The Precision of "Haptic" Rod Length Perception Is Reduced by Lack of Visual Precision

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Abstract. In studies on haptic rod length perception, participants conventionally report their length estimates by placing a visual landmark at a position equal to the rod's perceived endpoint. We hypothesized that this visual aspect substantially increases the variability of the recorded length judgments. To examine this, we developed a virtual reality length judgment apparatus that provides better visual information. Participants performed a rod length perception task in both the conventional apparatus and the virtual reality apparatus. The variability of the length judgments was found to be higher in the conventional apparatus. We determined that between half and two-thirds of the variance in the conventional apparatus is haptic variance. Thus, vision accounts for between one-third and half of the variance that was previously thought to be haptic variance. Our finding implies that the virtual reality apparatus may be more suitable for studying subtle effects in haptic rod length perception.

Keywords: multi-modal perception, dynamic touch, sensory integration.

1 Introduction

When holding and wielding a rod at one of its ends, one can obtain a purely haptic impression of its length [e.g., 1]. Length judgments, however, have been found to be rather variable, both within and between subjects [e.g., 2]. This seems to suggest that haptic rod length perception is a complicated task that can only be achieved with low precision (precision reflects inter-trial variability) and low accuracy (accuracy reflects biases). In this study we focused on the precision of rod length judgments, because we suspect that the high variability may be an experimental artifact. Perceivers conventionally report their length estimates by indicating the estimated endpoint of the rod with a visual landmark. In congruence, one could define two perceptual aspects that both involve a certain degree of variability: (1) haptically perceiving the rod's length (haptic variability), and (2) visually perceiving the distance to the landmark (visual variability). We hypothesized that a substantial proportion of the variability in rod length judgments is actually visual variability.

To test our hypothesis, we compared the variability of length judgments made in two different experimental apparatuses that differed in the quality of the visual information. In the conventional apparatus (CONVENT), participants wielded the rod behind a screen and indicated their length percept on a scale that was parallel to the

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screen. They did so by putting a visual landmark at the position where the endpoint of the rod would be if it were on the visible side of the screen (see Fig. 1A). There are at least two visual complexities in this apparatus: first, a static visual depth scene does not provide very precise cues for estimating distance [e.g., 3]. Second, the haptic estimate of rod length is made relative to the hand, whereas the visual judgment of distance to the landmark is made relative to the body. Positioning the visual landmark thus requires a transformation of reference frames.

In the virtual reality apparatus (VIRTUAL), participants wielded the visually occluded rod while they viewed a virtual three-dimensional image of a rod. Participants adjusted this virtual rod’s length – the rod was short at trial onset – until it matched the perceived length of the physical rod. The virtual rod was displayed at the same position and orientation in space as the physical rod, so that their movements were identical. The virtual apparatus thus offered at least two benefits over the conventional apparatus: first, the dynamical visual information provided better depth information [e.g., 4], and second, no transformation of reference frames was required. In consequence, the visual variability will be lower using this experimental apparatus.

If this visual variability adds significantly to the variability of the rod length estimates, the length judgments’ variability should be lower in the virtual reality than in the conventional apparatus. If, on the other hand, the visual variability is negligible compared to the haptic variability, the length judgments should be equally variable.

2 Methods and Materials

The experiment was part of a research program that had been approved by the ethics committee of the Faculty of Human Movement Sciences of VU University Amsterdam.

Setups. In the conventional apparatus, participants were seated on a height-adjustable chair with a black opaque screen on their right hand side. Their right hand was placed behind the screen with the upper arm slightly abducted, the elbow 90° flexed, and the forearm positioned on a horizontal armrest so that rod movements were restricted to rotations about the wrist. A horizontal rail was present on the left hand side of the screen in front of the participants and at the same height as the armrest. By turning a wheel with their left hand the participants could slide a square surface (15×15 cm) back and forth along this rail. Participants indicated their rod length estimate by positioning this landmark at the position where they felt that the endpoint of the rod would be if it were of the left side of the screen (see Fig. 1A). Along the rail was a measuring tape from which the experimenter recorded the length estimates with a resolution of 5mm.

In the virtual reality apparatus, participants were seated on a height-adjustable chair in a custom designed virtual reality setup. Their upper arm was slightly abducted and about 30° flexed, their elbow 90° flexed, and their forearm was positioned on a horizontal armrest so that rod movements were restricted to rotations about the wrist. A virtual image of a rod was created with two monitors, each of which projected onto a mirror that subsequently reflected the two monitor images into the participants’ left and right eye (see Fig. 1B). The image of the virtual rod was projected with the exact position and orientation of the physical rod. In order to achieve this, we equipped the physical rod with a cluster of three infrared markers and measured its position with an Optotrak 3020 camera system. Similarly, we determined the position of the participants’ eyes using a marker cluster on a bite-board. Participants held this bite-board between their teeth during the experiment. The rod-images on the two monitors were constructed based on the measured rod and eye positions with as little as 20 ms delay (see [5] for detailed information). The virtual rod consisted of two parts: the handle and the rod itself. The virtual handle had the same dimensions as the physical handle; the virtual rod had a radius of 8mm and an adjustable length. At trial onset, only the virtual handle was visible; the virtual rod had a length of 0mm. Participants indicated their rod length estimate by adjusting the length of the virtual rod. They did so by pointing their thumb up or down to signal the desired length adjustment to the experimenter who thereupon adjusted the virtual rod’s length with 5mm increments by pressing a keyboard. The experimenter recorded the length estimates from a computer screen that displayed the virtual rod’s length. The room was darkened to enhance the virtual rod’s visibility.

