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Phalanx force magnitude and trajectory deviation increased during power grip with an increased coefficient of friction at the hand–object interface ☆

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ABSTRACT

This study examined the effect of friction between the hand and grip surface on a person's grip strategy and force generation capacity. Twelve young healthy adults performed power grip exertions on an instrumented vertical cylinder with the maximum and 50% of maximum efforts (far above the grip force required to hold the cylinder), while normal and shear forces at each phalanx of all five fingers in the direction orthogonal to the gravity were recorded. The cylinder surface was varied for high-friction rubber and low-friction paper coverings. An increase in surface friction by replacing the paper covering with the rubber covering resulted in 4% greater mean phalanx normal force (perpendicular to the cylinder surface) and 22% greater mean phalanx shear force in either the proximal or distal direction of the digits ($p < 0.05$; for both 50% and maximum grip efforts). Consequently, increased friction with the rubber surface compared to the paper surface was associated with a 20% increase in the angular deviation of the phalanx force from the direction normal to the cylinder surface ($p < 0.05$). This study demonstrates that people significantly changed the magnitude and direction of phalanx forces depending on the surface they gripped. Such change in the grip strategy appears to help increase grip force generation capacity. This finding suggests that a seemingly simple power grip exertion involves sensory feedback-based motor control, and that people's power grip capacity may be reduced in cases of numbness, glove use, or injuries resulting in reduced sensation.

1. Introduction

Hand grip is essential for many daily living activities. Grip force control has been thoroughly studied for pinch grip (Johansson and Westling, 1984; Latash and Zatsiorsky, 2009; Park et al., 2010; Westling and Johansson, 1984). However, grip control studies are sparse for power grip. Power grip is probably the most often used grip posture in daily tasks such as holding a bottle or cup (Landsmeer, 1962). Thus, knowledge on how people control power grip force generation will be useful for biomechanical and rehabilitation applications.

Power grip involves force generation by each phalanx of the five fingers (Amis, 1987; An et al., 1980; Lee and Rim, 1991; Radhakrishnan and Nagaravindra, 1993). Each phalanx produces force in three dimensions. When a vertical cylinder is gripped, the three dimensional phalanx force can be decomposed to (1) normal force in the direction normal to the cylinder surface, (2) shear force in the gravity direction, and (3) shear force in either the proximal or distal direction relative to a digit (referred to as proximal–distal shear force hereafter) (Fig. 1). The shear force in the gravity direction is determined by the weight of the grasped object (Johansson and Westling, 1984; Westling and Johansson, 1984). The proximal–distal shear force does not directly contribute to lifting of the grasped object, but people still apply this shear force during power grip (Amis, 1987; Irwin and Radwin, 2009).

It is unknown how people adjust the magnitude and direction of phalanx force during power grip, and whether proximal–distal shear force can contribute to normal force. Biomechanical models and empirical evidence (Seo et al., 2007; Wu et al., 2009) suggest that proximal–distal shear force can affect normal force, when muscle force is constant. Therefore, proximal–distal shear force may contribute to increased normal force.

So far, negligible proximal–distal shear force has been reported (Amis, 1987; Wimer et al., 2009). This negligible shear force, however, may have resulted from instrumentation setups and analysis methods and may be inappropriate to demonstrate that people do not use substantial proximal–distal shear force during power grip. In Wimer et al. (2009), an instrumented cylinder recorded only one resultant normal and shear forces across multiple fingers and phalanges, not specific to individual fingers and phalanges. If multiple fingers and phalanges

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