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# Simultaneous Sketching Aids the Haptic Identification of Raised Line Drawings

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**Abstract**
Haptically identifying raised line drawings is difficult. We investigated whether a major component of this difficulty lies in acquiring, integrating, and maintaining shape information from touch. Wijntjes, van Lienen, Verstijnen, and Kappers reported that drawings which participants had failed to identify by touch alone could often subsequently be named if they were sketched. Thus, people sometimes needed to externalize haptically acquired information by making a sketch in order to be able to use it. We extended Wijntjes et al.'s task and found that sketching while touching improved drawing identification even more than sketching after touching, but only if people could see their sketches. Our results suggest that the slow, serial nature of information acquisition seriously hampers the haptic identification of raised line drawings relative to visually identifying line drawings. Simultaneous sketching may aid identification by reducing the burden on working memory and by helping to guide haptic exploration. This conclusion is consistent with the finding reported by Lawson and Bracken that 3-D objects are much easier to identify haptically than raised line drawings since, unlike for vision, simultaneously extracting global shape information is much easier haptically for 3-D stimuli than for line drawings.

**Keywords**
Haptic, object, touch, picture, externalization

Have you ever tried to use your hand like a scanner? Probably not, but if you try it, you will discover that your fingers are easily able to identify familiar 3-D objects in the absence of vision. Klatzky, Lederman, and Metzger (1985) showed that people are both fast (often taking under 2 s) and accurate at naming everyday objects using haptics (active touch). In contrast, it is well-established that both sighted and congenitally blind people find it difficult to identify raised line drawings using touch alone (e.g., Heller, 1989; Heller, Calcaterra, Burson, & Tyler, 1996; Kennedy & Bai, 2002; Klatzky, Loomis, Lederman,

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Wake, & Fujita, 1993; Lawson & Bracken, 2011; Lederman, Klatzky, Chataway, & Summers, 1990; Loomis, Klatzky, & Lederman, 1991; Picard & Lebaz, 2012). Error rates at naming such drawings are often over 50% and response times over a minute. In contrast, visually presented line drawings representing everyday objects are usually easy and quick to identify (Lawson & Jolicoeur, 2003; Snodgrass & Vanderwart, 1980).

It is not yet fully understood why line drawings are so much harder to identify by haptics than by vision. There are a number of possible reasons. One factor is that line drawings do not unambiguously specify the shape of 3-D objects, and this may be particularly detrimental for touch since depth cues are more important for haptics than for vision. For example, Lawson and Bracken (2011) found that the error rate for identifying 3-D models of familiar objects (25%) was less than half that of matched line drawings of the same objects (65%) and response times were also faster (7 s vs. 10 s). A second issue is that line drawings are simplified or impoverished stimuli in contrast to everyday 3-D objects (Lederman & Klatzky, 1987). For example, they do not provide useful information about texture, material, weight, and size, and these cues may be more important for haptics than for vision. A third reason is the greater time needed to explore line drawings by haptics compared with vision. Line drawings are mainly explored haptically by following the contours, and this typically takes many seconds (Lawson & Bracken, 2011; Symmons & Richardson, 2000; Wijntjes, van Lienen, Verstijnen, & Kappers, 2008a). In contrast, line drawings can usually be visually identified in a fraction of a second and with no need for eye movements. For example, Lawson and Jolicoeur (2003) reported that even low contrast, immediately masked line drawings of upright views of objects could usually be identified with presentation durations under 100 ms.

In the present study, we examined the possible consequences of this third factor for the haptic perception of raised line drawings. Since haptic information is usually acquired from only a small portion of a drawing at a time, it must be accumulated and maintained for a long time while the drawing is fully explored. People are quite accurate at integrating spatial information from touch across several seconds (Moscatelli, Naceri, & Ernst, 2014). Nevertheless, this slow, serial acquisition of haptic information is likely to hamper processing. Analogously, visual processing is known to suffer when the field of view is restricted to force serial exploration of stimuli. Indeed, the accuracy of visual object recognition through a narrow aperture can be reduced to be similar to that of haptic object recognition (Craddock, Martinovic, & Lawson, 2011; Loomis et al., 1991).

