusion (RHI) is a paradigmatic experiment that promotes the representation of an external limb within the body schema of a participant, a mechanism referred to as embodiment (De Vignemont, 2011), through synchronous visuotactile stimulation of a participant's real limb (hidden from sight) and the external one (Botvinick & Cohen, 1998). The RHI has been extensively used to manipulate and investigate how the brain integrates afferent multisensory information (touch, vision, and proprioception) to configure a mental representation of the body parts and reachable (peripersonal) space. All existing literature involving healthy participants provides evidence that the body schema is continuously updated (Armel & Ramachandran, 2003; Holle, McLatchie, Maurer, & Ward, 2011; Kalckert & Ehrsson, 2014; Petkova & Ehrsson, 2009) to ready the body for forthcoming movements (Rosenbaum, 2010). This mechanism appears to be not only confirmed but also enhanced after physiopathological changes in the brain (Ding et al., 2017; Llorens et al., 2017; Schmalzl, Kalckert, Ragnö, & Ehrsson, 2014).

As in some neurological pathologies, there is substantial consensus regarding the deterioration of sensory processes with age; for example, in visual acuity (Cerella, 1985; Spear, 1993), motor coordination (Bullock-Saxton, Wong, & Hogan, 2001), auditory

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perception (Alain, Ogawa, & Woods, 1996), and proprioception (Skinner, Barrack, & Cook, 1984). Moreover, age-related neurophysiological changes have been reported both in localized brain areas and distributed brain networks (Reuter, Behrens, & Zschorlich, 2015; Siman-Tov et al., 2016). Although aging and its derived effects could provide an interesting framework to investigate the embodiment mechanisms, the literature is scant.

The few existing reports on age-related effects in embodiment have evaluated subjective and behavioral responses using ad-hoc questionnaires and the proprioceptive drift, the spatial incongruence between the perceived location of a limb and its actual location, respectively. A study that compared these two responses to the RHI in three groups of children with different ages (4–5, 6–7, and 8–9 years old) and a group of young adults (mean age 23.9 years old) reported comparable sense of embodiment in all the groups but increased proprioceptive drift in children (Cowie, Makin, & Bremner, 2013), which was hypothesized to be promoted by developmental differences in the brain processes that underlie body-ownership (Bremner, Hill, Pratt, Rigato, & Spence, 2013; Cowie et al., 2013). Another study that involved young adults with a small age range (17–24 years old) examined different conditions of movement (active, passive, and asynchronous) during the RHI and also reported no effect of age in the embodiment elicited during the RHI (Dummer, Picot-Annand, Neal, & Moore, 2009). In contrast, the responses of participants in the range of 20–60 years old to a modified version of the RHI, where the rubber hand was replaced by a real-time video of the real hand being stroked displayed on a screen, indicated decreased elicited embodiment and increased proprioceptive drift with age (Graham, Martin-Iverson, Holmes, & Waters, 2015). Another study evaluated age-related differences in a group of young adults (17–38 years old) during the enfacement illusion, an experiment similar to the RHI. In which a participant's face is stroked in synchrony with a pre-recorded video that shows other individuals being analogously stroked (Tajadura-Jiménez, Longo, Coleman, & Tsakiris, 2012). In line with the previous study, the authors reported that younger participants experienced higher embodiment and suggested that the plasticity of self-face representations reduces with age. Thus, existing reports provide an interesting base of study; however, the absence of studies that involve wider age ranges, comparable controlled conditions, and physiological correlates limit the extrapolation of the preliminary results.

We hypothesized that age-related changes would limit the plasticity of the body-schema reconfiguration, thus restricting the effects of the RHI, and it would be reflected by a decrease in the elicited sense of embodiment, and in behavioral and physiological responses. Therefore, the objective of this study was to investigate the subjective, behavioral, and physiological responses during the RHI in healthy adults at different ages.

2. Methods

2.1. Participants

Healthy adults from 20 to 80 years were recruited from the student body, staff, and relatives of three different universities (Universitat de Valencia, Universitat Politècnica de València, and Universitat Jaume I) and a medical center (Servicio de Neurorrehabilitación y Daño Cerebral de los Hospitales NISA). Ninety-three volunteers (40 men) agreed to participate in the study. The participants were divided into three groups according to their age: early adulthood, from 20 to 35 years old, N = 41, mean age = 26.83 (SD = 4.29); midlife, from 36 to 60 years old, N = 28, mean age = 49.43 (SD = 7.67); and mature adulthood, from 61 to 80 years old, N = 24, mean age = 67.54 (SD = 5.29). All participants provided written informed consent. Ethical approval was obtained from Universitat de València.

2.2. Procedure

The experiment was conducted by two experimenters in three quiet rooms free of distractors that were arranged in the same locations of recruitment. The participants, who were blind to the purpose of the study, were briefly introduced to the experiment and were equipped with a wearable wireless armband, the Q-sensor (Affectiva®, Waltham, MA, USA), which recorded the skin temperature and conductance during the entire experiment. The participants sat on one side of the table in a comfortable position with both arms resting on the table and palms facing downward; they were instructed to relax and maintain the position for 10 min for temperature and skin conductance stabilization. A movable wooden vertical board (50 × 40 × 4 cm) was placed in front of the participants' left or right shoulder depending on whether they were right or left-handed, respectively. This shoulder was also covered with a piece of black cloth to avoid direct line-of-sight of the participants with their own non-dominant hand. After the acclimation time, a sex-matched left or right rubber hand was placed in the other side of the frame at 15 cm to the participant's real hand (measured between index fingers) (Aimola Davies & White, 2013; Kammers, de Vignemont, Verhagen, & Dijkerman, 2009; Llorens et al., 2017) and 5.5 cm of the wooden frame. The participants were instructed to stare at the rubber hand, and the experiment was inititated. The fingers and the dorsum of the real and rubber hands were synchronously stroked with two identical small brushes. Strokes of different lengths were provided in a proximal to distal direction at approximately 1 Hz with an unpredictable origin (Kammers, Rose, & Haggard, 2011; Llorens et al., 2017; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Rohde, Wold, Karnath, & Ernst, 2013). After two minutes, the stimulation was terminated, and the rubber hand was smashed with a hammer, which was hidden until this point.

2.3. Outcome measures

Subjective, behavioral, and physiological responses to the experiment were collected. The subjective assessment of embodiment was conducted after the experiment using the Embodiment of Rubber Hand Questionnaire (ERHQ) (Longo et al., 2008). The