Identification of Haptic Virtual Objects with Different Degrees of Complexity

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Abstract

Haptics used in natural contexts is much more efficient in identifying real objects than virtual objects via haptic displays. The aim of this study was to get some insight about the effects of object complexity on the identification of virtual objects varying in complexity on the basis of form properties. The virtual objects were synthetic human heads with varying number of face features. Fourteen sighted and ten visually impaired people took part in an experiment. The results were significant effects of complexity on both proportion of correct responses and exploration time, This indicates the relevance of object complexity for judgements about the usefulness of haptic displays. Training of users, simplification of virtual objects and development of more efficient haptic displays are discussed as potential solutions.

1. Introduction

Natural haptics is a much more efficient sense than is often recognised, as demonstrated in general already by Katz [8] and concerning identification of common objects by Klatzky et al. [9]. The capacity of natural haptics is only partially possible to utilize when the hand is exploring virtual objects via the haptic displays developed so far. Typically, there is only one contact point at a time between the observer and the virtual object, which reduces the available information radically. The main information is from force feedback provided when the only point moved around by the observer collides with the virtual object. Over time the exploration theoretically provides information about features such as object form, texture, friction and hardness, but it has to be investigated in perception experiment to what extent the available information is useful.

It should also be observed that there are kinds of information that is available in natural haptics, which are, so far, not available in most haptic displays, such as spatially distributed finger tip force information, simultaneous information from more than one contact point, thermal information and weight information (when the object is static). The perceptual effects of the lack of the first two kinds of information were discussed in [11] and [4], respectively. The many restrictions of the information provided by haptic displays in comparison with the information obtained in natural situations make it an open question how useful they may be. The restrictions can be expected to be especially critical when haptics provides the only information available, as when the displays are used by blind people.

The usefulness of haptic displays differs depending on what perceived properties are considered. For perception of surface texture one point of contact functions well, but for perception of object form this restriction is more problematic [6]. The differences between natural and virtual haptics were apparent when the efficiency in judging object form was investigated. Judgements of real objects are 100 % correct and haptic exploration took only a few seconds, while judgements of virtual objects are correct only in about 75 % of the cases and exploration takes around 25 sec [3]. It should be noted that these investigations of the shape of virtual objects were concerned only with objects of simple form.

A main reason for the difference between texture and shape judgements is probably their different demands on exploratory procedures. Judgements of texture can be based on simple strokes on the surface of the object, while judgements of shape demand more sophisticated procedures. The common procedure for judgement of global shape, grasping with several fingers (and possibly both hands), is not available with only one point of simultaneous contact. What is available is following along the surface of the object, for 2D forms often called contour following. For 3D objects without edges the task is more complex. Exploratory procedures in this case are very different from those used in natural contexts, even if it may be improved by special practice. However, also after three hours of practice the performance is far from the levels obtained in natural contexts [7].

A standard method in tactile graphics to make it possible to perceive also complex pictures is to simplify them [1]. There have been efforts to simplify also complex virtual scenes for the same purpose. König et al. [10] rendered 2D planes of a 3D object and provided non-pictorial information about the relations between these planes. Jansson [5] suggested presentation of scenes in successively increasing complexity. However, none of these options have yet been fully developed, and much research remains to be done before it is possible to judge their usefulness. It has also been suggested that, in visuo-haptic contexts, the rendering of haptic properties should match the richness of the visual properties, which talks against the option of simplifying the haptic rendering [12]. The necessity of such a matching has not been proven in perceptual experiments, however. The effect of complexity of virtual objects on the usefulness of haptic displays has hardly been investigated, but this problem is highly significant when only haptic information is available, as when the displays are used by blind people, but may also have relevance in visuo-haptic contexts where also visual information is available.

2. Problem

The possibilities of perceiving form properties of complex objects is a main problem concerning the usefulness of present-day haptic displays, especially the majority of them that have only one contact point between observer and virtual object. The aim of the present study was to get some basic facts about the effects of object complexity on the identification of objects varying in complexity on the basis of form properties.

3. Method

3.1. Haptic display.

A PHANToM 1.A equipped with the standard stylus (http://www.sensable.com) was used.