In the present study, we investigated whether problems caused by only feeling one small part of a raised line drawing at a time could be alleviated by sketching during exploration to externalize the drawings. Externalization means to make an external representation of an internal, mental representation. In this article, externalization refers to people making visual sketches based on haptically perceived inputs; in the wider literature, externalization often refers to making visual sketches based on mental images (e.g., Pearson & Logie, 2014). However, externalization need not involve making visual sketches. For example, a verbally described stimulus could be haptically externalized by moulding an unseen blob of plasticine. Note that perceiving externalizations produced in the same modality as the input modality is likely to lead to similar problems as are found when perceiving the original stimulus. Evidence for this in haptics comes from Experiment 2 of Wijntjes, van Lienen, Verstijnen, and Kappers (2008b). They found that using a raised line drawing kit to make a haptic sketch did not aid identification of drawings which people had just explored haptically. Only 4% of previously unidentified objects were identified in this haptic externalization condition.

This study by Wijntjes et al. (2008b) motivated the present one. They reported that raised line drawings which people had failed to identify haptically could sometimes subsequently be identified if, after removing the drawings, people sketched the drawings that they had just felt. Here, people could look at their sketches as they made them. In a control condition, people again sketched after haptic exploration of the line drawings, but they were blindfolded so they never saw their sketches. This condition equated the time available to identify the drawings. However, only 2% of previously unidentified objects were identified in this control condition, compared with 31% when the sketch was visible. Wijntjes et al.'s results show that quite often people had stored sufficient information to support haptic identification of raised line drawings, but they could not interpret it until it was externalized by producing a visible sketch. More generally, externalization is known to aid both the identification of ambiguous pictures presented visually (such as the rabbit/duck stimulus; Chambers & Reisberg, 1985) and the identification of mental images constructed from verbal instructions (Finke, Pinker, & Farah, 1989).

The results of Wijntjes et al. (2008b) leave open the question of the stage at which people fail to haptically identify line drawings. People could encounter problems during the early processes of guiding exploration, acquiring, and maintaining haptic information and then integrating it into a global shape (Loomis et al., 1991). Alternatively, their main difficulty could lie at a later stage, when they try to match a percept to an object representation stored in long-term memory (Heller et al., 1996). Predictions based on these two alternatives were compared in the present study. In the former case, identification during the initial exploration stage could be helped by externalizing haptic information as it was being acquired, with a sketch of the whole stimulus gradually emerging over time. For example, externalization (sketching) could help to focus exploration on the most important parts of the drawing. It could also reduce the need to integrate and maintain information in working memory. In contrast, in the latter case, although sketching would, again, be predicted to lead to an identification advantage, this advantage should not depend on when externalization (sketching) occurs. This is because the latter account proposes that the main difficulty in haptically identifying raised line drawings is in matching a percept to representations in long-term memory.

Results from a recent experiment by Kalia and Sinha (2011) support the former explanation. They found that the haptic identification of raised line drawings correlated with the complexity and symmetry of the drawings, whereas measures of image agreement and familiarity had little influence on haptic identification. They, therefore, argued that successful identification reflected early processes involved in integrating shape information rather than subsequent object matching processes. In the studies of both Wijntjes et al. (2008b) and Kalia and Sinha (2011), all of the information extracted during haptic exploration had to be stored in memory before sketching began. Studies measuring neural activity during exploration by touch suggest that there is a substantial burden on working memory as the haptic percept is built up (Grunwald et al., 1999; Martinovic, Lawson, & Craddock, 2012). We investigated whether externalization through sketching might reduce this burden by letting people sketch during haptic exploration rather than sketching starting only after exploration.

