Haptic Adjustment of Cylinder Radius

Astrid M.L. Kappers

Utrecht University, Helmholtz Institute, Physics of Man,
Padualaan 8, 3584 CH Utrecht, The Netherlands
a.m.l.kappers@uu.nl

Abstract. Haptic curvature discrimination experiments have typically been done with relatively small stimuli (at most hand-sized) placed on a table. In daily life, however, we often handle large curved objects (think of basket balls), which we usually hold with two hands. Here, I focus on the question how well shape information from the two hands is integrated. I investigated subjects' ability to adjust the distance between two large cylindrical shells in such a way that the two shells together would perceptually form a circular cylinder. All subjects were able to perform this task in a consistent way, but adjustments were often far from veridical. As deviations were often larger than discrimination thresholds, I hypothesize that they are either due to systematic biases in curvature perception or to misestimations of the distance between the hands. These results contribute to our understanding of haptic shape perception.

Keywords: Shape, curvature, bimanual perception.

1 Introduction

Haptic manipulation objects is an important aspect of dealing with our environment. In this respect it is of interest to investigate how well we are able to perceive shapes. Most quantitative studies focus on curvature discrimination performance with usually finger-sized [1,2] or hand-sized [3,4,5,6] stimuli. The current study uses stimuli that simulate objects that are much larger and would typically be handled with two hands. The main research aim is to investigate how well shape information derived from the two hands can be integrated.

In a study in which hand-sized stimuli were placed next to each other, bimanual curvature discrimination performance was found to be worse than unimanual performance [4]. However, in another study in which the stimuli were placed upright as if touching a large object, bimanual thresholds were in the same range as unimanual thresholds reported in other studies [7]. In the latter study, distance between the stimuli and relative placement of set-up and subject were not of influence on the threshold, but they caused subject-dependent biases (physically the same curvatures presented right and left could be judged as different).

For hand-sized cylindrical objects, humans are very sensitive to small deviations to a circular cross-section [8]. By just grasping cylinders, aspect ratios of 1.03 could be distinguished from 1.00 (circular cross-section). It was hypothesized that subjects are apparently sensitive to small variations in curvatures, as rectangular blocks with similar aspect ratios could not be distinguished. Aspect ratio discrimination experiments are

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not feasible with very large objects, due to handling limitations for both subject and experimenter. Therefore, I chose a matching paradigm in the present study, using an adaptation of the set-up of [7]. The following questions were addressed: How well are subjects able to adjust the distance between two cylindrical shells so that together they form a virtual circular cylinder? Does this depend on the orientation of the virtual cylinder axis? Does this depend on the position of the subject with respect to the set-up?

2 Methods

2.1 Set-Up

The set-up consisted of a rail with two vertical plates on which cylindrical shells could be fixed, such that their curved sides faced outwards (see Fig. 1 for a schematic drawing and details about dimensions). The rail was positioned on a small table. The distance between the cylindrical shells could be adjusted by the subjects by pushing or pulling the shells towards or away from each other. Within the rail the two plates were connected by a steel thread that caused them to always move symmetrically with respect to the center of the rail. The adjusted radius could be read off with an accuracy of 1 mm. In different conditions, the subject was seated at positions C, R, or L, so that the set-up was in the center, to the right or to the left of the subject, respectively (see Fig. 1).

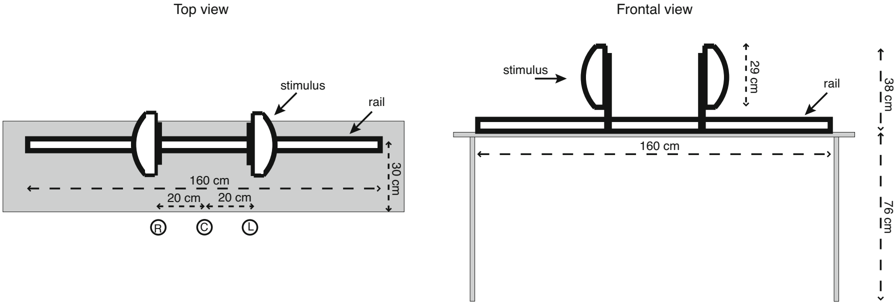

Fig. 1. Schematic drawing of the set-up. In the top view, the virtual cylinder axis is vertical; in the frontal view, the virtual cylinder axis is horizontal.

