Chapter 1

Introduction

Imagine yourself in a crowded hall attending a lecture. The audience quietly listens to the speaker until suddenly a phone starts to ring. You realise the sound comes from your phone that is somewhere in your bag. Quickly, you start to rummage through the bag, seize the phone and turn it off. You have just performed a successful haptic search task!

Because your phone was inside your bag, you could not see it. Therefore, you had to rely on your sense of touch to detect it. But how did you do it? You had to distinguish it from the other objects in your bag, like your keys and lunch box, by certain properties. So, you had to perceive these properties correctly and combine them into an object. Furthermore, you had to select an efficient way to perform this, so you would find the phone, but also do it quickly in order to not further disturb the talk. Of course, you could have taken out each object that was in the bag one by one, to see if it was the phone, but this would not have been a very fast strategy. How haptic search depends on object properties and what strategies are used are the topics of this thesis.

Haptic perception is the perception of the environment with the tactual sense in an active manner. More specifically, both cutaneous cues from the skin and proprioceptive cues caused by the active movement are taken into account. Cutaneous information arises from the receptors that are present in the skin: Merkel cells, Meissner corpuscles, Pacinian corpuscles and Ruffini corpuscles (Johnson, 2001). Together, these receptors form the skin's tactual sense. In passive tactile perception, where an object is pressed against the skin, mainly cutaneous information is acquired. In an active movement, other sensors in the joints and muscles also play a role to give rise to proprioceptive information. This, for instance, tells where the hand is when it cannot be seen. For example, a passive touch is when someone taps your finger with a pen. In an active touch, you would tap the pen with your finger. It has been shown that the recognition of shape is more accurate when an active exploration can be used (Gibson, 1962; Heller, 1984), although passive exploration might be better in the recognition of line-drawings (Magee & Kennedy, 1980).

It has long been known that people are very skilled in recognising everyday objects by touch alone (Klatzky, Lederman, & Metzger, 1985). When using only the haptic sense, humans seem to categorise objects more based on material properties (like hardness and texture) than when vision can be used (Klatzky, Lederman, & Reed, 1987). For the understanding of the recognition and perception of objects, it is important to know how the object properties can be perceived. This includes the study of the discrimination abilities of properties by, for instance, measuring discrimination thresholds. The discrimination performance indicates how well one object property can be distinguished from another. However, often you handle multiple objects at the same time. For object perception, it is also important to know how well an object property can be detected among other properties. This can tell you how efficiently a certain object feature can be picked up. To investigate this, a method adapted from vision research can be used: the search task.

The search task

In vision research, the search task has been widely used for the investigation of processing of visual properties. The basic procedure is to define a target object that differs from one or more distractor objects. The number of distractor objects in the set that has to be searched is then varied. Participants have to detect whether the target object is present and they have to do this as fast as possible, but also accurately. For instance, in a colour search task one might have to detect the presence of a red disk among blue disks. The time it takes to search the stimulus set is measured as a function of the number of stimuli. The slope of this relation is called the search slope. This search slope is a powerful tool to investigate the search efficiency. If the slope is positive, the stimuli are explored serially. Because they are explored one by one, more stimuli imply longer search times. If the slope is flat and the reaction time does not depend on the number of stimuli in the set, this means that the stimuli can be processed in parallel. In such a case, there will be a pop-out effect: the target is immediately seen and 'jumps out' of the display (Treisman & Souther, 1985). The property that distinguishes the target from the distractors is then said to be processed very efficiently. These properties are very salient with respect to the context (i.e. the distractors). Therefore, these properties are also called salient features. For visual perception, Treisman and Souther (1985) called such features visual primitives that lie at the basis of visual perception. They stated that these primitives could be identified by a search asymmetry. In such a situation, the flat search slope disappears when the identity of the target and distractors is interchanged.

For instance, the search for a moving object among stationary objects can be very fast, whereas a stationary object among moving objects is much slower. In this case, motion would be a primitive which is absent in the stationary object. Hence, the stationary object is more difficult to detect.

After the introduction of the visual search paradigm, the search task was also used in the tactile domain. Most often, the stimuli were presented in a passive manner where they were pressed to the fingertips (Lederman, Browse, & Klatzky, 1988; Lederman & Klatzky, 1997; Overvliet, Smeets, & Brenner, 2007; Overvliet, Mayer, Smeets, & Brenner, 2008; Overvliet, Smeets, & Brenner, 2010). The movements that can be made, are limited to small finger movements. In an active haptic search task, the whole hand can be used to explore the stimuli. Here, the stimuli can be presented on a display or as small objects in the hand. The first case is a 2D search task and resembles the visual version. For instance, in a study of Plaisier, Bergmann Tiest, and Kappers (2008), rough and smooth patches were placed on a display over which the participants could slide their hand. In a 3D search task, the stimuli are presented as 3D objects in the hand (e.g. Plaisier, Bergmann Tiest, & Kappers, 2009b; Plaisier & Kappers, 2010). This is probably the most active form of a haptic search task, as the objects can be moved and enclosed in the hand.