We tested the haptic identification of raised line drawings across three conditions. The control, only-touch-before-sketch condition replicated the experimental condition tested by Wijntjes et al. (2008b). Here, people explored a raised line drawing haptically for 45 s. The drawing was then removed, and they had a further 30 s to sketch what they had just felt; their sketch was visible in this second part of the trial. They tried to identify the drawing throughout both parts of the trial, but only in the second part did a sketch provide a visible record of what they had perceived haptically. Just the first part of the trial differed for the other two conditions tested. In the second, visible-sketch + touch condition people sketched the drawing as they felt it in the first 45 s of each trial. Here, people could see their sketch, as it emerged during haptic exploration so they did not need to remember what they had felt, unlike the control, only-touch-before-sketch condition. If the cost of keeping information in working memory makes raised line drawings difficult to identify haptically then identification should be superior in this condition relative to the control condition. This condition might also aid people to explore the drawing more effectively, for example, by helping to direct their fingers to the most critical areas. The final, unseen-sketch + touch condition checked whether it was difficult to combine sketching with one hand and using the other hand to feel a drawing. To test this, the first 45 s of each trial was identical to the visible-sketch + touch condition except that people could not see their sketch so they were not expected to benefit from making it. Performance here should be worse than in the control condition if it was hard to sketch at the same time as exploring the drawing.

We used two versions of each raised line drawing. They differed with respect to the salience and ease of tracking the lines by touch. The thermoform stimuli were similar to those used in most previous studies using raised line drawings. The lines were less than 1 mm high and were difficult to follow so haptic exploration was slow. In contrast, the plastic drawings had lines which were at least 6 mm high and which were faster and easier to trace around. Lawson (in submission) used similar stimuli and reported that people were much slower and less accurate at exploring thermoform (37 s median correct reaction time [RT], 25% correct) than plastic (20 s, 41%) stimuli. We predicted that any benefit of sketching during exploration should be greater for the thermoform stimuli since exploration should be slower. This should increase the burden of integrating and maintaining a representation of the drawing as it is felt.

## Method

### Participants

A total of 36 students (26 females and 10 males, aged 18–30 years old) from the University of Liverpool volunteered to take part in the experiment, with most receiving course credit. All participants reported being right-handed, having normal or corrected-to-normal vision, and no known conditions affecting touch perception.

### Stimuli

Each participant felt 27 drawings which depicted outlines of familiar, nameable objects, see Figure 1. The outline is the same as the occluding contour of an object at an infinite viewing distance, that is, in parallel projection. Two versions of each drawing were produced, one with thermoform lines and the other with plastic lines. In 24/27 cases, both versions had identical outlines. The remaining three cases differed as matched pairs were not available, see Figure 1. The thermoform lines were printed on swell paper and were 1 mm tall × 2 mm across. The plastic lines were printed in acrylonitrile butadiene styrene plastic using a 3-D printer and were an average of 20 mm tall (minimum 6 mm) × 2 mm across. Each drawing was mounted onto a rigid base (140 mm horizontal × 120 mm vertical). All stimuli had dimensions greater than 40 mm × 60 mm and fitted inside this base except for the hammer and scissors which had a maximum extent of 200 mm and so extended beyond the base.

### Design and procedure

There were two main factors. There was a between-subjects factor of stimulus (thermoform lines and plastic lines) with 18 people randomly assigned to feel each type. There was also a

