Size Identification via a Visual and Haptic Interfaces: Error Rates and Tolerances

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Abstract. How much perceptual error is involved in daily tasks of estimating object sizes? This paper shows the error rates (ER) and tolerances (TR) that occur when objects of different sizes (3.5, 5.5, and 7.5cm) are being identified by size under different grasping conditions (bare hand, gloved hand, hand in ringed glove, and force noise). The experiments in this paper offer separate visual and haptic information to participants to help them find the correct value of the indirect condition. The need for safety in the work environment requires accurate assessments of error rates and tolerances. Accurate values for both ER and TR can be used to enhance the performance of control algorithms. This paper presents three major findings: 1) the ER magnitude varies only with the size of the object, 2) wearing something on the hands affects the accuracy of the size identification, but has no effect on the ER; and 3) the TR value is generally about 4 times the ER value.

Keywords. JND, Safety, Inter-sensation, Human-computer Interface, Control parameters

1. Introduction

1.1 Motivation

Industrial workers frequently take special precautions (e.g., using gloves or robotic arms) when picking up and handling dangerous, burning or corroding products. Their ability to grasp these objects is based on optical and haptic sensations. An inter-sensation effect should occur during the brain's translation of both kinds of information. The increasing usage of remote controls has increased the salience of this issue. When confronting hazardous environments such as those caused by catastrophic climate change or a nuclear crisis, human beings will more often utilize indirect perception to comprehend and confront the conditions. Perception, itself, is made up of a series of different properties. What sort of error rate (ER) is acceptable between the information coming from the eyes and the hands? What is the normally acceptable tolerance value (TR) under general conditions?

The current development trend is toward highly precise positioning control of the end effectors. The automobile industry is a prominent example (see Fig. 1a). Engineers are accustomed to working with the rigid components used in today's automotive assembly systems in which a series of robots execute a finely tuned sequence of orders in an isolated cage to avoid life-threatening injuries to workers. In other words, the majority of human-computer interfaces (HCI) focus solely on the intended functionality and underestimate the possible consequences of crush.

Working with such an unnatural design can be particularly dangerous for humans. The risks incurred by the lack of flexibility and such tight tolerances and are akin to those of walking a tightrope.

Obtaining the visual-haptic ER and TR values has dual benefits. The first is the opportunity to improve the safety of the control system. Manipulators that use an HCI to remotely control tasks with robots or virtual hands in virtual reality (VR) often receive visual and haptic information, respectively. A better comprehension of humans' ER and TR can enhance the functionality and precision of fuzzy neural controls, impedance controls, etc., which can apply these values to provide more appropriate functional parameters for intensifying the interaction suitability and safety of HCI (Dongkyoung 2015). The second benefit of obtaining ER and TR values is that researchers can use the acceptable ranges of these parameters to guide the subject's behavior toward the substituted objects via visual reorientation for grasping or touching (Achibet et al. 2015).


(a)


(b)

***Figure 1**: Applications of Virtual Reality and Robots: (a) High-precision automobile plant in the isolation area. © ROBOTIQ. (b) The Haptic Workstation, a commonly used haptic feedback apparatus. © CyberGlove System.*

1.2 Context

Optical information is highly useful; it serves as the primary source of information for VR and most robotic systems. However, optical information alone is insufficient. A haptic-aided system must always be added to enhance the level of immersion (Fig. 1b). The haptic system is one of the most complex and informative perception systems in the human body, comprising both cutaneous touch and kinesthetic touch. Cutaneous touch refers to the 2D sensations felt on surface of the skin which conveys mechanical, thermal, chemical and electrical stimuli via mechanoreceptors, etc (Cholewiak and Collins 1991). Kinesthetic touch refers to the sense of force and angle within muscles, tendons, skeletal joints and other proprioceptive receptors. To measure length, previous studies have focused on the just noticeable difference (JND) perceived by a bare hand via the finger-span method (tips of the thumb and forefinger). For example, Gaydos (1958) showed that the JND follows Weber's law, and the increment is about 3% over the range of 35-100mm. Stevens and Stone (1959) used a linear equation, $(\Delta L)_0 = 0.0286L + 0.8$, to describe the relationship between the JND, $(\Delta L)_0$, and the reference length L, but this equation violates Weber's law by allowing for a nonzero intercept. *Durlach et al. (1989)* investigated manual discrimination and identification of length as reported with the sensitivity index *d'*. *McKnight et al. (2004)* found that the multi-fingered size discrimination method is of higher fidelity than the finger-span method. The limits of human capabilities have been explored in a wealth of haptic literature regarding HCI and precise discrimination thresholds, but there is a dramatic shortage of data regarding the boundary conditions of the ER and TR between the eyes and hands.

