PREHENSION SYNERGIES: EFFECTS OF FRICTION

Tomoko Aoki, Mark L. Latash and Vladimir M. Zatsiorsky
Department of Kinesiology, The Pennsylvania State University
email: vxzl@psu.edu

INTRODUCTION

Friction at the digit-object interface is a critical factor for the central nervous system to adjust digit forces applied to a manipulated object. In two-digit grasps, force normal to the surface becomes greater for an object with a more slippery surface, resulting in a higher normal/tangential force ratio, but the safety margin to prevent slippage is normally kept relatively constant [1]. In multi-digit holding tasks the effects of surface friction have been investigated only for tripod grasps [2]. We therefore investigated these effects in a five-digit object grasping task in relation to changes in the torque acting on the object.

METHODS

Six right-handed healthy young males held an aluminum handle equipped with five six-component force/moment transducers and a level. The level was used to visually guide the subjects to keep the vertical handle orientation. The external torques (-0.5, -0.25, 0, +0.25 and +0.5 Nm) were applied by changing the location of a suspended weight. The total weight of the apparatus was 11.5 N. Sandpaper (S) and rayon (R) materials were used to change friction at the sensor-fingertip interface. There were four surface conditions classified as symmetric — namely SS (all surfaces are S) and RR (all are R) — and asymmetric, SR (S for the thumb and R for the others) and RS (the reverse of SR). Data were collected for each of these conditions while torques were changed (20 trials par subject). Signals were recorded for 3 s after reaching a steady holding condition. In a separate trial for the SS and RR, a hold-to-drop task was performed to measure the minimum normal force to hold the handle, from which we estimated coefficient of static friction (μ), 0.6±0.2 for R and 1.8±0.3 for S. Forces normal (F_n) and tangential (F_t) to the grip surface were analyzed for each digit. Safety margin (SM) was evaluated based on the following equation, SM = $((F_n)_i - |(F_t)_i|/\mu)$.

RESULTS AND DISCUSSION

As expected, both F_n and F_t of all digits were largely influenced by surface condition (Figure). In the symmetric tasks, the F_n was larger in the RR conditions. The effect of friction on F_n was larger than the torque effects: even the smallest value of the F_n for the thumb and virtual finger (VF: an imaginable finger that generates the same mechanical effect of four actual fingers) in the zero torque task was larger than any F_n value in the SS task. There was an equal sharing of the F_t by the thumb and VF for the zero torque condition.

In the asymmetric tasks, force vectors of the thumb and VF differed substantially: the digit force vectors were torque dependent (Figure a). In the zero torque conditions the F_n of the thumb and VF were larger than in the SS and smaller than in RR tasks. At a zero torque, the thumb and VF exerted unequal F_t. Such an unequal sharing of F_t generated a moment of the tangential force that had to be negated by the moment of the normal forces. In the non-zero torque tasks when the torque production required an exertion of a tangential force at the more slippery side, the F_n were as large as in the RR condition (Figure b). The SM values at the zero torque were similar for the thumb and VF for SS and RR, while for the SR and RS tasks they were larger for the S side than the R side.

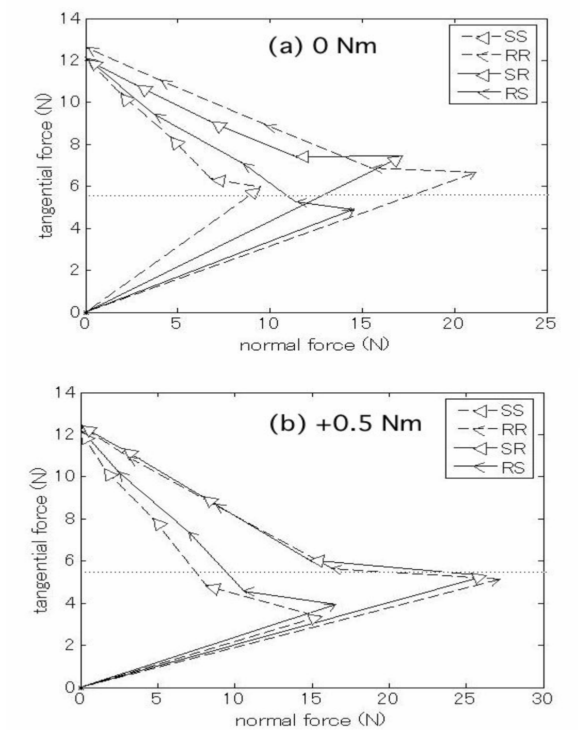

Figure: Mean force vectors for different surface conditions across all subjects. The force polygons have been obtained by adding tail-to-head the individual force vectors. Vectors represent the forces of the thumb, index, middle, ring and little fingers, respectively, in a counterclockwise sequence (starting from the bottom left corner).

SUMMARY

In the asymmetric tasks the subject decrease the F_t production at the places of low friction. Such a strategy results in changes of F_n and the moments produced by the normal and tangential forces (chain effects).

REFERENCES

1. Johansson & Westling. *Exp Brain Res* **56**, 550-564, 1984.
2. Burstedt et al.. *J Neurophysiol* **82**, 2393-2405, 1999.

ACKNOWLEDGEMENTS

Supported in part by NIH grants AR-048563, AG-018751, and NS-35032.