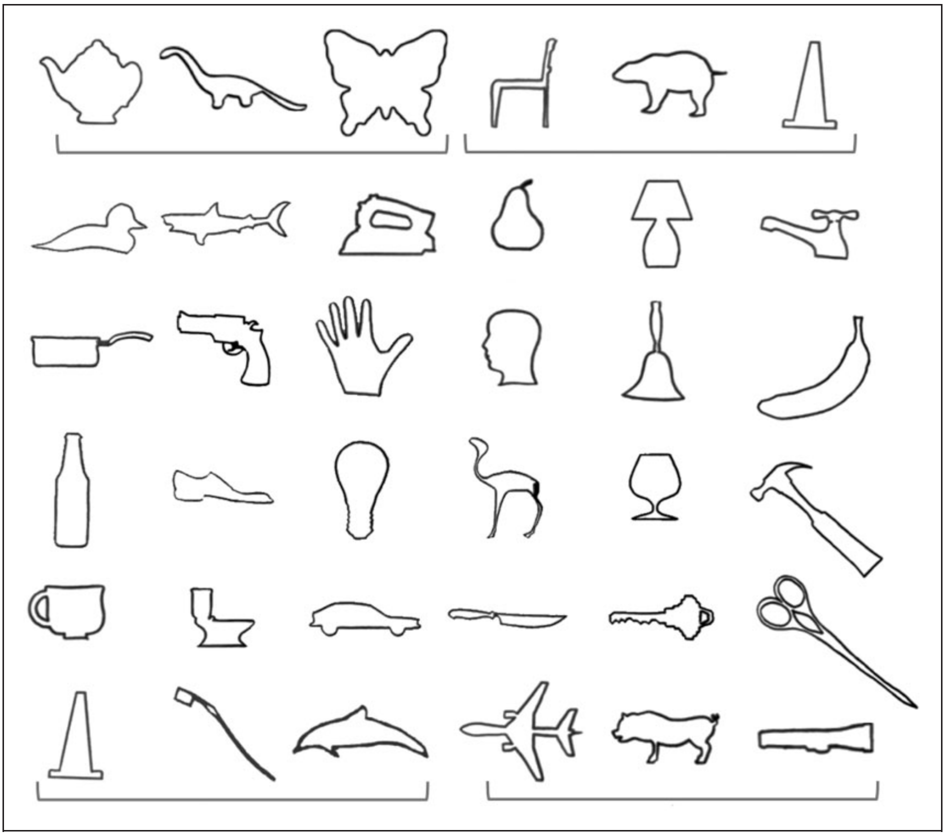

**Figure 1.** The drawings representing the outlines of familiar objects which were used in the study. The top row shows the practice stimuli for the plastic line versions (teapot, dinosaur, and butterfly) and the thermoform versions (chair, bear, and cone). The remaining rows show the experimental stimuli. These were identical for the plastic line and thermoform versions except for the three pairs on the bottom row (the cone, toothbrush, and dolphin were used for the plastic line versions; the aeroplane, pig, and torch for the thermoform versions). From the second row, the remaining experimental drawings depict a duck, shark, iron, pear, lamp, tap, saucepan, gun, hand, head, bell, banana, bottle, shoe, light bulb, camel, glass, hammer, cup, toilet, car, knife, key, and scissors.

within-subjects factor of sketching condition (control, only-touch-before-sketch, visible-sketch + touch, unseen-sketch + touch). All participants felt each of the 27 stimuli once. The stimuli were divided into three sets of nine items. The order of allocation of item set to each of the three sketching conditions and the order of presentation of these conditions within the experiment were both counterbalanced using a Latin Square design. For each pair of participants assigned to a given Latin Square condition, items were presented in one order for one participant and the reverse order for the other participant.

Participants were tested individually at a desk in a quiet laboratory. They sat to the right of a 50 cm tall barrier which blocked their view to the left. Drawings were placed into a slot on the left of the barrier and were explored by the left hand, see Figure 2. There were no instructions as to how to explore but most participants appeared to use just one finger. Sketching was done on the right of the barrier using the right hand only. Each sketch was made on a separate sheet of paper (150 mm horizontal × 105 mm vertical) placed into a slot. The primary task was to name each drawing as quickly as possible.

