FINGER COORDINATION DURING MOMENT PRODUCTION ON A MECHANICALLY FIXED OBJECT

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INTRODUCTION

This study deals with the fingertip forces exerted during moment production on a handle affixed to an unmovable support, which is a quite common task in everyday life. As compared to holding a free object — to date the most popular object for studying prehension (Augurelle et al. 2003; Shim et al. 2003, 2004; Zatsiorsky et al. 2003)—this task possesses one essential distinction. When a handle is affixed to an external support, the forces exerted on the handle can be of any magnitude; in this sense, the task is constriant free and it is not dictated by typical static equilibrium constraints ($\sum \boldsymbol{M}=0$, $\sum \boldsymbol{F}=0$).

The goal of this study has been to investigate effects of three task parameters—(1) the mechanical advantage of the fingers, (2) the magnitude, and (3) the direction of the produced moment—on the following outcome variables: (a) the net forces exerted on the object, (b) the internal grasp force, (c) the percentage contribution of the free moment (a force couple) and the net force to the total moment production, (d) the agonist and antagonist moments, and (e) the individual finger forces.

METHODS

Equipment: Five six-component (three forces and three moments) transducers (Nano-17, ATI Industrial Automation, Garner, NC, USA) were attached to an aluminum handle which was fixed to a small force plate (PY6, Bertec Co., Columbus, OH, USA).

Experimental Procedure: Subjects (n=13, male, right-handed) sat on a chair and flexed the right elbow joint 90° in the sagittal plane. The forearm was in a neutral position between pronation and supination. The instruction to the subjects was to grasp the handle by placing the digit tip centers over the centers of the corresponding sensors and to produce a required moment about the moment axis as accurately as possible. The moments were generated in the counterclockwise (pronation, positive) and clockwise (supination, negative) directions, in total four moments: –2.0 Nm, –1.0 Nm, 1.0 Nm, and 2.0 Nm. The position of the handle with respect to the moment axis, P (6.0 cm, 4.0 cm, 2.0 cm, 0 cm, –2.0 cm, –4.0 cm, and –6.0 cm) defined the finger force moment arms that varied systematically across trials.

RESULTS AND DISCUSSION

The performance variables changed symmetrically with P. In particular, the magnitudes of the net horizontal and vertical forces both showed an S-shape change (Fig.1). The internal grasp force varied as a function of P being maximal at P=0 (Fig.2).

The index finger produced 69% of the total normal force during positive torque tasks while the little and the middle together

produced 70% during negative torque tasks (Table 1).

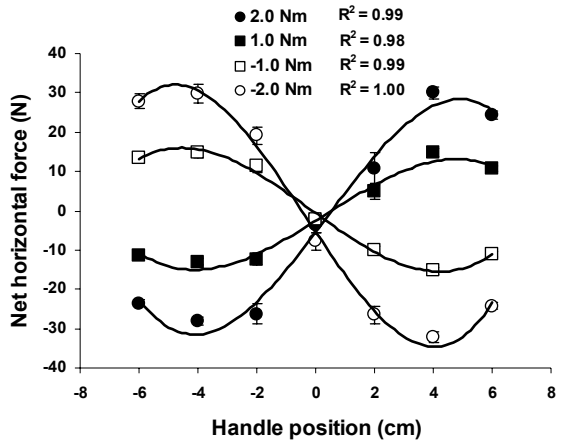

Figure 1. Net horizontal force.

The position of the point of zero free moment (PZFM) was determined. For the intermediate grasp locations (when $0<|P|<$PZFM), the contributions of M_{free} (moment produced by pronation or supination effort) and the moment of the resultant force (moment generated mainly by pushing) into the total moment production scaled linearly with P.

The magnitudes of both agonist and antagonist moments (those acting in and against the direction of the required moment, respectively) of normal forces increased with $|P|$ while the magnitude of agonist moments of tangential forces decreased.

For individual fingers, the ratio of finger force to its moment arm was not constant.

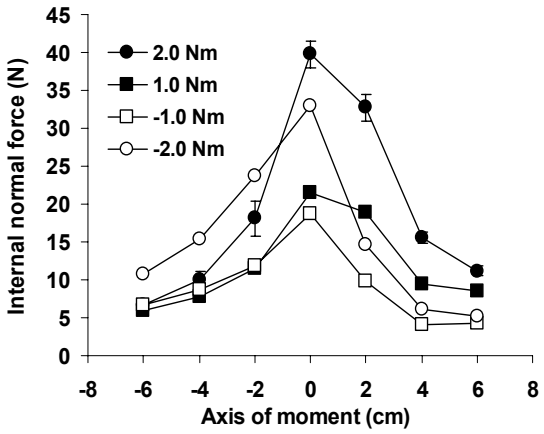

Fig.2. Internal grasping force

The mechanical advantage hypothesis was successful in explaining some of the data but could not cope with other findings. We assume, therefore, this hypothesis is limited in its applicability and may be task and effector specific.

REFERENCES

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Table 1. Sharing total normal and tangential force among individual fingers, %. Mean ≤ S.D.

Task	Normal force (%)				Tangential force (%)			
moment	I	M	R	L	I	M	R	L
2.0 Nm	68.4≤4.3	14.9≤2.4	11.8≤2.1	4.9≤1.2	50.0≤16.1	***19.0±12.1**	6.5≤6.3	9.6≤3.0
1.0 Nm	69.0≤4.0	14.8≤2.4	11.4≤1.9	4.8≤1.0	48.0≤16.3	***14.2±11.8**	6.3≤4.0	8.8≤2.5
-1.0 Nm	***14.1±4.1**	***15.9±2.5**	36.1≤1.8	34.0≤1.0	18.3≤17.7	23.3≤12.0	27.0≤4.4	***28.2±2.7**
-2.0 Nm	***12.2±4.3**	***17.3±2.4**	35.4≤2.0	35.0≤1.0	15.3≤18.2	26.6≤11.7	26.5≤4.3	***31.1±2.7**

Mean and S.D. values were calculated over all handle positions for all subjects. *Significant ($p<0.05$) differences of finger force sharing between 2.0 Nm and 1.0 Nm or between –2.0 Nm and –1.0 Nm.