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Age-related operator deficits in a realistic instrument-control task: Assessment of possssible motor, cognitive and mental causes☆

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ABSTRACT

With advancing age, motor and mental functions gradually change. As these changes have been revealed by standardized laboratory tests, it remains unclear how much they affect older persons' performance in industrial workplace tasks. The present study therefore compared young and older participants in a task modeled after a complex, realistic industrial workplace scenario, and additionally assessed motor, cognitive and mental variables that might have an impact on overall task efficiency. 25 participants (13 young, mean age 25 years; 12 older participants, mean age 65 years) sat in front of a panel with multiple displays - indicating the momentary state of a simulated nuclear power plant (i.e., power supply and demand, fuel rod stock, temperature) - and multiple actuators - allowing them to modify that state. Their task was to maximize the plant's momentary earnings, which were displayed as well. Participants could increase the earnings by keeping the difference between power supply and demand as small as possible, and to sufficiently use the fuel rod stocks since they did cost earnings. Operator efficiency was defined as final earnings after 8.7 min of work. Kinematics and dynamics of grasping the actuators were assessed with a motion capture system and force sensors. Workload and strain was assessed with established questionnaires, and cognitive abilities with PC-based tests. We found that operator efficiency dramatically declined in older age (−70%). This decline was not related to differences in grasping kinetics and kinematics, workload, or cognition, but was related to the age-related decay of motivation, suggesting reduced motivation as one explanatory factor. We therefore conclude that performance on a simulated complex industrial workplace task is partially dependent of age and motivation, but is difficult to predict from other motor or mental functions. This conclusion is relevant for the assessment of industrial job skills, and possibly also of driving and household skills.

1. Introduction

As the workforce ages and computer-based technology advances, an increasing number of older employees is needed for the control of complex industrial processes in which they have to observe multiple displays and operate multiple input devices. To successfully perform such complex tasks and to keep efficiency (i.e., the amount of work in a given time) on an acceptable level, various cognitive and motor abilities are needed (Salthouse, 2012; Smith et al., 1999). However, several studies in the past have documented an age-related decay of cognitive functions (Prakash et al., 2009; Raz, 2000; Solbakk et al., 2008), and motor skills (Cole, 1991; Ketcham et al., 2002; Lindberg et al., 2009), suggesting that with increasing age performance of such complex tasks may become increasingly difficult, which in turn might affect efficient working. The majority of previous research has used standardized laboratory tasks, which may not be valid indicators of workplace performance (Salthouse, 2012). Typical laboratory tasks are repetitive, externally triggered, purposeless and attention-attracting, while many real-life activities are part of a complex behavioral sequence, volitionally initiated, ecologically valid and carried out either automatically or with only limited attention (Bock and Hagemann, 2010; Bock and

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Züll, 2013). In fact, our group has documented that age-related deficits of gait (Bock and Beurskens, 2011) and of manual prehension (Bock and Steinberg, 2012) are substantially different when assessed in a natural context versus in the laboratory. The same has been reported for age-related deficits of cognition (Verhaeghen and Cerella, 2002).

Several previous studies have assessed age-related performance in more realistic tasks: Studies evaluated age-related deficits during simulated car driving (Kramer et al., 2007) and simulated air traffic control (Nunes and Kramer, 2009), observing deficits in older participants only if the task was unpracticed or combined with another task. Other studies used experimental setups that were more likely based on complex realistic workplace scenarios and assessed operator performance using complex human-machine systems or life-support control setups, but these studies did not focus on age-related performance changes and/or work efficiency (Sauer et al., 2003; Ting et al., 2010). Further studies have investigated the role of motor functions in age-related performance during simple computer mouse control tasks. These studies found age-related deficits of performance and of motor functions, but also pointed out that age-related performance assessments based on simple functions might underestimate the difficulty elderlies have when performing more complex and realistic tasks (Riviere and Thakor, 1996; Smith et al., 1999). It therefore remains unclear how age-related deficits when performing a realistic and complex task are related to age-related decline of basic motor function. This relationship is explored in the present study, which examines age-related differences in performance and motor functions in a realistic industrial instrument-control task.