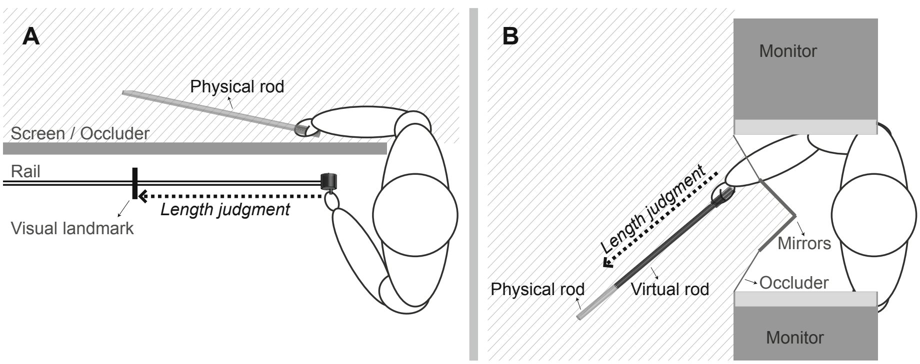

Fig. 1. Shown here are a top-view of the conventional apparatus (panel A), and the virtual reality apparatus (panel B). The gray-shaded area indicates what was occluded from the participants’ view. In the virtual reality apparatus, participants did see the virtual rod that was projected by the monitors via the two mirrors. Length judgments were reported by altering the position of the visual landmark (A), or by altering the length of the virtual rod (B). All participants used their right hand to hold the rods and their left hand to repost their length judgments.

Materials. We used seven rods that were made of a homogeneous aluminum cylinder and a plastic handle. The rods weighed between 0.24 and 0.57kg; the marker cluster added .03kg. The rods had various lengths and radii, while the handles were identical (10cm length; 15.7mm outer radius). As such, the rods were indistinguishable by grip size and there was no simple relationship between the rods’ moments of mass distribution and their length, which kept the task challenging. They were never visible throughout the entire experiment.

Procedure. Participants estimated the length of the seven rods in both experimental setups. Each rod was presented four times, so the total experiment comprised 2 (apparatus) × 7 (rods) × 4 (repetitions) = 56 trials. The order of the two apparatuses was counterbalanced over participants; the order of the seven rods was randomized within four repetition blocks. Each trial started with the experimenter handing a rod to the participant, who firmly held it at its handle. The participants verbally informed the experimenter when they had finished their length estimate. The experimenter subsequently took over the rod and ended the trial. Participants could take as long as they needed to complete a trial and there was a short break between the two apparatuses. The entire experiment lasted about 90 minutes.

Participants. Four men and six women (mean age: 22 ± 2.2 years) voluntarily participated in the experiment after having signed an informed consent form. All participants were right-handed, had normal or corrected-to-normal vision, and were naïve about the purpose of the experiment. Two participants could not complete the experiment due to a technical failure; their data were excluded from analysis.

Data Analysis. Recorded length estimates were first analyzed for outliers, defined as a length judgment that deviated more than 35% from the mean length judgment in the other three repetitions with the same rod. Out of the 224 trials per apparatus, 13 were removed in CONVENT and 11 in VIRTUAL. Three outcome measures were determined: the mean (1) and the standard deviation (2) over the remaining repetitions per rod. In order to correct for a potential effect of the magnitude of the length judgment on the magnitude of the variability, we also determined the coefficient of variation (3) (standard deviation/mean length judgment). We analyzed these measures for an effect of apparatus and rod using a 2 × 7 ANOVA for repeated measures. For the main effect of the factor apparatus, we report the 95% confidence interval for the difference between the two apparatuses (95%CI_D), as obtained by post-hoc pairwise comparisons.

3 Results

The ANOVA on the mean recorded length judgments (Fig. 2A) revealed that the length judgments tended to be larger in CONVENT (65.6cm) than in VIRTUAL (52.2cm) ($F_{1,7}$ = 4.12, p = .082, 95%CI_D: -2.2cm–28.9cm). In addition, the ANOVA revealed a significant main effect of rod ($F_{6,42}$ = 27.98, p < .001). There was no significant interaction between the factors rod and apparatus ($F_{6,42}$ = 1.12, p = .365).

