Thumb invariance during prehension movement: effects of object orientation

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Received 2 May 2001; accepted 10 May 2001

The aim of the present study was to examine the contribution of the thumb and index finger during the task of reaching to grasp a cylinder positioned at different orientations. To this end an axis was defined between a marker positioned on the subjects' wrist and the target. For each frame the perpendicular distances of the thumb and index finger from this axis were determined. The perpendicular distance was greater for the index finger than the thumb, confirming a relative stability of the thumb during natural prehension and supporting the notion of the thumb as a guide for the transport component of reaching. Further, index finger perpendicular distance was varied according to object orientation. When the object was positioned at an angle that requires hand pronation, the perpendicular distance for the index finger was the greatest. It is concluded that changes in the index finger distance are necessary to allow the thumb to maintain stability in order to provide appropriate movement guidance. *NeuroReport* 12:2185–2187 © 2001 Lippincott Williams & Wilkins.

Key words: Humans; Kinematics; Object size; Orientation; Reach to grasp; Spatial trajectories; Thumb invariance

INTRODUCTION

The everyday action of reaching to grasp an object is commonly described in terms of a proximodistal distinction. The reaching action, effected by upper arm and forearm musculature, is subserved by a visuomotor mechanism that is largely independent of mechanisms subserving the hand and digit opening and closing upon the object for its grasp (channel hypothesis [1,2]).

The influence of object orientation on the organisation of the reach to grasp action may be relevant to clarify an important issue debated within this research area; that is, the investigation of the contribution of fingers and thumb to grasping movements [3]. Wing and Fraser [3] have suggested that the thumb has the role of a spatial reference which guides the transport component of reaching. They studied a proficient user of a manually operated artificial hand during grasping movements. The exhibited pattern was such that the index finger rather than the thumb was responsible for reduction of grasp aperture as the hand approached the target object. The same pattern was noticed in the artificial hand even though the mechanics of the artificial hand make it no easier to move the finger than the thumb [3]. These observations are of interest when considered in the context of the organization of directed arm movements. For example, the biomechanical adaptations that have occurred with the evolution of the primate hand include an opposable thumb [4] which has separate extrinsic muscular control [5]. Although its importance in manipulative tasks is fundamental, there has been no further behavioral investigation of the contribution of the thumb to reaching movements since the study of Wing and Fraser [3]. Similarly, the contribution of other fingers, such as the index finger, is still largely unknown.

The aim of the present study is to investigate the contribution played by thumb and index finger during the action of prehension with respect to changes in object orientation.

MATERIALS AND METHODS

Subjects: Eight women and seven men, aged 21–38 years, volunteered to participate. All were right-handed, reported normal or corrected to normal vision, and were naive as to the purpose of the experiment. They attended one experimental session lasting ~1 h.

Apparatus: The stimulus consisted of a red wooden cylinder (2 cm diameter), resting horizontally on the working surface placed at a reaching distance of 30 cm from the starting position and at three different predefined positions from the midline that correspond to three different orientations (Fig. 1).

Reflective passive markers (0.25 cm diameter) were attached to the following points of the reaching limb: (a) wrist: radial aspect of the distal styloid process of the radius; (b) index finger: radial side of the nail; and (c) thumb: ulnar side of the nail. Movements were recorded with the ELITE motion analysis system. This consisted of two infrared cameras (sampling rate 100 Hz) inclined at an angle of 30° to the vertical and placed 3 m in front of the table and 3 m apart. The spatial error measured from