This paper aims to provide a comprehensive, practical study of error rates (the distance between the errors and the actual values) and tolerances. The unnatural touch offered by HCI (e.g., data gloves, finger caps, and unnatural force noise) is expected to lead to different results. Our two main studies intend to achieve the following.

1. Find the ER and TR of grasping under different conditions (bare hand, gloved hand, hand in ringed glove, and force noise).
2. Identify the bias trends of size identification.

2. Method

2.1 Design

To accomplish our goals, we performed our tests in two sessions: one for size and one for conditions. For the size session, we used three different reference sizes (3.5 cm, 5.5cm and 7.5cm), and the subjects performed all tests bare handed. We used four different conditions in the condition session: 1. bare hand (BH), 2. hand in a 3mm thick glove (GH) (Fig. 2a), 3. hand in a glove with 1.5mm thick finger-rings (RH) (Fig. 2b, development of a haptic simulator), and 4. hand in a glove with rings and force noise (NH) (Fig. 2c, haptic simulator). All conditions tests were carried out using a reference size of 3.5cm. GH tested the common condition. RH tested conditions involving the wearing of a thick glove or hard finger caps. NH tested the condition in which force noise generated by the apparatus provided feedback. The thick rings in the RH condition are linked by a plank to ensure consistency in the NH test. The force noise in the NH condition is generated by two springs, up to 14N, placed in two hollow rods which parallel the direction of grasping movement.

(a) (b) (c) (d) (e)

***Figure 2**: Experimental apparatus for (a) the GH condition, (b) the RH condition, (c) the NH condition; (d) object size simulator; (e) experimental setting, with a visual obstruction plate between the screen and the object simulator*

In this experiment, the haptic stimulus consist out of a pair of planks, one fixed and one movable along a leadscrew (Fig. 2d), offering variable sizes for grasping.

In order to assess the user’s ER and TR during size identification via remote manipulation, a forced-choice method of limits was applied to the five-fingered estimation examination (McKnight et al. 2004).

Participants were required to identify the reference size (i.e., the width of a rectangle showed on a display) (Fig. 2e), and to use their five-fingered grasp to judge whether the haptic stimulus was the same size as the visual reference. They were asked to choose one of two the alternatives, “different” or “similar”, for the estimation of the size in each stimulus. The starting points of the haptic stimuli were offset from the reference size in increments of 5mm, ranging from ±5mm to ±25mm. This distance from the reference size was gradually reduced in 1mm steps until the participant could no longer detect the difference between the visual reference size and the haptic stimulus. Each instance of this complete process was referred to as a “run.” To avoid potential pitfalls, the normal starting points, $\Delta L = \pm 5,\ \pm 10,\ \pm 15,\ \pm 20,\ \pm 25mm$, were chosen in random order in each run, but the ascending and descending methods were still used in alternating order. The starting and stopping points were documented for analysis.

2.2 Participants

According to *Durlach et al. (1989)*, there is no learning effect when subjects use their dominant hand, but there is a learning effect when using the non-dominant hand. Seven right-handed people participated in our study: 3 females and 4 males. The mean age was 38.1 years, with a standard deviation of 17.8 years. None of the subjects had upper extremity musculoskeletal disorders, and all reported normal or corrected-to-normal vision.

2.3 Procedure

To make the assessment, participants were seated in front of a 24” screen at a distance of about 50 cm. The haptic simulator was set on the right-hand side at the same distance as the viewing distance, next to a partitioning plate which prevented the subject from obtaining additional visual information via a glimpse of the object size simulator (Fig. 2e). In accordance with the Declaration of Helsinki, participants were informed of the procedures and gave written consent prior to the procedure. Participants were allowed to practice a few times for two reasons: 1) to get used to grasping the haptic stimulus simulator without seeing it, and 2) to become accustomed to receiving the reference information via visual input.