Since age-related changes of mental (Germain and Hess, 2007) and cognitive functions, such as sustained attention (Madden et al., 2005; McAvinue et al., 2012) and attention breadth (Hüttermann et al., 2012; Ivnik et al., 1996; Tombaugh, 2004) are well known, we additionally assessed different and relevant cognitive and mental functions in our study. Furthermore, to control for the critical role of prior experience (Nunes and Kramer, 2009; Salthouse, 1990), we designed a task that is realistic and motivating but new to all participants. Similar to typical industrial process-control tasks, our task requires the observation of multiple displays and the usage of multiple input devices (rotary knobs, switches), and has periods of high and low cognitive and motor demands (Steinberg et al., 2015).

The main goal of the present study was to evaluate age-related operator efficiency differences in young and older participants, performing a realistic and complex industrial instrument-control task. A second goal was to assess multiple motor control variables, as well as cognitive, stress and mood functions, and to evaluate them as possible predictors of age-related deficits. Our working hypothesis was that (i) compared to young participants, older ones will perform less well in an unfamiliar realistic complex industrial instrument-control task, and (ii) their performance deficit will be associated with a motor decline.

2. Materials and methods

2.1. Participants

Twenty-five right-handed volunteers participated, twelve older (mean age 65 ± 3 years, 6 female) and thirteen young persons (mean age 25 ± 3 years, 6 female). They had no prior experience in sensorimotor research and no history of vestibular or sensorimotor deficits except for corrected vision. All lived independently in the community, arrived for testing without assistance in the agreed-upon place at the agreed-upon time, understood our instructions and performed all tasks adequately. From this we conclude that the cognitive and motor functions of both age groups were not grossly impaired. Both groups had also a comparable education level.[1] All participants were informed about the study aims and procedures prior to the experiment, and signed a written informed consent statement before being included in the study. The study was conducted in accordance to the Declaration of Helsinki, and was pre-approved by the local Ethics Committee.

2.2. Experiment setup

We used the same task as in our companion study on process control in normal and in reduced gravity (Steinberg et al., 2015). As shown in Fig. 1a, participants sat in front of a 17″ screen with a built-in eye tracking system (Tobii® T60, sampling rate: 60 Hz). The analysis of gaze data has been presented in a separate communication (Kalicinski et al., 2016). To the right of the screen was a control panel with four actuators: A cylindrical rotatable knob of 70 mm diameter, one of 35 mm, a rotary switch of 17 mm length which could be turned in six steps of 20° each, and a standard flip switch of 17 mm length. Force sensors (ATI® Nano 17) registered the grip forces (250 Hz sampling rate) and rotary encoders (RoHS® RES20; 20 Hz) registered the position of each actuator except for the flip switch. Four Vicon® Bonita cameras were placed above, left and right beside the subject and registered the positions of six infrared-light reflecting markers (6 mm in diameter) that were attached by double sided adhesive tape to the subjects' index fingertip, thumb tip and midpoint of the index-finger's metacarpal bone; marker positions recorded by the four cameras were subsequently converted into 3D signals at a rate of 240 Hz and an accuracy of 1 mm.

2.2.1. Process-control task

Participants task was to control a simulated nuclear power plant as efficiently as possible. The status of the power plant was presented by seven displays on the screen (see Fig. 1b). The bar on the right showed the momentary earnings of the power plant, i.e., revenue minus expenses; the participants' task was to maximize those earnings within the allotted time. Thus, the displayed earning was a direct measure of task efficiency, i.e. the better the power plant has been controlled, based on the task rules described in the following, the higher the earning. The circular display at the top left presented the momentarily produced power and the requested power. Participants could rotate the 70 mm knob at the control panel (see Fig. 1c big rotatable knob) to increase or decrease power production, thus to reduce the difference between supply and demand and as a consequence, to increase earnings. Requested power changed every 5–10 s, and subjects therefore had to regularly watch the top display. The sequence of power requests was the same in all participants.

The circular display at the middle left indicated the momentary energy capacity of the fuel rod in use. This capacity decreased proportionally with power production, such that eventually, participants had to insert a new rod by moving the rotary switch one 20° step clockwise. Otherwise, the plant would shut down temporarily and produce no revenue. Inserting the new rod reset the capacity display, and decremented the display of rods in stock in the center of the screen. Once the last (sixth) rod was inserted, subjects had to purchase a new set of rods by moving the rotary switch six steps counterclockwise, which refilled the stock display and decreased the amount of earnings. The circular display at the

[1] We assessed the education level (years of education, academic vs. non-academic) of our participants with a questionnaire, and did not found significant differences between both groups (young/elderly) ($p > 0.05$).