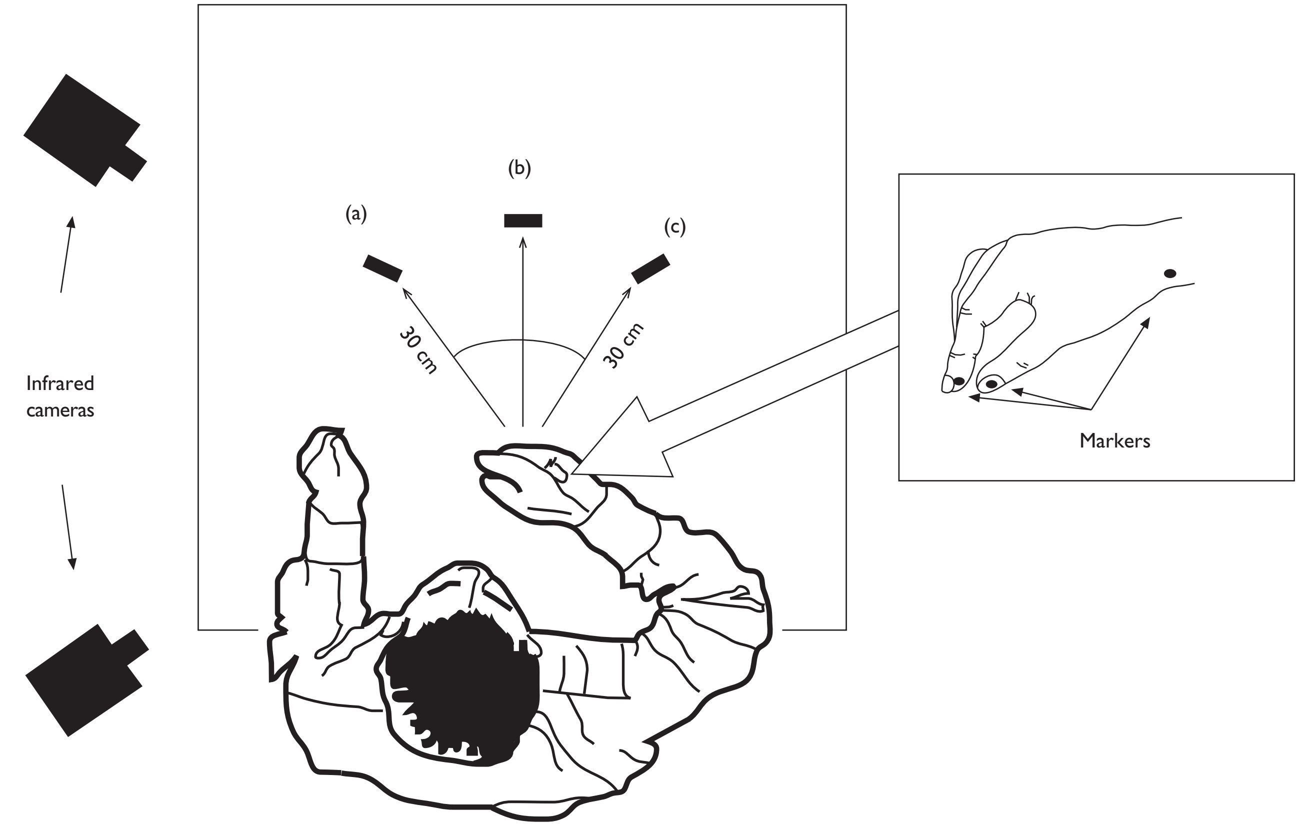

Fig. 1. Experimental set-up.

stationary and moving stimuli was 0.4 mm. Coordinates of the markers were reconstructed with an accuracy of 1/3000 of the field of view and sent to a host computer.

Procedure: The subject was seated at a table with the right hand placed on a pad (diameter 5 cm) positioned 20 cm in front of thier midline. The sound of a buzzer (800 Hz; duration 200 ms) indicated to participants that they should reach towards the target. The participants performed 30 counterbalanced trials, 10 trials for each orientation.

Data processing and analysis: The data were filtered using a finite impulse response (FIR) linear filter–transition band of 1 Hz (sharpening variable = 2; cut-off frequency = 10 Hz). The ELIGRASP (B|T|S|, 1997) software package was then used to analyze the data.

RESULTS

The purpose of the present study was to investigate the separate contributions of the thumb and finger to the aperture of the hand grip. To this end an axis was defined between the wrist marker and the dowel. For each frame the perpendicular distances of the thumb and finger markers from this axis were determined [3]. Mean data for each subject were analysed with an ANOVA with finger (index finger, thumb) and dowel position (left, centre, right) as within-subjects factors. *Post-hoc* comparisons were conducted on the means of interest using the Newman-Keuls' procedure (alpha level = 0.05). The main factor finger was significant ($F(1,12) = 19.13$, $p = 0.001$), revealing that the thumb holds an almost fixed position relative to the axis and the index finger is mainly responsible for opening and closing the hand grip. For the thumb, the average distance from the axis defined by the wrist marker and the target was 24.6 mm. For the index finger this distance was 52 mm. As shown in Fig. 2 the significant interaction between dowel position and finger ($F(1,12) = 8.24$, $p = 0.014$) indicates that the distance from the wrist–target axis was greater for the index finger than for the thumb at all object orientations ($p < 0.05$). Index finger distance was greater when the cylinder was positioned to the right than to the left and to the centre ($p < 0.05$; Fig. 2). In summary, the amplitude of the index finger movement relative to the wrist–target axis was noticeably greater than that of the thumb. Moreover, the extent of the index finger movement seemed to vary depending on the three different predefined object positions, which corresponded to the three different object orientations.