After the familiarization period, the experimenter began to record the data. Participants were exposed to 6 blocks of experiments in the following order: 3.5cm with BH (3.5BH), 5.5cm with BH (5.5BH), 7.5cm with BH (7.5BH), 3.5cm with GH (3.5GH), 3.5cm with RH (3.5RH), and 3.5cm with NH (3.5NH). Each block consisted of 10 runs which began at different starting points. In order to get the maximum ER, participants were instructed to release their current gesture after each trial by placing their fingertips together to form the shape of a church steeple. As soon as the participant stopped reporting the size as “different” and reported it as “similar,” the size of the stimulus was recorded using a vernier caliper. Experimental sessions lasted from 1 to $1^1/_2$ hours. Subjects were allowed to rest whenever they felt tired.

3. Results

The results of repeated measure analysis of variance (ANOVA) for the ER_s and the average reported value (ARV) are noted below. The subscript “s” is used to denote the “subjective point of view,” indicating that the reference size switched to the subject’s bias obtained from averaging the reported stopping points, not from the actual reference size showed on the screen. The ER_s value is the absolute difference between the reported size and the reference size. Nonparametric tests and Greenhouse-Geisser-corrected results are reported when the general assumptions of ANOVA failed. Effect size (η^2 eta-squared) and observed power (π) are reported for all significant results.

3.1 Error Rate Analysis

In the sizes session, "sizes" and "runs" are regarded as the independent variables. The effect of "sizes" is $F(2,12)=3.89,\ p=0.05, \eta^2=0.393, \pi=0.586$. The effect of "runs" is $F(9,54)=3.482,\ p=0.002, \eta^2=0.367, \pi=0.974$. We found no significant interaction effect.

In the conditions session, "conditions" and "runs" are regarded as the independent variables. We found no significant effects of "conditions" or "runs," and there was no interaction effect.

Pair-wise post hoc analysis is used to confirm factors in detail. Analyzing each size and condition, we confirmed that only the 3.5BH block had a significant learning effect ($F(9,54)=3.14,\ p=0.004, \eta^2=0.344, \pi=0.956$). There was no learning effect for any of the other blocks (i.e., 5.5BH, 7.5BH, 3.5GH, 3.5RH, and 3.5NH). We then performed pair-wise analyses. No significant effect was found for any pair of conditions and sizes, except for the comparison between 5.5BH and 7.5BH ($F(1,6)=18.756,\ p=0.005,\ \eta^2=0.758, \pi=0.947$) which showed a significant effect.

3.2 Trends

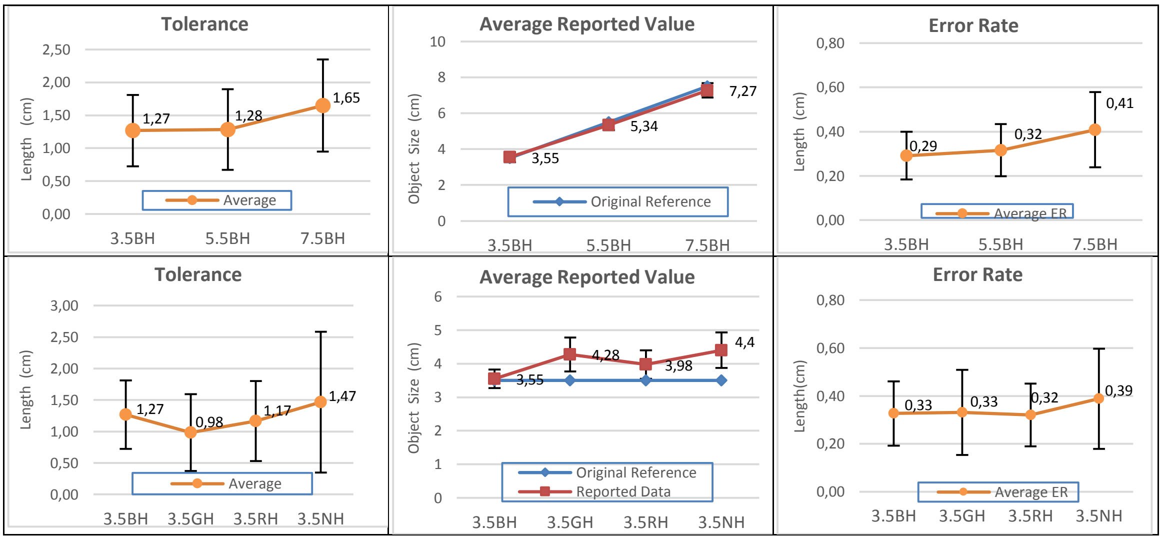

Figure 3: The upper and lower charts show the trends in different sizes and conditions. In the leftmost charts, the tolerance is equal to a given subject's maximum error rate (ERs) minus the minimum ERs of that subject. The leftmost charts show the average value of the subjects' maximum range of errors. The middle charts show the average values reported as similar to the reference value.

