NEUROSCIENCE
RESEARCH ARTICLE
S. Vieluf et al. / Neuroscience xxx (2018) xxx–xxx

Age- and Expertise-Related Differences of Sensorimotor Network Dynamics during Force Control

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Abstract—Age-related deterioration of force control is evident on behavioral and neural levels. Extensive and deliberate practice can decrease these changes. This study focused on detecting electrophysiological correlates of age- and expertise-related differences in force control. We examined young (20–27 years) and late middle-aged (57–67 years) novices as well as late middle-aged experts in the field of fine motor control. Therefore, EEG data were recorded while participants performed a force maintenance task. Variability and complexity of force data were analyzed. To detect electrophysiological correlates, dynamic mode decomposition (DMD) was applied to EEG data. DMD allows assessing brain network dynamics by extracting electrode interrelations and their dynamics. Defining clusters of electrodes, we focused on sensorimotor and attentional networks. We confirmed that force control in late middle-aged novices was more variable and less complex than in other groups. Analysis of task-related overall network characteristics, showed a decrease within the α band and increase within low β, high β, and θ band. Compared to the other groups young novices presented a decreased α magnitude. High β magnitude was lower in late middle-aged novices than for other groups. Comparing left and right hands' performance, young novices showed higher low β magnitude for the left hand. Late middle-aged novices showed high values for both hands while late middle-aged experts showed higher values for the right than for their left hand. Activation of attentional networks was lower in late middle-aged experts compared to novices. These results may relate to different control strategies of the three groups.

Key words: aging, fine motor expertise, variability, sensorimotor maps, dynamic mode decomposition, attentional networks.

INTRODUCTION

Force control is one key component of dexterous object manipulation. It is the product of temporary coalition of multiple subsystems, i.e. neural, cognitive, and muscular, as well as central integration of different sensory feedback loops acting on different time scales (Vaillancourt and Newell, 2002; Vieluf et al., 2015). The different subsystems as well as the different parts of the subsystems, e.g. different brain regions that interact in a task-specific manner, exchange information to achieve the goal of applying the right amount of force at the right moment in time. The efficiency of information exchange seems to be moderated by the activation or deactivation of attentional processes in relation to subjective task demands (Woollacott and Shumway-Cook, 2002; Temprado et al., 2015). This can be observed in time series, i.e. force fluctuations over time, and in electrophysiological measures characterized by coherent patterns in space and time at multiple frequencies that relate to information processing during rest or task (Brunton et al., 2016). Unlike activity at rest, the activity during a sensorimotor task represents the combined activity of cognitive, e.g. attentional, as well as visual and sensorimotor networks that have to be simultaneously activated. In this sense, the coupling of specific brain areas, related to those networks, has been shown to be associated to force control performance (Rilk et al., 2011; Papadelis et al., 2016). This study aims to determine effects of age and fine motor expertise on network activity as well as on behavioral characteristics of force control.

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Abbreviations: DMD, dynamic mode decomposition; FFT, fast Fourier transform; MSE, multi-scale entropy; PCA, principal component analysis.

https://doi.org/10.1016/j.neuroscience.2018.07.025
0306-4522/

Peripheral and central changes contribute to age-related differences in force control (Diermayr et al., 2011). On a behavioral level the magnitude of variability increases with age (Vaillancourt and Newell, 2003; Christou and Tracy, 2006; Ofori et al., 2010; Sosnoff and Newell, 2011; Vieluf et al., 2013), while the structure of variability, referred to as complexity, decreases (Vaillancourt and Newell, 2002; Newell et al., 2006; Vieluf et al., 2015). On an electrophysiological level brain network connectivity during rest is higher and lower during tasks for older than for young adults accompanied by a less strong suppression of default mode network activity (Steffener et al., 2012; Betzel et al., 2014; Sala-Llonch et al., 2015; Binder et al., 2017). An increase of prefrontal activation was reliably observed to maintain performance levels similar to younger adults, which has been interpreted as a potential mechanism of compensation through increased attention allocation for age-related deficits in cognitive performance (Calautti et al., 2001; Ward and Frackowiak, 2003; Reuter-Lorenz and Cappell, 2008; Hong et al., 2016). We intended to confirm alterations in task-specific and attention networks for elderly and investigate whether they depend on their expertise level in fine motor control.