DISCUSSION

The aim of the present study was to investigate the contribution of the thumb and index finger during the action of prehension towards an object located at different positions and having different orientations. Our results are in accord with those of Wing and Fraser [3], whose study of reaching and grasping has indicated more stability for

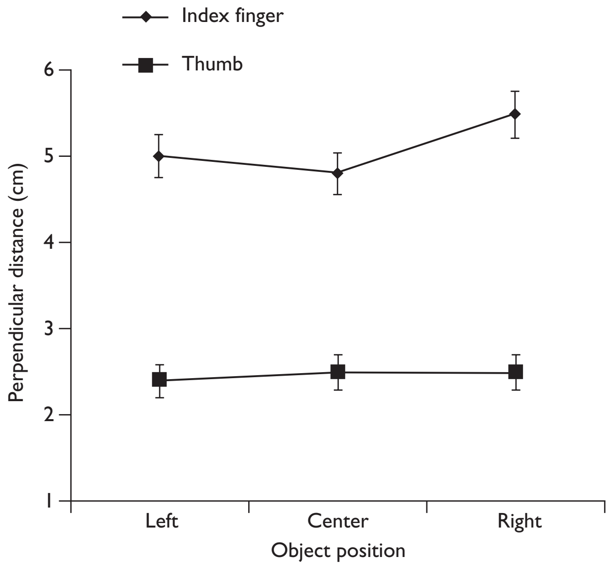

Fig. 2. Difference between the perpendicular distances for the index finger and thumb from the wrist–target axis for the three different object orientations.

the thumb than the index finger relative to the line of approach to the object. We extend these findings, demonstrating that the contribution of the index finger to the grasping action varies with respect to the position and orientation of the object to be grasped.

For simple reaching tasks, using the thumb as a point of reference for the position of the object might be one mechanism whereby the nervous system can program virtual trajectories which satisfy the assumption that intended movement can be computed in terms of a neurally defined virtual position [6]. For this to occur, the thumb must have unique characteristics, including selective motor control. Biomechanically, there is a structural separation of the extrinsic muscles of the thumb from the multi-tendoned muscles acting on the other digits [5], permitting more selective, independent movement of the thumb [7]. The direct corticomotoneuronal connections between the motor cortex and the motoneurons of muscles controlling the digits [8,9] also confer a capacity for skilled independent movements of the digits including the thumb. Indeed, the neural control of thumb muscles appears to be more specialized than for muscles acting on the index finger, as illustrated by experiments involving accuracy of weight matching [10]. Moreover, the proprioceptive acuity of the thumb is higher that that of the digits when the hand is flexed as in a functional grasp [11].

The observation that index finger deviation is greater during the reaching action when the object was positioned on the right might be explained by the greater range of ulnar deviation than radial deviation at the wrist, and therefore fewer biomechanical constraints on the wrist and finger in this direction. Deficits in reaching and grasping following lesions affecting the sensorimotor system might be correlated with deficits in thumb stability. Goal-directed movements of the arm are often impaired following stroke [12], and although the nature of this impairment varies according to the side of the lesion, it is worth noting that the long flexor and extensor of the thumb are considerably weakened [13]. Changes in preshaping of the hand for grasping have been noted in monkeys following temporary inactivation of the digit representations in somatosensory or motor cortex [14], or following unilateral lesion of the cervical spinal cord [15]. In these cases, the inability to use the thumb reliably as a point of reference may have contributed to the observed deficits in reaching and grasping. This issue could be fruitfully pursued in studies of reaching in human infants, as well as in adults following nervous system disorders affecting control of the thumb.

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Acknowledgments: This research has been supported by an Australian Research Council grant to U.C. Dean Lusher is thanked for helping with data analysis and other aspects concerned with this research.