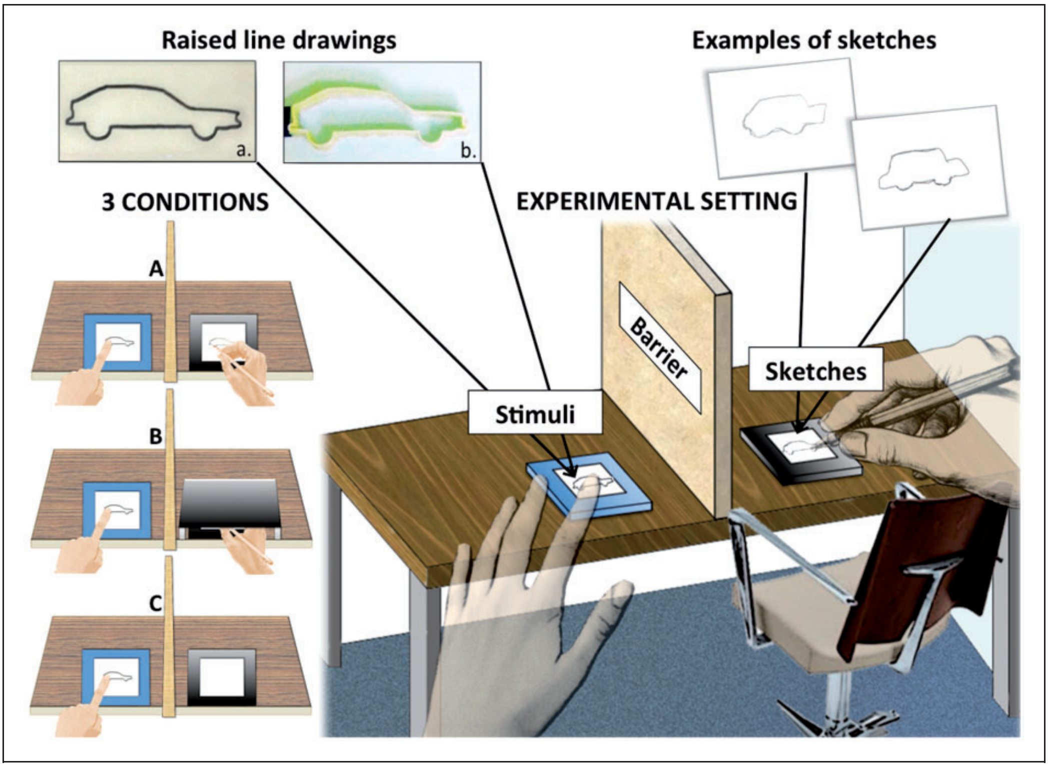


**Figure 2.** From the top left corner, examples of (a) the thermoform line and (b) the plastic line drawings. The difference between the three sketching conditions during the initial 45 s of haptic exploration for (A) visible-sketch + touch, (B) unseen-sketch + touch, and (C) control, only-touch-before-sketch conditions is shown. In the centre, the experimental setting is depicted with two sample sketches of the car from the first 45 s of the trial in the visible-sketch + touch condition.

At the beginning of each trial, participants rested their left index finger on the lower left corner of the left slot. The computer program then triggered a voice saying "Go now" which was their signal to start to feel the drawing for 45 s. A beep sounded 30 s after the start of this exploration to indicate that there was only 15 s remaining. Another beep sounded at the end of the 45 s. Participants stopped feeling the drawing and any sketch that they had made was removed. The three sketching conditions only differed in this first 45 s of each trial. During this first 45 s, no sketching was done in the control, only-touch-before-sketch condition whereas sketches were made in both the visible-sketch + touch condition (where the sketch was visible) and in the unseen-sketch + touch condition (where the sketch and the participant's right hand were both hidden by a cover).

The second part of each trial was identical for all three sketching conditions. Participants had 30 s to produce a visible sketch of the drawing that they had just felt. In the control, only-touch-before-sketch condition, this was the first sketch to be made. In the visible-sketch + touch and the unseen-sketch + touch conditions, a new, second sketch was produced during this 30 s. A beep sounded at the end of the 30 s period.