It has been proposed, that extensive and deliberate use of hands may lead to a stable and outstanding performance level, referred to as domain-specific expertise (Ericsson and Smith, 1991; Salthouse et al., 2002) and that it might compensate for age-related changes. Indeed, older experts demonstrated less variable performance in force maintenance tasks than non-experts of the same age (Vieluf et al., 2012). Whether complexity decreases or increases in experts is still under debate. Complexity changes due to fine motor expertise have been tested in force control with a tendency toward an increase in regularity (Vaillancourt and Newell, 2002; Newell et al., 2006; Vieluf et al., 2015). Contrary, a study on dancers performing balance tasks showed that motor control experts have a more complex sway structure than their age-matched controls (Stins et al., 2009), interpreted as less attention devoted to the task and greater behavioral flexibility (Donker et al., 2007). Further, expertise in a specific task leads to differences in brain activation patterns and altered network properties, like an expansion of the respective cortical areas (Elbert et al., 1995; Sterr et al., 1998), a task-related decrease in frontocentral alpha power (Babiloni et al., 2008), and an increase of frontal midline theta power (Doppelmayr et al., 2008). In addition and in line with the *neural efficiency hypothesis*, functional networks were shown to be larger and more efficient in experts than novices (Binder et al., 2017). We therefore expected older experts to activate attentional networks less strongly and reveal higher activation within the sensorimotor network.

Against this background, we aimed to detect changes in electrophysiological activity related to age-and expertise-related differences of variability and complexity in force control. For this purpose, we characterized sensorimotor maps during isometric force maintenance tasks. We expected behavioral performance to be more variable and less complex with increasing age. Further, we expected age-related changes to be stronger in late-middle-aged novices as compared to late middle-aged experts, due to the continuous and deliberate use of the hands by the later ones. Based on the assumption that performance in a force control task relates to the suppression of the resting network and the activation of attentional and sensorimotor networks (for anatomical network description see Rosazza and Minati, 2011), we focused on electrophysiological markers representing those networks. We used dynamic mode decomposition (DMD) as a method to extract network-specific dynamics, i.e. to capture the characteristics of the overall relations of the measured signals among the electrodes. We expected to find markers of sensorimotor and attentional network activation for all participants. With advancing age, we assumed a higher activation level of attentional networks and higher interrelation with sensorimotor networks. Based on the neural efficiency hypothesis we expected lower interrelation within the attentional network and higher interrelation within the sensorimotor networks in the group of experts compared to non-experts of the same age.

EXPERIMENTAL PROCEDURES

Participants

A total of 40 participants took part in the study. Participants were recruited by flyers, telephone calls, and newspaper announcements in the framework of the Bremen–Hand–Study@Jacobs (Voelcker-Rehage et al., 2013). All participants enrolled voluntarily, provided their informed consent and were compensated for their participation with 8 € per hour. The experimental procedure was approved by the ethics committee of the German Psychological Society and was in accordance with the ethical standards laid down in the Declaration of Helsinki.

Based on their age and their occupational field, participants were assigned to three subgroups: young novices (YN: 14; 20–26 years; mean age 22.64 ± 1.82 years; 9 females), late middle-aged novices (LMN: 12; 57–67 years; mean age 58.17 ± 2.95 years; 7 females), and late middle-aged experts (LME: 14; 57–67 years; mean age 57.93 ± 2.91 years; 8 females). The groups of young and old novices were formed by service employees, i.e. consultants, office clerks, insurance agents, and vocational trainees in these occupations. The group of experts included precision mechanics who manipulate small objects in a highly dexterous way as part of their daily work routines, i.e. opticians, goldsmiths, watchmakers, hearing care professionals (Reuter et al., 2012; Vieluf et al., 2012). Based on the definition of Ericsson and Smith, 1991, experts were only included when they had at least 10 years of work experience in the specific field. Consequently, we could not recruit young experts and decided against including other young experts, like musicians, as expertise was shown to be highly task specific. To verify expertise, we used a questionnaire that assessed the frequency of hand use at work (Trautmann et al., 2011). It showed that our experts had a significantly higher frequency of dexterous hand use than the novices ($p < .01$). Further, all partici-