Imagined spatial transformations in the visual discrimination of left and right parts of the human body.

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Much research has demonstrated that to discriminate between pairs of differently oriented but very similar objects, one very often finds it necessary to imagine (or physically produce) the rotation of the two objects into a similar alignment to compare their shapes (Cooper and Shepard, 1982; on physical rotations, Parsons and Hinton, Note 1.) An important property of the ability to imagine the rotation of an object is that often the time required for such a rotation is a linearly increasing function of the extent of rotation.

Most of this research has been done either with abstract shapes that are unfamiliar to subjects or with alphanumeric characters. There has been little investigation of the effect of orientation on the discrimination of more naturalistic stimuli. A few (mostly recent) studies of the perception of natural objects have examined mirror-image discrimination tasks in which subjects apparently imagined a human body or body-part at the orientation of a stimulus (Cooper and Shepard, 1975; Parsons, 1983, Notes 2-5, and 7). This paper reports on a few results of my own investigations in this area (Parsons, 1983, Notes 2-5, and 7).

Participants in my experiments made left-right judgments of variously oriented hands and feet, and of the raised arm of a human body depicted from many perspectives. Figure 1 shows examples of the kind of stimuli used in these experiments.

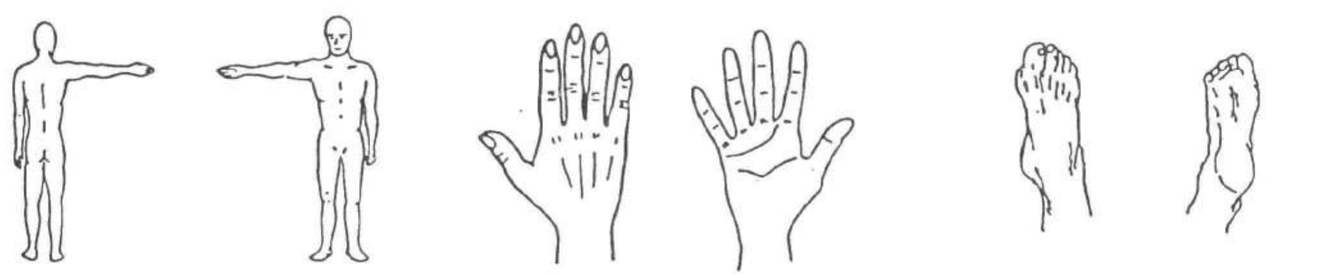

Figure 1.

This task requires button press responses with the left hand for a stimulus portraying a part of the left half of the body and with the right hand for a stimulus portraying a part of the right half of the body. Subjects in various experiments viewed a set of stimuli which depicted either a human body (with a raised arm), a hand, or a foot from many different perspectives.

A major feature of this research is the examination of subjects' abilities and preferences for selecting planes or axes for imagined rotations of objects when the number and variety of possibilities is relatively unconstrained by experimental design. In nearly all previous research, one or the other of two planes or fixed axes of rotation was most efficient to "correct" for the difference in orientation between the standard and comparison objects. Most studies have used orientation differences (ODs) in one or both of two planes (the "picture" and/or "depth" planes); and trials have frequently been blocked by the plane of the OD. By contrast, on any trial in the experiments reported here, any one of many different planes (or fixed axes) of rotation could be uniquely most efficient to bring the standard and comparison object into

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congruence. In addition, the orientation difference between standard and comparison objects in these experiments could be considerable. For instance, they could differ simultaneously in the orientation of their "front-back", "top-bottom", and "left-right" aspects. For these kinds of OD, an object can be brought into congruent alignment with another object (i) by being sequentially rotated about a different fixed axis for each dimension by which the two objects differ in orientation; or (ii) by being "simultaneously" rotated about different axes, producing rotations which are effectively about unfixed axes (i.e., about an instaneously changing axis); or (iii) by being rotated about a fixed axis which simultaneously corrects for all differences in orientation.

Thus, in this paradigm, to "correct" for orientation differences, subjects must select planes (or axes) of rotation from among a relatively large set of possibilities, according to their own criteria of efficiency. Their solutions to these geometrical problems provide new information about basic aspects of the imagination and spatial reasoning ability.

In addition to investigating spatial reasoning abilities in this context, I have been studying in detail how subjects make these seemingly simple and mundane discriminations; further, because subjects (as it turns out) do seem to imagine the rotation of parts or all of their own body in this task, I have been comparing the imagined transformations to corresponding physical actions (Parsons, 1983, and Notes 2-7).