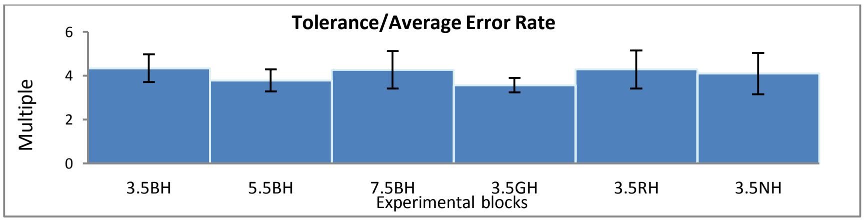

Figure 4: The multiples of tolerance divided by average error rate

With ARV as the dependent value, the results of ANOVA indicate that "sizes" is $F(2,12)=999.4,\ p<0.001, \eta^2=0.994, \pi=1$, and "conditions" is $F(3,18)=16.941,\ p<0.001$, $\eta^2=0.738, \pi=1$. The top-leftmost chart in fig. 3 indicates that the trend of tolerance is similar to that of the JND (Durlach et al. 1989). The bottom-leftmost chart (fig. 3) shows that while the ER_s is relatively similar in various conditions, the 3.5NH condition shows a more salient difference. The top-middle chart shows that the average reported values are almost identical to the reference value when measured with a bare hand. In contrast, the perceived values are greater than the actual reference values. Figure 4 illustrates how the tolerance value is about 4 times the average ER_s value (mean over all =4.06, standard deviation=0.3).

4. Discussion

According to these results, we can say that a learning effect is present in the 3.5BH condition, but we cannot ensure that there is no learning effect in the other blocks. Furthermore, we find that regardless of the kinds of materials worn on the hand, people underestimate the size of the object in their hands. Though wearing gloves on the hand can cause the size identification to deviate from the actual size, it causes no change in the error rate. The top-rightmost chart, above, notes that that the ER_s values appear to follow the same trend as the JND (Stevens and Stone 1959). However, at this point, we cannot confirm that apparent behavior. General ER_s values resemble JND values, but they are not identical. In general, the tolerance value is about 4 times the size of the ER_s value.

5. Conclusion

Overall, the results indicate that wearing any wearable things on the hand causes a bias in the size identification. However, the ER_s are similar across all tested ranges. The variance in ER_s depends only on the objects' size, regardless of what is worn on the hands. In general, the tolerance value is about 4 times the size of the ER value. These findings suggest that those attempting to identify an object's size should be aware that accuracy will be impacted when they wear anything on their hands. The possible relationship between JND and ER_s may prove to be significant. We recommend to explore this relationship in future studies.

6. References

Achibet, M., A. Girard, A. Talvas, M. Marchal and A. Lecuyer (2015). Elastic-Arm: Human-scale passive haptic feedback for augmenting interaction and perception in virtual environments. Virtual Reality (VR), 2015 IEEE.

Cholewiak, R. and A. Collins (1991). Sensory and Physiological Bases of Touch. The Psychology of Touch. M. Heller and W. Schiff, Erlbaum: 23-60.

Dongkyoung, C. (2015). "Fuzzy Adaptive Output Feedback Tracking Control of VTOL Aircraft With Uncertain Input Coupling and Input-Dependent Disturbances." Fuzzy Systems, IEEE Transactions on 23(5): 1505-1518.

Durlach, N. I., L. A. Delhorne, A. Wong, W. Y. Ko, W. M. Rabinowitz and J. Hollerbach (1989). "Manual discrimination and identification of length by the finger-span method." Percept Psychophys 46(1): 29-38.

Gaydos, H. F. (1958). "Sensitivity in the Judgment of Size by Finger-Span." The American Journal of Psychology 71(3): 557-562.

McKnight, S., N. Melder, A. L. Barrow, W. S. Harwin and J. P. Wann (2004). Psychophysical size discrimination using multi-fingered haptic interfaces. EuroHaptics. Munich: 274-281.

Stevens, S. S. and G. Stone (1959). "Finger span: ratio scale, category scale, and JND scale." J Exp Psychol 57(2): 91-95.