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Review article

Embodiment in the aging mind

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ABSTRACT

Bodily awareness is a central component of human sensation, action, and cognition. The human body is subject to profound changes over the adult lifespan. We live in an aging society: the mean age of people living in industrialized countries is currently over 40 years, and further increases are expected. Nevertheless, there is a lack of comprehensive knowledge that links changes in embodiment that occur with age to neuronal mechanisms and associated sensorimotor and cognitive deficits in older adults. Here, we synthesize existing evidence and introduce the NFL Framework of Embodied Aging, which links basic neuronal (N) mechanisms of age-related sensorimotor decline to changes in functional (F) bodily impairments, including deficits in higher-level cognitive functions, and impairments in daily life (L). We argue that cognitive and daily life impairments associated with old age are often due to deficits in embodiment, which can partly be linked to neuronal degradation at the sensorimotor level. The framework may encourage the development of novel approaches to improve autonomous living for older adults.

1. Introduction

Body perception and bodily awareness play central roles in human sensation, action, and cognition (Gallagher, 2005; Pfeifer et al., 2007). Research that is conducted on embodiment typically investigates interactions between perceptual, motor, and cognitive processes and how they influence our daily living. Bodily processes, mediated by peripheral receptors, muscles, and associated neuronal pathways, indeed influence many aspects of our daily life, such as the way we interact with our peers (Buccino et al., 2001; Rizzolatti and Craighero, 2004; Rizzolatti and Fabbri-Destro, 2008), the way we perceive and evaluate our spatial environment (van der Hoort et al., 2011), the way we make important decisions (Damásio, 1994; Reimann et al., 2012; Selen et al., 2012) and feel about their outcomes (Brassen et al., 2012), and the way we memorize events (Bergouignan et al., 2014).

However, the various and complex changes the human body undergoes over the lifespan are not taken into account in most current theories on embodiment. But we live in an aging society: the mean age of people living in industrialized countries is currently over 40 years, and further increases are expected (Vaupel, 2010). Nevertheless, so far, little attention has been paid to age-related changes in embodiment, the associated sensory, motor, and cognitive abilities, and the underlying neuronal mechanisms determining these effects. Critically, the lack of a comprehensive framework discussing the effects of bodily changes on sensory, motor, and cognitive processes and their influence on daily life can lead to an underestimation of the importance of changes in embodiment for cognitive disorders and sensorimotor deficits that are specific for older adults. This can slow down the development of treatment strategies to counteract these deficits and improve autonomous living for older adults. In addition, it leads to a limited basic understanding of the neuronal mechanisms that underlie age-related changes in cognitive functions. A better understanding of these changes may help policy makers to ensure that people aged 65 and older continue to play an integral role in their community.

Here, we take a first step in filling this current knowledge gap. We review the available empirical evidence on age-related changes in embodiment and synthesize it to introduce the NFL Framework of Embodied Aging. This novel theoretical framework clusters age-related changes in embodiment into three basic categories: neuronal mechanisms (N), functional consequences (F), and daily life relevance (L). The framework highlights the interactions between these levels, supported by empirical evidence. We refer to each category (N, F, and L) in the text and summarize the framework in Fig. 1. To increase readability, we have structured our review according to standard classification schemes