Participants could try to identify the object at any point during the trial. The experimenter pressed the spacebar as soon as the participant correctly named the object. Participants were told if their response was correct. Participants began

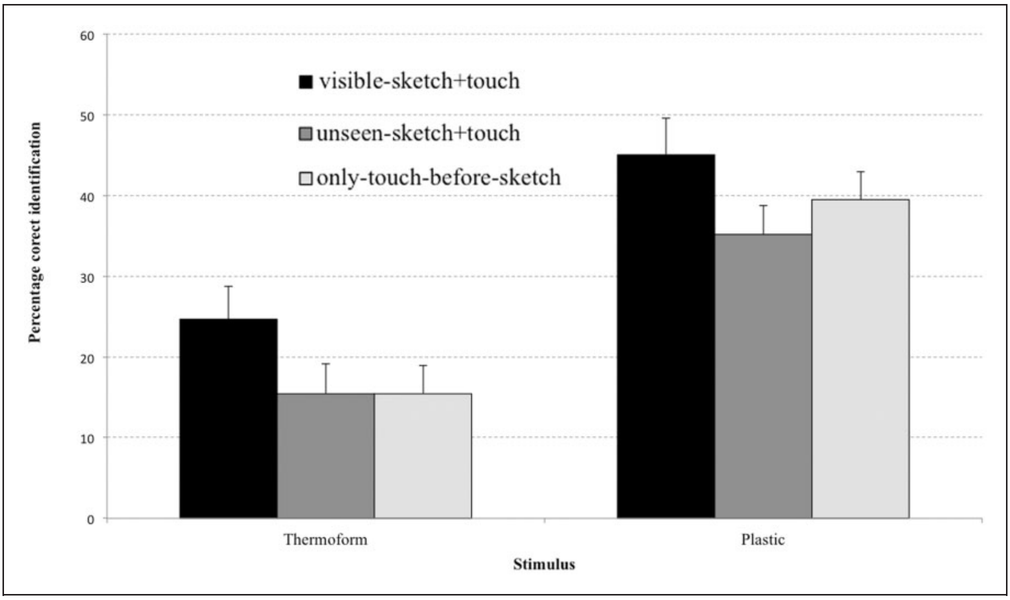


**Figure 3.** Percentage of correct identifications of the raised line drawings in the first 45 s of the trial (when haptic exploration occurred) for each of the three sketching conditions for thermoform lines and plastic lines. Error bars represent the standard error of the mean.

**Table 1.** The number of correct identifications which occurred in each of the three sketching conditions.

| | First 45 s of trial | | | Remaining 30 s of trial | | |
|---|---|---|---|---|---|---|
| | V | U | C | V | U | C |
| Thermoform lines ($n = 18$ participants) | 40 | 25 | 25 | 21 | 15 | 18 |
| Plastic lines ($n = 18$ participants) | 73 | 57 | 64 | 8 | 7 | 11 |

*Note*. The number of correct identifications which occurred during the first 45 s of the trial and during the remaining 30 s of the trial in each of the three sketching conditions (visible-sketch + touch—V; unseen-sketch + touch—U; and control, only-touch-before-sketch—C) for the groups presented with thermoform lines and with plastic lines. To illustrate the relation of this data to that shown in Figure 3, if we ignore whether a correct response occurred in the first 45 s or the remaining 30 s of a trial, the total number of trials in each of the six cells was 18 participants $\times$ 9 drawings per condition, so 162 trials. Thus, overall accuracy for the thermoform lines in the V condition was $(40 + 21) = 61$ trials out of 162 trials = 38%. This comprises 25% correct in the first 45 s of the trial, as plotted in Figure 3, and 13% in the remaining 30 s of the trial.

by doing three practice trials in the same sketching condition as the first condition they were assigned to. Unlike the experimental trials, the practice drawings were shown visually to the participant after the practice. Participants then did 27 experimental trials which comprised three blocks of nine trials, one for each of the three conditions. The experiment lasted approximately 40 min.

## Results

No participant reported having seen any of the drawings prior to or during the experiment. One participant in the thermoform group identified just one drawing and was replaced.

As expected, people found the stimuli difficult to identify so our primary analysis was for accuracy, although we also report RT below. Only identifications that were correct at the first attempt were included as correct. We analyzed separately the correct identifications which occurred in the first part of the trial (45 s of haptic exploration) and the second part of each trial (30 s of sketching without feeling the stimulus), see Table 1.