2.2 Stimuli

The stimuli consisted of a series of pairs of cylindrical shells, manufactured on a computer-controlled milling machine out of a compound of polyurethane foam and artificial resin (Cibatool BM 5460). The shells had a square bottom (29×29 cm) with a thickness of a few cm. Their curvature varied in a systematic way, such that the radii of the virtual circular cylinders that could be formed with a pair ranged from 15 to 85 cm in steps of 5 cm. The shells could be positioned in the set-up in two orthogonal ways, such that the virtual axis of the cylinder would either be horizontal (see Fig. 2 left) or vertical (see Fig. 2 right).

Fig. 2. Subject adjusting the radius. Left: horizontal orientation of the virtual cylinder axis and moderate value of the physical radius. Right: vertical orientation of the virtual cylinder axis and large physical radius. In both examples the subject is seated in the center position.

2.3 Subjects

The subjects were 6 adult students (3 females) at Utrecht University. Their age ranged from 20 to 23 years. Two females (EH and FS) were lefthanded, the others righthanded as assessed by means of a standard questionnaire [9]. All participated on a voluntary basis and they received a financial compensation for their time. They were naive with respect to the task and the research aims.

2.4 Procedure

Before subjects entered the experimental room, the set-up and shells were covered. Subjects were blindfolded and seated on a stool. They were instructed to adjust the distance between the shells by pushing the inner or outer sides in such a way that the virtual cylinder that would be formed by extrapolating the curvature of the two shells had a circular cross-section. They were not allowed to systematically scan the sides of the shells. Subjects were informed that they were allowed to “pass” a trial if they thought the shells should be moved closer to or further apart from each other than the set-up allowed, or if due to their limited arm span, the shells became out of reach. Time was unlimited, but in practice about 40 s per trial was needed. They started with a few practice trials, but they did not receive any feedback. A block of 30 trials consisted of 15 different radii in two orientations (horizontal and vertical) in random order. Per session of about an hour two such blocks could be measured. Three subjects (EH, ET and ME) participated in all conditions C, R and L, the other three only took part in condition C. The former subjects received blocks of different conditions in pseudorandom order. All blocks were presented eight times, resulting in a total number of trials of either 240 or 720 per subject (i.e. 4 or 12 hours, respectively).

3 Results

Although the number of trials for each combination of radius, orientation and condition was always 8, the actual number of settings was often less due to passes of the subject (see Procedure), especially for the higher radii. Therefore, instead of taking the average of the actual settings, the median (taking into account the passes) was taken as the

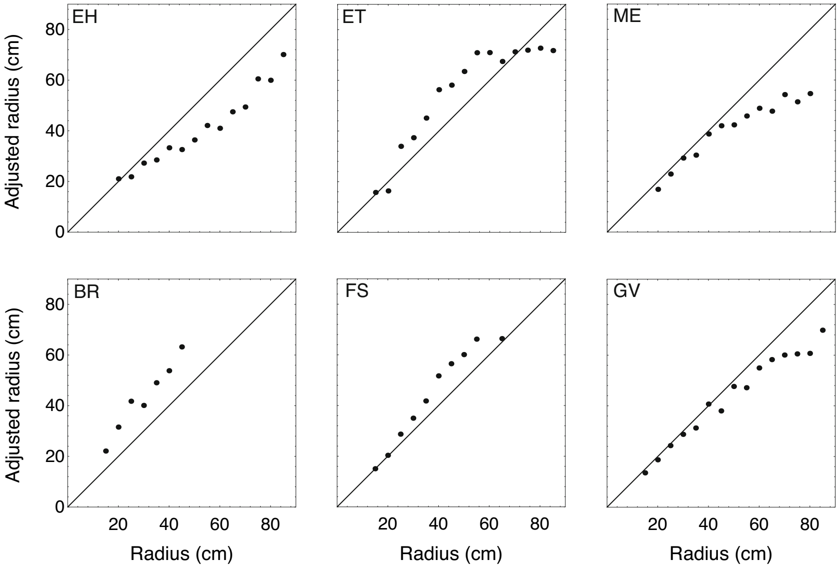

Fig. 3. Median adjusted radius as a function of radius for all subjects in the horizontal orientation in the center condition. The solid line indicates what would be veridical.

