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Repetitive pointing to remembered proprioceptive targets improves 3D hand positioning accuracy

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Abstract

Repetitive pointing movements to remembered proprioceptive targets were investigated to determine whether dynamic proprioception could be used to modify the initial sensorimotor conditions associated with an active definition of the target position. Twelve blindfolded subjects used proprioception to reproduce a self-selected target position as accurately as possible. Ten repetitions for each limb were completed using overhead and scapular plane pointing tasks. A 3D optical tracking system determined hand trajectory start and endpoint positions for each repetition. These positions quantified three-dimensional pointing errors relative to the target position and the initial and preceding movement repetitions, as well as changes in movement direction and extent. Target position and cumulative start position errors were significantly greater than the corresponding preceding movement (inter-repetition) errors, and increased as the trial progressed. In contrast, hand trajectory start and endpoint inter-repetition errors decreased significantly with repeated task performance, as did movement extent, although it was consistently underestimated for each repetition. Pointing direction remained constant, except for the angle of elevation for scapular plane pointing,

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which consistently decreased throughout the trial. The results suggest that the initial conditions prescribed by actively defining a proprioceptive target were subsequently modified by dynamic proprioception, such that movement reproduction capability improved with repeated task performance.

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1. Introduction

The ability to move the arm to position the hand in three-dimensional space represents one of the nervous system's most important achievements. With this ability humans grasp implements and interact with their environment in a limitless number of ways. The processes involved in planning, executing and controlling a multi-link, multiple degree of freedom system with the functional precision necessary to successfully acquire a three-dimensional target are extraordinarily complex. The loss of motor function and level of incapacitation experienced by individuals with Parkinson's disease (Majsak, Kaminski, Gentile, & Flanagan, 1998; O'Suilleabhain, Bullard, & Dewey, 2001; Seidler, Alberts, & Stelmach, 2001) and sensory neuropathy (Gordon, Ghilardi, & Ghez, 1995; Sanes, Mauritz, Dalakas, & Evarts, 1985) attest to the importance of understanding these processes.

The control of coordinated movement is contingent on the delivery of proprioceptive feedback from specialized peripheral receptors (Bevan, Cordo, Carlton, & Carlton, 1994; Cordo, Carlton, Bevan, Carlton, & Kerr, 1994; Gandevia, 1996). Proprioception is required for interjoint coordination and for controlling proximally produced joint interaction torques (Ghez, Gordon, Ghilardi, Christakos, & Cooper, 1990; Sainburg, Ghilardi, Poizner, & Ghez, 1995; Sainburg, Poizner, & Ghez, 1993; Smith & Zernicke, 1987). In a variety of animals such as the cat, proprioceptive afferents regulate rhythmic movements via the influence of central pattern generators (Bässler, 1986; Conway, Hultborn, & Kiehn, 1987; Lennard, 1985; Wolf & Pearson, 1988), and recent evidence suggests this is also the case for walking in humans (Dietz, 2002). With respect to the control of reaching movements, it has been suggested that motion-dependent proprioception modulates subsequent motor output by updating an internal model of the arm with movement specific limb dynamics information (Ghez et al., 1990; Messier, Adamovich, Berkenblit, Tunik, & Poizner, 2003; Sainburg et al., 1995).

Hand position errors for reaching movements to remembered visually defined (Darling & Miller, 1993; Flanders & Soechting, 1990; Soechting & Flanders, 1989) and proprioceptively defined targets (Adamovich, Berkinblit, Fookson, & Poizner, 1998) indicate that initial limb dynamics estimates may be insufficient and depend on the initial conditions used to define the movement (Hasan, 1992). When pointing to remembered proprioceptive targets (targets that correspond to spatial limb and/or