Figures 2-4 show the reaction time-orientation difference (RT-OD) functions for subjects' judgments of whether a particular stimulus body part (a raised arm, a hand or foot) is of the left or right half of the body. Each RT-OD function is an average of results in 2 to 5 different experiments, using different subjects. Each stimulus in Figure 1 was presented in random ordered trials at 30 degree intervals in the "picture" plane, beginning at the position (0 degrees of OD) shown in Figure 1.

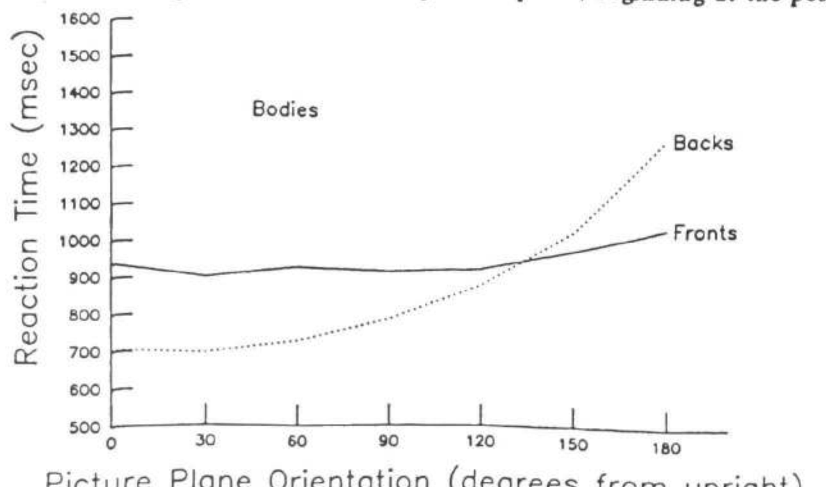

Figure 2. RT-OD functions for fronts and backs of bodies. Based on 4610 correct responses of 31 subjects.

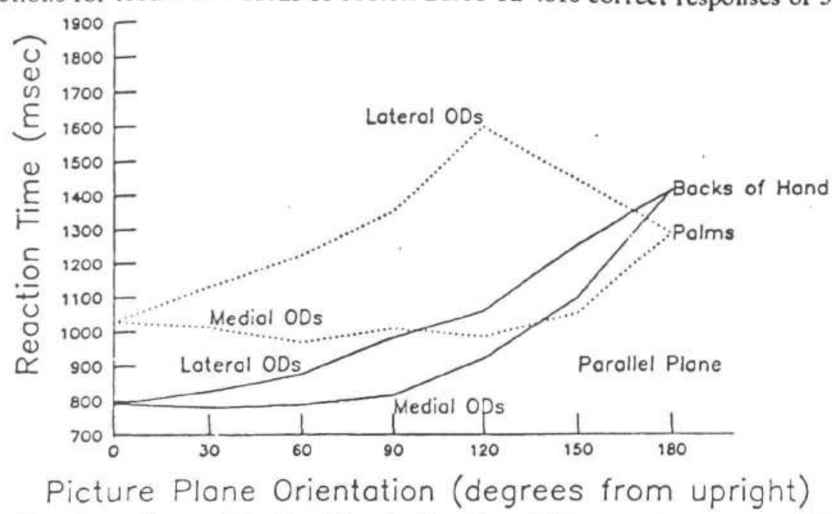

Figure 3. RT-OD functions for palms and backs of hands. Based on 4992 correct responses of 19 subjects.

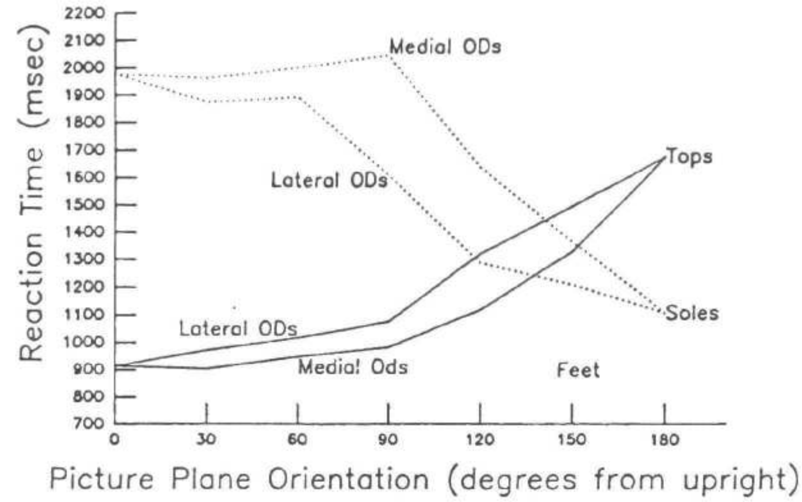

Figure 4. RT-OD functions for soles and tops of feet. Based on 4416 correct responses of 16 subjects.