In this thesis, the search task is used to identify haptic salient features and investigate their influence on search performance and exploration strategies. The chapters can be divided into three parts. In the first part, the saliency of some properties is investigated. Secondly, the interaction of multiple properties and the influence of salient properties on the perception of other properties are studied. Lastly, the strategies and exploration movements that are used in the search for different features and how these strategies are adapted to the target saliency are looked at.

One property: saliency

The first part of the thesis deals with the perception of a single property and the saliency of properties. In a passive search task, Lederman and Klatzky (1997) found that some properties were easier to find among others than in the reversed situation. For example, a rough item is quickly detected among smooth items, whereas it takes much longer to find a smooth item among rough ones. As explained above, the rough item is then more salient than the smooth one. They found that not only for roughness, but also for hardness, softness, thermal conductance and edges low search slopes were measured in this passive set-up. In an active haptic search task, where stimuli were presented on a display, Plaisier et al. (2008) showed an efficient search for rough items among smooth items. In a 3D task, where items could be held in the hand, edges and vertices in 3D-shapes (Plaisier et al., 2009b) and temperature (Plaisier & Kappers, 2010) produced relatively flat search slopes. Roughness, edges and temperature can thus be considered haptic salient features. Lederman and Klatzky (1997) mention several reasons for the investigation of salient properties. These properties are processed fast and efficiently and are therefore available early in the perception of objects. In the initial contact with an object, salient properties are already perceived. These properties might therefore be important for the identification of objects. Furthermore, they can be used to guide further exploration or repositioning of the hand to use the object (e.g. a tool). Finally, the knowledge of which properties are salient can help designers in the development of sensors for haptic devices and robots that are, for instance, used in teleoperation.

Still, many haptically available properties have not been looked at so far or only in a passive, limited exploration method. In the first two chapters of this thesis, some other object properties are investigated. In Chapter 2, the saliency of movability is studied. Here, ball transfer units are presented on a display, as seen in Figure 1.1A. The balls in the units can either move or are anchored. The participant can slide his or her hand over the display and feel the movability of the units. The target is a movable ball among stationary balls or vice versa.

In Chapter 3 the saliency of hardness and softness in active search tasks is examined. The target is a soft sphere among hard spheres or the other way round. In one task, participants hold rubber spheres in their hand, which they can move and manipulate freely. In another task, the spheres are placed on a display and participants press their hand on the spheres. So, the saliency of compliance is evaluated in a 2D and a 3D set-up.

Two properties: integration and disruption

When we know more about which properties are important for haptic perception, it is interesting to see how these properties can be combined. The second part of the thesis investigates the influence of two properties on each other's perception. Of course, in the search for your phone in your bag, there is more than one property that distinguishes it from the other objects in the bag. When it comes to perceiving two sources of information, basically two scenarios are possible. In the first scenario, one focuses on a single dominant property and most of the other property is ignored (e.g. Levy, Bourgeon, & Chapman, 2007; Robles de la Torres & Hayward, 2001; Bergmann Tiest & Kappers, 2009; Srinivasan & LaMotte, 1995). In the other scenario, the two cues can

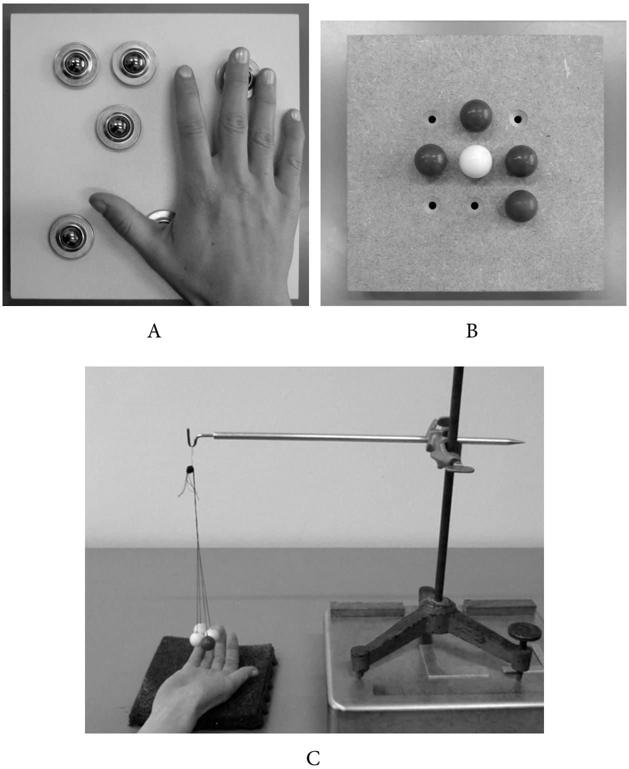

Figure 1.1: Examples of experimental set-ups. Stimuli could be placed on a display (A and B) or are hanging from wires so they could be grasped (C). A: a 2D set-up with movable and anchored balls in the ball transfer units as used in Chapter 2 and Chapter 6. B: A display with hard and soft spheres (Chapter 3). C: a 3D set-up with hard and soft spheres as used in Chapter 3. The stimuli hang from wires, but can be manipulated freely in the hand. A similar set-up was used in Chapters 4, 5 and 8.

be integrated and both information sources can be used (e.g. Drewing & Ernst, 2006; Drewing, Wiecki, & Ernst, 2008; Drewing & Kaim, 2009; Voisin, Lamarre, & Chapman, 2002). The maximum likelihood estimate (MLE) model predicts that the information is integrated in an optimal way depending on the reliability of the two signals (Ernst & Banks, 2002).