3.2. Stimuli

Complexity was in this experiment defined as number of protruding kinds of features of a virtual synthetic head. The head could have up to six kinds of features protruding from the basic head form: nose, mouth, chin, ears, eyes and eyebrows. A head with all the features in "normal" size, rendered with the software ENCHANTER [2], is presented in Fig. 1. The heads at the lowest complexity level had only one of the six features, the second level two features and so on up to the sixth level with all the features. One of the features on each head was either 40 % smaller or 40 % larger in all three dimensions than "normal" size. In all, 72 heads were rendered: 6 levels of complexity, 6 features and 2 feature sizes, that is smaller or larger than normal". All possible combinations of "normal" features could not be used for practical reasons, why a random choice between the options was made when necessary. As stimuli to be used in pre-experimental trials for training in the meaning of the different feature sizes, 18 heads, each with only one of the six features and one of the three sizes, small, large and "normal" size were rendered.

The stimuli were named according to which feature had deviating size and in what way it deviated, for instance "nose, big".

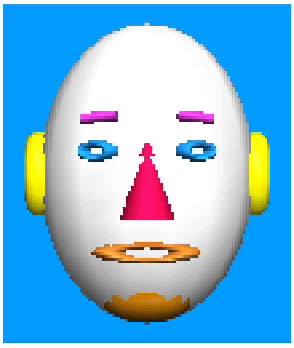

Figure 1. A synthetic head with the six features used in the experiment, all in "normal" size.

3.3. Participants.

Two groups of observers participated: 14 students of psychology (2 men and 12 women, 21-48 years, M = 28 years) and 10 visually impaired people (8 men and 2 women, 27-69 years, M = 45 years). The student group participated as part of a course requirement, and the visually impaired were paid. In the visually impaired group five were totally blind and five had partial vision, but only two in the latter group had any vision potentially of some use in the present experiment.. None in the student group had earlier experience of working with the PHANToM, while halt of the participants in the visually impaired group had taken part in a PHANToM experiment some years ago.

3.3. Procedure.

The experiment ran over three days, about one hour each day. During the first day instructions were given and training in making the size judgments with the 18 training heads were provided during one hour. The instructions to the visually impaired were adapted to their available senses. During the training information about the correctness of the judgements was given.

The main part of the experiment took place during the two following days, each day with 36 stimuli. The participants were seated in front of the device in a chair with armrest and wore a blindfold (except the eight participants without any useful vision) and headphones with white noise to prevent visual and auditory information. In addition they wore a device as protection against any harm by the PHANToM. It was suggested that the participants should hold the stylus similar to a pen. Their task was (1) to identify the feature that had a size deviating from “normal”, which could be based both on location of the feature on the head and its form, and (2) to judge if it was smaller or larger than "normal". This gives 12 possible responses, “nose, small”, “mouth big” and so on. The response was judged correct, only if both judgements were correct. No feedback about correctness was provided. A maximum exploration time of 2 min for each head was allowed. The performance was videotaped, and the participants were interviewed after the session on the third day.

4. Results

The main results for both groups are presented in Figure 2. A 2x6x6x2 mixed between-within (i.e. Split-Plot) ANOVA with repeated measures on the second, third and fourth factors was used. The *proportions of correct responses* were very similar in the two groups, the accuracy on level 6 being about half the one on level 1. These differences were statistically significant in both groups ($F_{5,110}=47.96$, $p<.001$). There were also statistically significant differences between features of the head ($F_{5,110}=15.37$, $p<0.001$) in both groups concerning proportions of correct responses (Fig. 3). No significant differences were obtained between large or small features ($F_{1,22}=0.00$, $p>0.05$). A separate ANOVA was performed for the visually impaired people. There was no significant difference ($F_{1,8}=0.03$, $p>0.05$) in the visually impaired group between those who had taken part in an earlier experiment with the PHANToM (n=5) and those who had not (n=5).

The means of *exploration times* increased in both participant groups, but not as much as the proportion of correct responses. However, the differences were statistically significant in both groups ($F_{5,110}=17.76$, $p<.001$). Further, there was a statistically significant difference between the participant groups ($F_{1,22}=5.61$, $p<0.05$); the values for the visually impaired group being about 10 sec lower. Concerning head features there was a significant difference in both groups ($F_{5,110}=4.10$, $p<0.05$). No significant differences were obtained between large or small features ($F_{1,22}=0.12$, $p>0.05$).