To make these judgments, subjects reported imagining the rotation of their body, hand, or foot, into the orientation of the stimulus to compare the left-right features of the stimulus body or body part with the familiar left-right features of their own body or body part. Only for backs of bodies, backs of hands, and tops of feet stimuli at or near ODs of 0 degrees, did subjects report knowing "immediately" (i.e., without "thinking" about the orientation difference between themselves and the stimulus) whether the stimulus was of the left or right of the body. Accordingly, they produced their shortest RTs for such trials. Overall, RT depended on how the orientation at which the stimulus body or body-part was portrayed differed from the task-specific (or perhaps "canonical") orientation of the subjects' own body or body-part. The geometry implicit in subjects' strategies may be used to explain the difference observed between RT-OD functions for the views in Figure 1 of (i) backs and for fronts of bodies, (ii) backs and palms of hands, and (iii) tops and soles of feet.

The functions for backs of bodies and of hands, and tops of feet, are somewhat more extreme forms of the mental rotation function typically observed for another set of familiar objects (i.e., sets of letters or digits; Cooper and Shepard, 1973, and Hinton and Parsons, 1981). This kind of function is slightly sloped near a standard or most familiar orientation (e.g., upright) and is increasingly sloped as the remaining orientations increasingly differ from the standard. The RT-OD functions observed here are consistent with subjects' introspections about their performance. For trials with each of these stimuli, subjects reported imagining themselves or their hand or foot rotating from its present (or most familiar) position into the orientation of the stimulus. Subjects' introspections indicated that, for backs of bodies, backs of hands, and tops of feet, they imagined rotations about the same axis for the presentation of that stimulus at every OD in the experiment. For trials with backs of bodies, subjects reported imagining themselves rotating in a plane parallel to the frontal surface of their body, by tilting laterally about an axis perpendicular to the front of the trunk of the body and passing through the center of the body. For trials with backs of hands and tops of feet, they reported imagining rotations about long axis of the forearm and of the leg respectively.

With respect to the body of the observer, left hand and foot stimuli at clockwise ODs and right hand and foot stimuli at counterclockwise ODs are in medial positions. Similarly, left and right foot stimuli at oppositely directed ODs are seen by the observer as being at lateral positions. This aspect of spatial relationship between the observer and the portrayed position of the stimulus considerably affects subjects' performance in this task. RT-OD functions for all four hand and foot stimuli discussed here are reliably different for stimuli at lateral and medial positions. (These effects are discussed further below.)

The difference between functions for stimuli portraying the back of the hand and top of the foot at lateral and medial positions, appears to result from differences in the range of subjects' familiarity with appearance of these stimuli. The functions observed for backs of hands and tops of feet both have a flat or very slight slope (with subjects' most rapid RTs) for medial ODs near 0 degrees, which is more extensive than the range of rapid RTs for comparable lateral ODs. In each of these cases, the functions at lateral and medial ODs (beyond the initial flat portion of each function) have comparable slopes, and there is no indication of the use of alternative paths or axes of imagined rotation. Thus the longer mean RTs for lateral ODs seem related to the difference in the extent of this initial flat or slight slope. This difference in familiarity is consistent with the differences in the range of normal motion of a hand or foot (Parsons, 1983, and Notes 3 and 7). This suggests that the normal range of physical motion can affect the imagined rotation of body parts, because the orientations of the hand or foot which become extremely familiar to the subject are within this range.

Though the functions for backs of bodies and of hands, and for tops of feet are relatively similar, there are striking differences between the RT-OD functions observed for fronts of bodies, palms of hands, and soles of feet. For fronts of bodies, subjects' introspections and RT-OD functions suggest that they imagined rotations about a single fixed, "shortest path" axis. Rotations about such an axis, which is unique for each OD, minimizes the degrees necessary to move an object from one orientation to another. The shortest path rotations for differences in orientation like those between subjects' position and that portrayed by the fronts of body stimulus, are always and only 180 degrees--regardless of the picture orientation of the stimulus (Parsons, 1983, and Note 4).

It is apparent from other results of Parsons (1983 and Note 4) that subjects' tendency to use shortest path rotations (as opposed to less efficient rotation paths) for imagining the rotation of their body is influenced by (i) properties of the difference between subjects' task-specific (or canonical) orientation and that at which the stimulus is depicted, and (ii) the familiarity of the perspective from which the stimulus is depicted seemed to influence subjects' tendency to imagine shortest path rotations.