In a search task, something similar might happen. A target that is defined by two properties might be detected faster than when it differs only in a single property with respect to the distractors. Alternatively, a single cue might dominate the percept. When both sources of information are used in the search task, this is called integration in this thesis. How these properties are combined is another question that can be asked. In

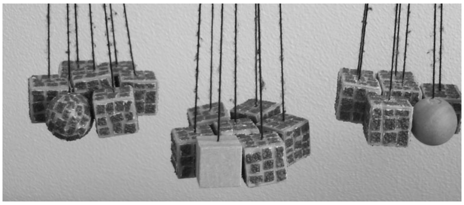

Figure 1.2: Examples of stimuli used in Chapters 4 and 5. Three stimulus bundles are shown, with a rough sphere, smooth cube or smooth sphere as a target. The distractors are rough cubes. The bundles were grasped and manipulated to detect whether the target was present.

Chapter 4 and Chapter 5 the combinations of multiple properties are investigated. Chapter 4 examines how texture and shape influence each other in haptic search. In Figure 1.2, an example of the searches for three different targets in the same context is shown. A comparison between these conditions can reveal how the difference between targets and distractors affect search performance and whether integration is possible. In Chapter 5, the integration of shape and texture is studied in detail. The question here is: if multiple sources of information are used, how are they processed together?

It is not only of interest whether multiple properties can enhance performance, but also whether they can disrupt performance. Even if something is not relevant, its presence might still influence the perception. For example, in the search for your phone, you might be distracted by a sharp edge of your keys, even though they are not searched for. Whether salient features could disrupt a search task is also investigated in Chapter 4.

Moving the hand: Exploration strategies

The last part of this thesis focuses on the exploration strategies that are used in a haptic search task. As mentioned earlier, in the search for your phone, you could have taken out each object in your bag until you have the phone, but this would be a slow strategy. However, if you just put your hand in and out, you might miss it. To be fast and accurate, the exploration strategy has to be adjusted to the specific task. It is known that the exploration manner is adjusted to specific object properties in an optimal way when objects are explored (Lederman & Klatzky, 1987). That is, for the perception of hardness a different movement is used than for the perception of shape. In search tasks, the movement characteristics are also adjusted to the task (Overvliet et al., 2007; Smith, Gosselin, & Houde, 2002) and to the saliency of a target (Plaisier et al., 2008). This means that when you want to perceive or search for a certain property, you choose a specific manner of exploration that seems to be optimal or at least suited for the property.

Besides some movement characteristics, little is known of how the search strategy is adjusted to the saliency of the target. Usually, the strategy is deduced from the search slope into a parallel or serial search strategy. A division between serial and parallel search is also often mentioned in visual search tasks. As explained above, if a flat search slope is found, the stimuli can be processed in a parallel way. If a positive slope is found, the reaction time increases with the number of items and the stimuli are searched in a serial manner. However, this is just a rough classification and the movements that are used are not analysed in detail. In haptic exploration, many different movement strategies are possible. In Chapter 6 and Chapter 8 the aim is to classify the movement strategies of search tasks into different categories. In Chapter 6 the motions in a 2D task are examined, where the stimuli are presented on a display. Similar to Chapter 2, participants have to detect a movable target among anchored ones or the other way round. The movement patterns that are used are of interest and how they differ between the different target properties. A 3D search task is studied in Chapter 8. Participants search for a smooth cube among smooth spheres or vice versa or a rough sphere among smooth spheres or vice versa. Here, the stimuli are grasped and can be manipulated in the hand. To investigate the movement patterns and the parts of the hand that are used to explore the stimuli, a model of the hand is used that is described in Chapter 7. This model consists of a number of rigid hand segments and is derived from a few sensors that are placed on the hand.

Summary

To summarise, this thesis aims to investigate haptic perception using search tasks. The saliency of different features is investigated to see whether these haptic properties can be processed efficiently. Furthermore, combinations of different properties in the targets and distractors are manipulated to examine the influence of irrelevant salient features and the integration capabilities in search performance. Finally, the influence of salient features on exploration strategies and how movements are adapted to the required perceptual information is evaluated. Together, this can provide insights into how object properties are perceived and influence the perception and manipulation of objects. The main findings in this thesis will be discussed in Chapter 9.