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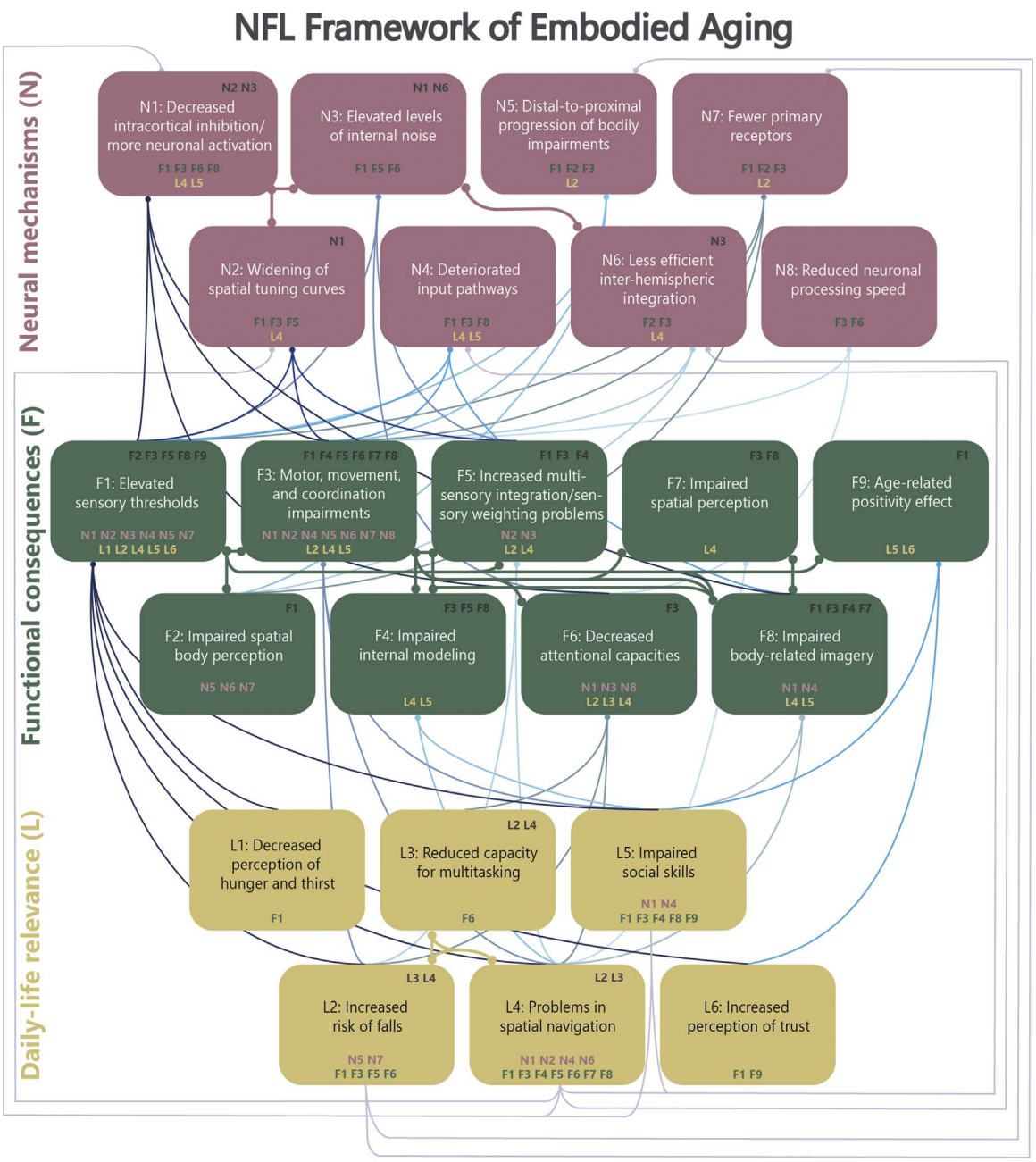

Fig. 1. NFL Framework of Embodied Aging. Displayed are interactions between neuronal mechanisms (N), functional consequences (F), and consequences for every-day life (L) of body-related impairments in older adults. Similar to the colored lines, the small letter-number pairs inside the boxes indicate relationships between different elements, which are explained in the text. Black pairs = relationships between elements within same level; red, green, yellow pairsom = relationships between elements across levels.

(e.g., touch, proprioception, interoception). Each category (N, F, and L) therefore appears in each of the specific sections. The NFL Framework of Embodied Aging was developed to allow a more detailed understanding of the interactions between age-related neuronal changes, age-related changes in perception, motor control, and cognition, and daily life experiences by older adults. The framework allows linking different research fields that have so far often been studied in isolation. Two reviews target similar issues (Vallet, 2015; Loeffler et al., 2016): Vallet et al. (2015) summarizes interactions between sensorimotor deficits and cognitive impairments in older adults, whereas Loeffler et al. (2016) provide a lifespan perspective on embodiment including literature both on children and on older adults. Our review extends this literature by (i) introducing specific neuronal mechanisms that may underlie age-related changes in embodiment, (ii) discussing a variety of modalities (e.g., touch, proprioception, interoception) and cognitive functions (e.g., spatial cognition, social cognition), and (iii) integrating existing evidence into a novel framework.

We focus on published studies in the field of human cognitive and clinical neuroscience that either introduce changes in basic sensorimotor processing in older adults, or have established or supported links between age-related changes in basic sensorimotor processes on the one hand and age-related changes in higher cognitive processes on the other hand. The basic neuronal mechanisms we identified are summarized in Table 1, and the NFL Framework of Embodied Aging is summarized in Fig. 1. We included higher-level cognitive functions whenever published research indicated a link between age-dependent deficits in basic bodily processing and cognitive functions. Due to this subjective approach, neither these links nor the cognitive functions included can be exhaustive. We expect that future research will expand our initial framework. We note that although the plasticity of bodily processes and

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