For trials with palm stimuli at ODs that portrayed the palm at medial positions, subjects apparently imagined approximately shortest path rotations (like those used for fronts of bodies). This conclusion is supported both by the flat slope of the observed RT-OD function and by subjects' introspections. However, with palm stimuli at ODs that portrayed the palm at lateral positions, subjects apparently imagined rotations about two different axes. This difference in imagined rotation paths into the palm at lateral and medial positions is consistent with the range of normal motion of the hand. As readers can probably verify for themselves, efficient (and natural) physical rotations of the hand into the medial positions portrayed by palm stimuli follow a path different from (and shorter than) that for rotation into lateral positions. These differences in the possible (or comfortable) physical rotation paths are of course related to the mechanical properties of the anatomical structures underlying such motions (cf. Parsons, 1983, and Note 3).

For trials with the sole of the foot stimuli, subjects' RT-OD functions and introspections indicate that they did not imagine shortest path rotations. The imagined rotation path of the foot seems to chosen to be within the normal range of motion of the foot (Parsons, 1983 and Note 5).

Overall, the following conclusions are suggested by my recent experimental results (some of which are presented above). The RT of these left-right judgments depended on how the orientation portrayed by the stimulus body or body part differed from the task-specific (or canonical) position of the subjects' body or body part. To make these judgments, subjects spontaneously imagined a part or all of their body rotating into the orientation of the stimulus to compare the left-right features of the stimulus body or body part with the familiar left-right features of their own body or body part. In some cases, subjects imagined rotations about an axis that simultaneously corrected for all differences between the orientation of their body or body part and that of the stimulus body. Use of such a "shortest path" axis minimizes the degrees of rotation necessary to align two objects. In other cases, subjects apparently imagined rotations about two axes. They may have used this latter strategy on trials with bodies, because of difficulty finding the shortest path axis, which is unique for each orientation difference (OD). Other results of Parsons (1983 and Note 4) suggest that the tendency to imagine shortest path rotations of one's body is influenced by various properties of the OD between oneself and a goal orientation, and by familiarity with an object's appearance throughout the range of its possible rotations.

On trials with hand and foot stimuli, subjects apparently imagine very efficient--or approximately shortest path--rotations only when the path from the task-specific (or canonical) position of the hand or foot into the position portrayed by the stimulus is within the normal range of movement of the hand and foot respectively.

These conclusions seem to require a theoretical framework in which there are spatial transformational procedures or schemas specific to different stimulus domains, and rather different from one domain to another. Further, in some domains such procedures seem closely related to--indeed, seem to simulate--the actual physical performance of a spatial transformation.

Reference Notes

1. Parsons, L.M. and Hinton, G.E. Egocentric and environmental frames of reference in the discrimination of mirror-image shapes. In preparation.
2. Parsons, L.M. Use of a "human body analogy" in the visual discrimination of abstract mirror-reflected shapes. Manuscript submitted for publication, 1983.
3. Parsons, L.M. Imagined spatial transformations in the visual discrimination of left and right hands. Manuscript submitted for publication, 1983.
4. Parsons, L.M. Imagined spatial transformations in the visual discrimination of left and right parts of the human body. Manuscript submitted for publication, 1983.
5. Parsons, L.M. Imagined spatial transformations in the visual discrimination of left and right feet. Manuscript submitted for publication, 1983.
6. Parsons, L.M. Geometrical properties of imagined rotation of abstract mirror-reflected objects. In preparation.
7. Parsons, L.M. The selection of paths for the imagined and physical rotation of an object from one orientation to another. In preparation.

References

Cooper, L.A. and Shepard, R.N. Chronometric studies of the rotation of mental images. In W.G. Chase (Ed.), *Visual information processing*. New York:Academic Press, 1973. Pp. 75-176.

Cooper, L.A. and Shepard, R.N. Mental transformations in the identification of left and right hands. *Journal of Experimental Psychology: Human Perception and Performance* , 1975, *104* , 48-56.

Cooper, L.A. and Shepard, R.N. Transformations on representations of objects in space. In E.C. Carterette and M.P. Friedman (Eds.) *Handbook of Perception, Vol. VIII*. New York: Academic Press, 1978. Pp. 105-146.

Hinton, G.E. and Parsons, L.M. Frames of reference and mental imagery. In A. Baddeley and J. Long (Eds.) *Attention and Performance IX*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1981.

Parsons, L.M. Mental rotation paths in the visual discrimination of left and right parts of the human body. Unpublished doctoral dissertation, University of California, San Diego, 1983.