An analysis of variance of the percentage of correct identification in the first 45 s of the trial revealed a significant effect of stimulus, $F(1, 34) = 23.917$, $p < .001$, partial $\eta^2 = .41$, with greater accuracy for plastic (40%) than thermoform (19%) stimuli. There was also a significant effect of sketching condition, $F(2, 68) = 4.934$, $p = .01$, partial $\eta^2 = .13$. Post hoc Newman-Keuls analyses revealed significant differences (at $p < .05$) between the visible-sketch + touch condition (35%) and both the unseen-sketch + touch condition (25%) and the control, only-touch-before-sketch condition (27%). There was no significant difference between the latter two conditions. Finally, the interaction between sketching condition and stimulus was not significant, $F(2, 68) = 0.268$, $p = .8$, partial $\eta^2 = .01$, see Figure 3.[1]

We checked whether the advantage for the visible-sketch + touch condition occurred simply because it allowed people to produce visible sketches earlier in the trial. If so then identification which would otherwise have occurred during the final 30 s of the trial (when people produced visible sketches in all three conditions) would instead have occurred in the first 45 s of the trial (when people only produced a visible sketch in the visible-sketch + touch condition). If this was the case then performance in the final 30 s of the trial should be better for the unseen-sketch + touch and the control, only-touch-before-sketch conditions as they caught up. In contrast, performance should be similar across all three conditions in the final 30 s of the trial if, early processes involved in acquiring, maintaining, and integrating haptically acquired information were easier in the visible-sketch + touch condition.

There was no evidence to support the former prediction. We considered only the correct responses that occurred in the final 30 s of the trial, and averaged over results for the plastic and thermoform lines. The visible-sketch + touch condition had just as many extra correct identifications (9%) as the control, only-touch-before-sketch condition (9%), and the unseen-sketch + touch condition (7%). As a percentage of the drawings that had not already been identified in the first 45 s of each trial, these extra identifications were 14%, 12%, and 9%, respectively.

Finally, we analyzed mean RT when the participant's first guess was correct, whenever that occurred in a trial. There were six empty cells in this analysis, all for the thermoform group. These cells were replaced by the mean for the appropriate condition. Stimulus was significant, $F(1, 34) = 26.390$, $p < .001$, partial $\eta^2 = .44$. RT to plastic lines (26 s) were much faster than to thermoform lines (40 s), consistent with Lawson (in submission). There was no significant effect of sketching condition and no interaction of stimulus × sketching condition ($F < 1$, $p > .5$, partial $\eta^2 < .01$ in both cases). This analysis was repeated including RT for incorrect as well as correct trials. The pattern of results was unchanged: stimulus was significant, $F(1, 34) = 34.870$, $p < .001$, partial $\eta^2 = .51$. RT to plastic lines (46 s) were much faster than to thermoform lines (61 s), and there was no significant effect of sketching condition or of the interaction of stimulus × sketching condition.

## Discussion

Wijntjes et al. (2008b) found that some raised line drawings that participants could not identify haptically could later be identified if participants sketched what they had just felt. We, too, found that some drawings that were not identified as they were being explored were later identified during the second part of the trial. The magnitude of this benefit due to externalization (around 11% of possible trials) was less than that reported by Wijntjes et al. (2008b), who found that 31% of possible trials were identified by novice sketchers, or by Kalia and Sinha (2011), who found that 27% of possible trials were identified by naive observers shown sketches done by expert sketchers. Given the many differences across these three studies, we do not wish to speculate on why the benefit of post-exploration sketching might vary in magnitude.

Making a sketch while haptically exploring a line drawing did not significantly disrupt identification even though participants had to control the movements of both of their hands. Identification accuracy during haptic exploration was similar when the right hand had to sketch, in the unseen-sketch + touch condition (25%), and when the right hand was inactive, in the control, only-touch-before-sketch condition (27%).

Most importantly, we found that an extra benefit from externalization occurred if a visible sketch was produced during the first, exploratory part of the trial, while the line drawing was being touched. During this first period, accuracy in the visible-sketch + touch condition (35%) was significantly greater than in the unseen-sketch + touch condition (25%) demonstrating that it was not enough to make a sketch: People needed to see it to benefit from it.

