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The magnitude and rate of reduction in strength, dexterity and sensation in the human hand vary with ageing

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ABSTRACT

Cutaneous sensation and motor performance of the hand decline with age. It is not known if motor performance declines are influenced by reductions in cutaneous sensation, or if motor performance deteriorates at a consistent rate across motor tasks. Handgrip strength, finger-tapping frequency and grooved-pegboard performance were assessed for both hands of 70 subjects (20–88 years), 10 per decade. Motor declines were compared to reductions in perceptual cutaneous sensation tested at 10 hand sites using calibrated von Frey filaments. Motor performance decreased with age for all motor tasks ($p < 0.001$). Handgrip strength (mean ± SEM) decreased from 42.6 ± 9.5 kg (in the 30s), to 23.7 ± 7.6 kg (80s) or 44%; finger-tapping frequency from 6.4 ± 0.8 Hz to 4.2 ± 0.9 Hz, 34%; and grooved-pegboard (median [IQR]) increased from 59 s [57–66 s] to 111.5 s [101–125 s], 47%. The onset of the deterioration in motor performance varied with sex and task. Cutaneous sensation also decreased with age, measured as increased von Frey thresholds of 0.04 g [0.02–0.07] to 0.16 g [0.04–0.4] ($p < 0.001$) between the 20s and the 80s, or 73%. Cutaneous sensation varied with sex, side-tested and site. Reductions in grip-based tasks were associated with sensory declines in the palm, but elsewhere there was little correlation among motor tasks and cutaneous sensation in the hand. Grooved-pegboard performance was the best predictor of age-related declines in motor performance regardless of sex or side-tested. Our results suggest age-related declines in motor function cannot be inferred from, or provide information about, changes in cutaneous sensation.

1. Introduction

Sensory feedback from low-threshold receptors in the glabrous or hairless skin is important for fine motor control of the hand (Caccia et al., 1973; Deuschl et al., 1995; Macefield and Johansson, 1996; McNulty et al., 1999). Motor control describes the neuromuscular factors contributing to voluntary movement. The relationship between sensory feedback and motor control is termed sensorimotor control, and is evident in cutaneomuscular reflexes in which the input from populations of low-threshold cutaneous mechanoreceptors activated by electrical or mechanical stimulation modulate ongoing EMG in muscles acting on the hand (Buller et al., 1980; Caccia et al., 1973; Datta and Stephens, 1981; Deuschl et al., 1995; Macefield and Johansson, 1996). Similar spinally-mediated reflexes can be elicited from the input of *single* cutaneous afferents in the hand (McNulty and Macefield, 2001; McNulty et al., 1999) and foot (Fallon et al., 2005). Fallon et al. (2005) demonstrated the strength of this synaptic connection in a one-to-one relationship between single cutaneous mechanoreceptors in the sole of the foot and single motor units in muscles acting about the ankle. The importance of cutaneous feedback for motor control is further emphasized in studies where attenuation of the sensory signal by cooling (Nowak and Hermsdorfer, 2003) or anesthesia (Augurelle et al., 2003; Monzée et al., 2003; Refshauge et al., 1998) compromised subsequent motor control.

Cutaneous sensation and motor control both deteriorate with age (e.g. Bowden and McNulty, 2012; Desrosiers et al., 1996; Lezak et al., 2004; Thornbury and Mistretta, 1981; Tremblay et al., 2005). Age-related declines in sensory and motor function are thought to represent global systemic changes across multiple physiological systems (see Narici and Maffulli, 2010). This may include declines in hormonal, metabolic or neural processes, and may be exacerbated by extrinsic factors such as lifestyle, traumatic injury and disease (Carmeli et al., 2003). Although still a topic of debate, the complex changes in both the peripheral and central nervous systems are considered the basis of the general age-related loss of muscle mass and strength associated with sarcopenia (Doherty, 2003). Reductions in cutaneous sensation may also be influenced by more peripheral factors such as morphological changes in the myelinated afferent fibers or reductions in the number of cutaneous sensory receptors (Cauna, 1965; O'Sullivan and Swallow, 1968). Similarly changes in skin mechanics due to reduced hydration and altered blood flow have been

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suggested to contribute to sensory loss, although little association has as yet been demonstrated (Bowden and McNulty, 2012; Vega-Bermudez and Johnson, 2004; Woodward, 1993). A more detailed discussion of mechanisms contributing to age-related changes in cutaneous sensation of the hand can be found in Bowden and McNulty (2012).

It is not known if the general declines in motor control are exacerbated by age-related reductions in cutaneous sensation. Given the strong links between cutaneous sensation and motor control this relationship seems likely, especially for tasks requiring fine motor skills (Smith et al., 1999; Tremblay et al., 2003), but the data are inconclusive (Aoki and Fukuoka, 2010; Kalisch et al., 2012; Murata et al., 2010; Ranganathan et al., 2001). We recently completed a comprehensive survey of age-related changes in cutaneous sensation at multiple sites in the hand and demonstrated the largest reductions occurred on the palm and not at the fingertips where sensation is routinely studied (Bowden and McNulty, 2012). Thus the larger reduction in cutaneous sensation on the palm may affect motor control more than sensory changes at the fingertips. As far as we can ascertain there are no studies comparing age-related changes in sensation in the palm or dorsal surface of the hand with changes in motor function.