The analysis of the videotapes demonstrated that the participants mostly used the instructed way of holding the stylus. The exploratory procedures varied in different ways, but no relation to efficiency in performance could be found. In the interviews after the experiment most of the participants reported the use of some intentional exploratory strategy, often a certain order in the examination of the different features of the head, but no especially efficient order could be detected.

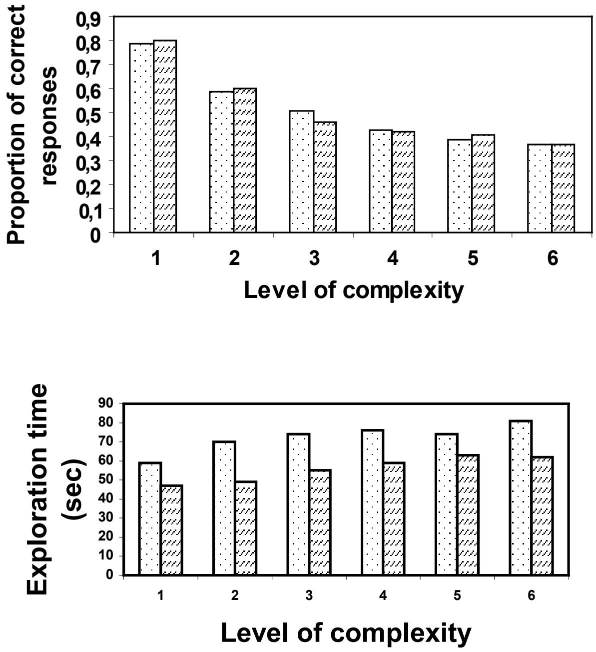

Figure 2. Mean results for the two participant groups (points/light grey for sighted and stripes/medium grey for visually impaired people).

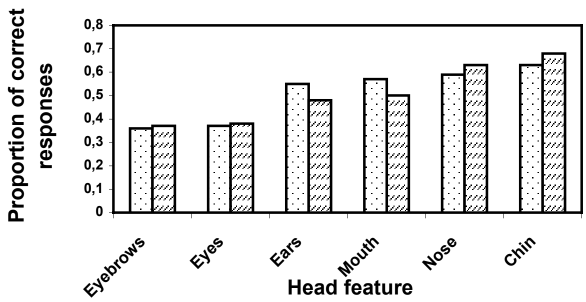

Figure 3. Mean results the different head features over all stimuli in the two participant groups(points/light grey for sighted and stripes/medium grey for visually impaired people).

5. Discussion

The results clearly demonstrate the great impact complexity has on the efficiency of identification of form via a one-point-of-contact haptic display, such as the PHANToM. Especially, the proportion of correct responses increases substantially with complexity, but also exploration time increases significantly. The usefulness of such a haptic decreases when complexity of virtual objects increases.

The problem with identification of complex forms via present day haptic displays is especially critical for situations where people not very trained in there use are expected to benefit from the display. However, the problem cannot be neglected for situations where the users have considerable training. Also for them there is a great risk of missing identification of forms and long exploration times.

5.1. Potential solutions

There are at least three potential solutions to the problems of complex scenes: training of users, simplification of the virtual objects and development of more efficient haptic displays.

(1) *Training*. The performance may improve with training [7], which was indicated also in this experiment by the benefit in exploration time for the visually impaired with their probably greater experience in using haptics. However, it is not known how much can be gained in this way. It should be observed that there was no benefit in proportion of correct responses for the visually impaired group compared with the sighted group in spite of their probably longer training in using haptics. Further, this option does not help users expected to use haptic displays more temporarily.

(2) *Simplification*. This standard method in haptic 2D representation may be a partial solution also in 3D contexts, but it necessitates more research on what kinds of simplification is most efficient. Those used in 2D representations can provide suggestions, but they must be tried out in a 3D context, where there may also be alternatives not available in 2D graphics. The optimal degree of similarity between visual and haptic objects needed to get efficient perception of the virtual objects is another urgent research topic.

(3) *More efficient haptic displays*. A most probable increase in efficiency ought to be obtained with more contact points between user and virtual object. There have been efforts to construct multi-finger displays, such as the CyberGrasp (http://www.immersion.com). However, even if they may be useful for grasping tasks, it cannot be taken for granted that they are useful also for judgements of complex object forms. So far, this has not been scientifically verified. There may be problems in utilising the information made available in these displays, and basic studies in what information is most useful are needed.

6. References

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