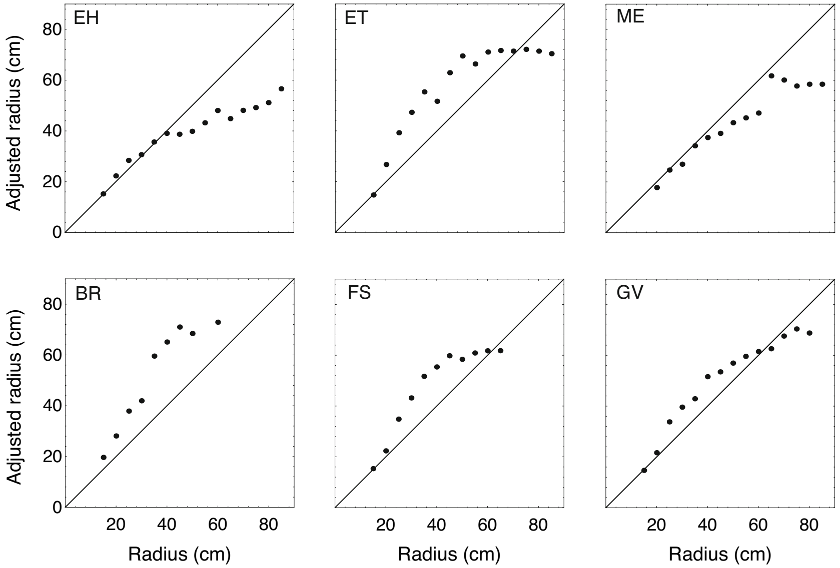

Fig. 4. Median adjusted radius as a function of radius for all subjects in the vertical orientation in the center condition. The solid line indicates what would be veridical. Note the similarity for each subject with the setttings for the horizontal orientation in Fig. 3: subjects that under(over)estimate here, also do so in the horizontal case.

Table 1. Significance of differences between settings in the three conditions (* indicates $p \leq 0.05$ and ** $p \leq 0.005$, with Holm-Bonferroni correction for multiple comparisons)

	Horizontal			Vertical		
Subject	C-R	C-L	R-L	C-R	C-L	R-L
EH	*					
ET	*	*				
ME	**	**		*	**	**

more informative quantity. In Figs. 3 and 4 the results are shown for all six subjects in the center condition, for the horizontal and vertical orientations of the cylinder axis, respectively. It can be seen that settings are mostly not veridical and, depending on the subject, are either under- or overestimations of the actual radius. The adjusted radius shows a monotonic increase with actual radius, albeit not always in a linear manner.

Most subjects preferred the horizontal orientation of the cylinder axis. They commented that especially for the larger radii, they would be sitting inside the virtual vertical cylinder, which made the task introspectively harder. However, paired t-tests (p-level 0.05) show that only for subjects ME and GV the difference between the horizontal and vertical medians was significant ($p \leq 0.005$ in both cases). The results shown in Figs. 3 and 4 are also representative for the results obtained in the R and L conditions. In the R condition, the difference between the horizontal and vertical settings was significant for all three subjects (EH and ET $p \leq 0.005$; ME $p \leq 0.05$), in the L condition only those of ET ($p \leq 0.005$).

In Table 1 the results of paired t-tests between the settings in the C, R and L conditions can be seen. For the horizontal orientation, R and L settings are significantly smaller than the C settings (except C-L for subject EH). For the vertical orientation, only the settings of subject ME differ (R<C; L<C; R<L).

4 Discussion and Conclusions

Subjects are able to perform this task in a consistent way, although they are often far from veridical. In this respect, it is important to note that adjusted radius shows a monotonic increase with physical radius. This indicates that the settings are systematic and not just random, which in turn implies that subjects are indeed integrating information derived from the two hands to form the concept of one large object. For the smaller radii, most settings are almost veridical, but for the larger radii settings may deviate by factors ranging from about 0.6 to 1.5. These factors are rather different from the high sensitivity to small aspect ratio differences found earlier [8]. However, in that study, stimuli could almost be enclosed with one hand (thus involving much higher curvatures) and, probably just as important, a discrimination paradigm may be more sensitive than a matching paradigm. The present deviations cannot be caused by curvature discrimination limitations, as discrimination thresholds are often smaller [7]. Likely explanations are that the deviations are either caused by misestimations of the distance between the two hands, systematic biases in curvature perception and for the higher radii, limited arm span.

The results obtained for the two orientations and the three different positions of the subject with respect to the set-up show subject-dependent differences. These differences are comparable to the biases found in [7], in which these were attributed to possible differences in scanning length of the right and left hands. Future studies would need measurements of hand movements to shed light on the influence of these movements on perception.

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