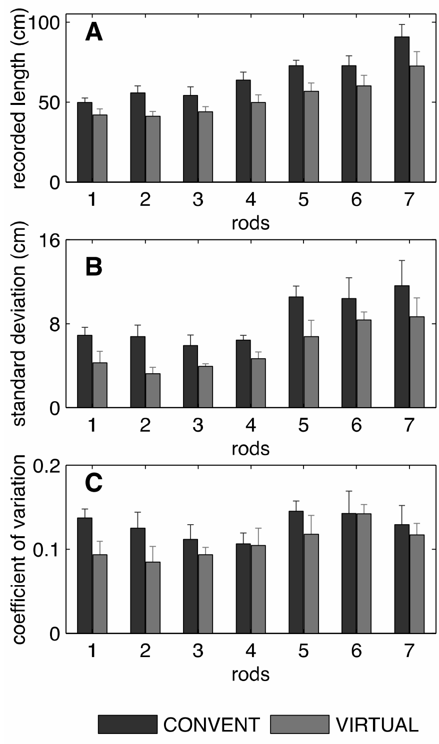

Fig. 2. The experimental results are shown here as the data averaged over the participants; the error bars indicate the standard errors

The ANOVA on the standard deviation of the length judgments (Fig. 2B) revealed that the standard deviation of the length estimates was larger in the conventional apparatus (8.4cm) than in the virtual apparatus (5.7cm) ($F_{1,7} = 7.28$, $p = .031$, 95%CI_D = 0.3cm–5.0cm). The ANOVA also revealed a main effect of rod ($F_{6,42} = 8.02$, $p < .001$). Post-hoc pairwise comparisons indicated a higher standard deviation in rods 5 to 7 than in rods 1 to 4. There was no significant interaction between the factors rod and apparatus ($F_{6,42} = 0.21$, $p = .973$).

The statistically non-significant difference in length judgments between CONVENT and VIRTUAL may have confounded the magnitude of the standard deviations. Therefore, we conducted an ANOVA on the coefficient of variation (Fig. 2C). This revealed higher values in CONVENT (.128) than in VIRTUAL (.108) ($F_{1,7} = 7.72$, $p = .027$, 95%CI_D: .003–.038). There was no significant main effect of rod ($F_{6,42} = 1.65$, $p = .158$) and no interaction between the factors rod and apparatus ($F_{6,42} = 0.47$, $p = .823$).This shows that the variability of the length estimates was larger in the conventional than in the virtual apparatus when differences in absolute length estimates were taken into account.

4 Discussion and Conclusion

The present study examined whether the variability in haptic rod length judgments originates from the haptic modality. We hypothesized that the visual aspect of the conventionally used experimental apparatus is responsible for a substantial proportion of the variability of length judgments. The results confirmed this hypothesis: we found a lower standard deviation and a smaller coefficient of variation in the newly developed virtual reality apparatus, in which more precise visual information was provided, than in the conventional apparatus. One could thus argue that rod length perception is a visuo-haptic matching task rather than a purely haptic task, at least when assessed with the conventional apparatus.

One plausible criticism of the present study is that we used only a small number of repetitions per trial. Similar numbers are generally used in experiments on haptic rod length perception as a trade-off between an accurate estimate of the perceived length and a reasonable duration of the experiment [e.g., 2, 6-8]. Hence, at this number of repetitions, a decrease in variability had to be observable in order for it to be relevant. Another question that might be raised is why we did not use the variance (i.e., the squared standard deviation) as a measure of variability. We found that the variances required a log-transformation, as they were not normally distributed. Hence, the standard deviation was chosen to ensure easily interpretable results.

The exact precision of the haptic task cannot be determined from the present study because the virtual reality apparatus also involves visually reported length estimates. To derive the precision of rod length perception based on haptic information only, a dedicated psychophysical experiment should be performed. However, if we assume a negligible visual variability in the virtual reality apparatus, we can roughly estimate the relative contributions of the haptic and visual variability in the conventional apparatus. The average standard deviations of 8.4cm and 5.7cm in the conventional and virtual apparatus, respectively, correspond to a variance of 69.8cm^2 and 32.4cm^2. The difference (i.e., 37.4cm^2) would be attributable to vision. The relative contributions of haptic and visual variance are thus 46% vs. 54%, respectively. When estimated based on the coefficient of variation, these percentages are 71% vs. 29%. Note that the haptic relative contribution only increases if the visual variability in the virtual reality setup is larger than negligible. These rough estimates suggest that about a half to two-thirds of the variability reported in rod length perception is actually haptic variability.

To conclude, the relative contribution of visual variability is smallest when very precise visual information is available. In other words, the more precise the visual information, the less influence it has on the precision of the haptic task. If one aims to solely study haptic rod length perception, one should either totally exclude vision –as well as other sensory modalities– from the experimental apparatus, or, when this is not feasible, one should provide as good as possible visual information to minimize its effect on the recorded length judgments. The present study clearly shows that the virtual reality apparatus is preferable to the conventional apparatus because the lower variability facilitates the detection of more subtle effects in the length estimates.

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