Performance in the second, nonexploratory 30 s of each trial showed similar levels of extra identifications across all three conditions. If the early externalization which was available only in the visible-sketch + touch condition had merely sped up the identification of raised line drawings then performance in the unseen-sketch + touch and control, only-touch-before-sketch conditions should have caught up with that in the visible-sketch + touch condition in this second, non-exploratory phase. There was no evidence to support this proposal.

In our study, in all three conditions, participants felt a raised line drawing, and in all three conditions, they drew a visible sketch of what they had felt. The only difference between the three conditions was *when* participants first sketched the drawing (during exploration vs. after exploration) and *when* they could first see their sketch (during exploration vs. after exploration). Our results showed that sketching during exploration was more useful than sketching after exploration but only if the sketch was visible. A likely reason why externalization aided performance in the first, exploratory part of the trial in the visible-sketch + touch condition was by reducing the burden on working memory processes involved in maintaining and integrating haptically acquired information (Loomis et al., 1991). Sketching during exploration may also have improved exploration, for example by directing the hand to touch more informative areas of the drawing.

Most studies of the haptic identification of raised line drawings have used shallow lines such as thermoform stimuli. We also used thermoform stimuli but in addition we presented plastic line stimuli which were easier to explore (Lawson, Boylan & Edwards, 2014). People were both faster and more accurate at naming the plastic (26 s, 40% correct) than the thermoform (40 s, 19%) line drawings during the first, exploratory part of the trial. This finding has important practical implications for the design of stimuli intended to be explored haptically, such as tactile diagrams. We advise that, where possible, raised line drawings and diagrams designed for the visually impaired should use similar lines which are easy and rapid to follow. Recent advances in 3-D printing technology have made such lines much cheaper and simpler to produce.

We did not find an interaction between our manipulation of stimulus type and the externalization benefit. We had expected that the thermoform stimuli would show a greater benefit of externalization during exploration because they were harder to explore.

The lack of an interaction could be because even the plastic line drawings were difficult to identify. These stimuli typically took tens of seconds to name so the burden on processes such as guiding exploration and working memory presumably remained high so here, too, externalization helped.

In this study, raised line drawings were easier to identify if people could sketch them as they felt them. This result is consistent with examples of how externalization can aid mental imagery in the visual perception literature (e.g., Verstijnen, Van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998) though strong benefits have not always been found (e.g., Anderson & Helstrup, 1993). For instance, Chambers and Reisberg (1985) presented ambiguous stimuli such as the Necker cube and the rabbit/duck figure and asked participants to use mental imagery to identify the other referent. Participants could not reverse these figures, whereas they usually succeeded at reinterpreting them after sketching them on paper. Similarly, Finke et al. (1989) gave verbal instructions to their participants to create mental images such as imagining the letter D on its side, fixed to the top of the letter J. Participants often reported perceiving the shape of an umbrella so they could transform and reinterpret mental images. However, on the trials where people failed to identify the shape using mental imagery, they often then did identify it after sketching (83% of the time). Here, again, externalization improved performance.

Our results have shown that externalization can aid haptic identification. We suggest that simultaneous sketching is helpful in reducing the difficulties that haptic perception has in the early stages of processing when spatial information must be sequentially acquired, maintained, and integrated in working memory. It remains for future research to determine whether externalization improved performance by guiding exploration or by reducing the burden on memory and whether externalization would also aid performance for participants who were skilled or trained in 2-D haptic perception. In addition, here we investigated the haptic identification of raised line drawings. Future work should also examine whether similar results occur for 3-D objects, particularly for large, novel, or complex shapes which require several seconds to fully explore.

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## Note

1. This analysis of variance was repeated but using combined data from the whole trial (the first, 45 s exploration phase and the second, 30 s sketching phase). The pattern of results was the same, and the main effects of stimulus and sketching condition were still significant while the interaction of stimulus × sketching condition remained nonsignificant ($F < 1$, $p = .5$, partial $\eta^2 < .03$).

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