Performance in simple motor tasks is commonly used as a predictor of declines in functional ability as people age (Giampaoli et al., 1999; Jette et al., 1990). Three commonly used clinical assessments are maximal handgrip strength, finger-tapping frequency and grooved-pegboard performance (for review see Lezak et al., 2004). These assessments cover the continuum of motor function from maximal strength, to simple repetitive finger tapping, and the fine dexterity required for the grooved-pegboard test. The maximal strength of upper-limb muscle groups reduced with age by ~35–60%, particularly after 75 years of age (e.g. Kallman et al., 1990; Mathiowetz et al., 1985; Puh, 2010). Age-related changes in finger-tapping and grooved-pegboard performance have been studied less commonly, but are estimated to reduce by ~10–30% (Cousins et al., 1998; Ranganathan et al., 2001; Ruff and Parker, 1993). Changes in movement speed and complex dexterity have been examined only over limited age ranges (Lezak et al., 2004). Few studies have compared any two of these assessments in the same cohort (e.g. Ashendorf et al., 2009; Marmon et al., 2011; Ranganathan et al., 2001; Ruff and Parker, 1993) and the only comparison of all three tests did not include subjects over 69 years or compare the rate of decline between the three tests (Bornstein, 1985). Therefore it is not known if the different components of motor function deteriorate at a similar rate with age.

This study aimed to investigate age-related declines in three different aspects of upper-limb motor performance and concurrent reductions in cutaneous sensation across the hand. A cross-sectional study was undertaken to examine motor performance declines in both hands of healthy adults across 7 decades, and to compare these to reductions in cutaneous sensation measured in the same subjects. A detailed report of the reductions in cutaneous sensation with age in this cohort has been reported previously (see Bowden and McNulty, 2012). We hypothesized that the grooved-pegboard test would have the largest declines in motor performance with age due to the complex nature of the task. Based on our previous findings of spared sensation at the fingertips (Bowden and McNulty, 2012) we also hypothesized this study would show a stronger relationship between declines in grip strength and cutaneous sensation on the palm, rather than at the fingertips.

2. Methods

2.1. General procedures

Studies were performed with 70 neurologically healthy subjects with ages spanning seven decades (20 to 88 years, 35 males, 35 females). Both sides were tested in five males and five females for each decade (mean, range): 20s (24.1 years, 20–29 years); 30s (34.6 years, 30–39 years); 40s (45.6 years, 42–49 years); 50s (53.8 years, 50–59 years); 60s (64.5 years, 60–69 years); 70s (74.6 years, 71–78 years) and 80s (84.1 years, 81-88 years). These subjects also participated in a detailed study of cutaneous sensation in the hands (Bowden and McNulty, 2012). Subjects were screened for overt motor or sensory dysfunction including diabetes, peripheral neuropathies, and other neurological conditions prior to testing. No overt symptoms of nerve entrapment disorders were encountered and older subjects who reported osteoarthritis in the hand or wrist were asymptomatic at the time of testing. Cognitive competency was assessed as a score ≥24 on the Mini-Mental State Examination (Folstein et al., 1975). All subjects gave written, informed consent. The study was approved by the Human Research Ethics Committee, University of New South Wales and experiments were conducted in accordance with the Declaration of Helsinki.

2.2. Experimental procedures

Subjects nominated their dominant hand which in all cases corresponded to the hand used to sign the consent form. The motor tasks were presented in a random order for each subject. After each test was explained and a brief (<15 s) practice completed, the dominant hand was tested first for each task to minimize learning effects. Subjects were seated except for the handgrip test. Cutaneous sensation was assessed first and motor tasks performed in the same order as described below. No feedback was provided on performance until testing was completed. All tests were administered by the first author in the same ~90 min session that included sensory testing (Bowden and McNulty, 2012).

Handgrip strength was measured using a hand dynamometer (Sammons Preston Rolyan, USA) with the grip adjusted for hand size. Subjects stood with the elbow flexed in the sagittal plane to ~90° and held firmly against the body, the wrist was semi-pronated. Three brief (2–3s) maximal voluntary contractions were performed with strong verbal encouragement. The highest force was recorded in kilograms (kg).

Finger-tapping was performed with the test forearm and wrist supported while subjects were instructed to tap as fast as possible with the index finger for 20 s during a single trial. The test hand was not masked from view as pilot testing ($n = 7$) demonstrated there was no difference between being able to see the hand or not. Data were recorded using a piezo-electric transducer (ADInstruments, Australia) mounted flush to the table. The unfiltered signal was digitized (2 kHz) using a 1401 data acquisition card and Spike2 analysis software (CED, UK).

Grooved-pegboard Subjects were instructed to place all 25 pegs into a grooved-pegboard from left to right as quickly as possible using a single hand (Lafayette Instruments, USA). The test began and ended with the hand flat on the table while the uninvolved hand remained at rest. The time taken to complete the task was recorded in seconds (s).

Perceptual sensory thresholds were tested as part of a comprehensive, multi-modal survey of cutaneous sensation (see Bowden and McNulty, 2012). von Frey filaments provided the most sensitive discrimination of age-related changes in cutaneous sensation across the hand and so only these data are reported here. von Frey thresholds increase as sensation is reduced. To avoid confusion we will refer to changes in sensation, except in Results where threshold data are reported. Briefly, perceptual thresholds for punctate stimuli were measured at 10 sites on the glabrous and hairy skin of the hand (Fig. 1) using calibrated von Frey filaments (North Coast Medical, USA). The filament was applied with a single stimulus orthogonal to the skin surface at each presentation. The location of a perceived stimulus was identified by the subject according to a numbered