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Haptic identification of raised-line drawings when categorical information is given: A comparison between visually impaired and sighted children

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Research into haptic picture perception has mostly concerned adult participants, and little is known about haptic picture perception in visually impaired and sighted children. In the present study, we compared 13 visually impaired children (early blind and low vision) aged 9-10 years and 13 age-matched blindfolded sighted children on their ability to identify raised-line pictures of common objects when information about object category was provided prior to picture presentation (semantic cueing). The visually impaired children had moderate practice with tactile pictures, whereas the sighted controls had no prior practice with tactile pictures. We sought to determine whether the benefits of semantic cueing would add to those of practice, resulting in higher performance in the visually impaired children compared to the sighted controls (hypothesis 1), or whether semantic cueing would compensate for the lack of practice with tactile pictures in the sighted children, leading to a possible disappearance of the advantage of the visually impaired children over the sighted controls (hypothesis 2). In line with hypothesis 1, the results showed that the visually impaired children outperformed the sighted controls on both identification accuracy and response time to correct naming. We concluded that the visually impaired children outperformed the sighted controls because they benefited from both semantic cueing and superior exploration skills. By contrast, in the sighted children, semantic cueing was not sufficient to compensate for their encoding difficulties.

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Raised-line pictures of common objects are the haptic equivalent of visual pictures (Kennedy, 1993). However, haptic picture identification is a far-from-easy task, at least compared to visual picture identification. Unlike vision, the haptic system gathers sequential and piecemeal information from raised-line patterns, and imposes heavy perceptual and cognitive demand of integration during exploration (Loomis, Klatzky, & Lederman, 1991; Revesz, 1950). As a result, humans' ability to identify raised-line pictures through haptics has been characterized by low identification rates (30-40%) and long response time to naming ($\simeq$ 90 s) (for reviews see Heller, 2002; Heller, McCarthy, & Clark, 2005; Picard & Lebaz, 2012). Most of the studies so far have tested adult subjects, with or without visual impairment (i.e., those who are blind, or have low vision). By contrast, little attention has been paid toward children. This is somehow surprising if we consider the utility of raised-line pictures for blind children (Norman, 2003). Several studies have shown the positive role of tactile pictures on text reading, comprehension and retention in blind children (Pring & Rusted, 1985; Stratton & Wright, 1991). Therefore, research into haptic picture identification by children has both theoretical interest for our understanding of haptic perception with and without visual impairment, and a potentially high applied value for the design and use of tactile pictures for blind children (see Theurel, Witt, Claudet, Hatwell, & Gentaz, 2013).

Previous research into children's ability to identify raised-line pictures by touch has provided mixed findings. For instance, a notable study by D'Angiulli, Kennedy and Heller (1998) provided an optimistic view on the usability of raised-line pictures of common objects with blind children, but not with sighted children. In this study, seven congenitally blind children aged 8-13 years had to identify a series of 8 raised-line pictures of common objects. The drawings included both projections of real-life objects (3D drawings) and flat depictions of real-life objects (2D drawings) (see Kennedy & Bai, 2002). The blind children recognized 45% of the picture set, and outperformed a group of age-matched blindfolded sighted children who identified only 9% of the picture set. A second group of age-matched blindfolded sighted children using passive (guided) exploration identified 35% of the pictures set, with no significant difference with the blind group. The authors concluded that the blind children have superior exploration skills, but that guided exploration can facilitate recognition by the sighted children (see also D'Anguilli & Kennedy, 2000, 2001). On the other hand, a recent developmental study by Picard, Albaret, and Mazella (2013), involving sighted participants (no blind children), provided a more optimistic view on the usability of raised-line pictures in sighted blindfolded children who lacked practice with tactile pictures and who were not guided in their exploratory movements. It should be noted, however, that due to variations in material and/or procedure across the studies, it is not possible to draw a direct comparison between performance levels obtained in different studies. This is a general limitation of this field of research.

In Picard et al.'s study, thirteen sighted children aged 5-7 years had to identify a series of 8 raised-line pictures of common objects. The drawings were produced on Swell paper, and were all flat depictions of real-life objects (2D drawings). The authors also tested two additional groups of adolescents (13-17 years) and young adults (20-25 years) so as to assess whether haptic picture perception improved with increasing age. In order to avoid floor performance, all participants were given the category name of the objects prior to the presentation of each picture (see Heller, Calcaterra, Burson, & Tyler, 1996). In this specific context, the blindfolded sighted children were able to recognize 32.75% of the picture set. The identification performance increased up to 69.25% in adolescents, and reached 86.5% in adults. The age-related improvement in performance was significant. The authors also observed an age-related improvement in haptic short-term memory capacity, concomitant to the age-related improvement in picture identification ability. The authors concluded that the identification of raised-line drawings by sighed subjects is an age-related skill, and that improvements in haptic short-term memory capacity may play a role in the development of that skill.

Overall, Picard et al.'s study shows that raised-line pictures of common objects can make sense to sighted blindfolded children who lacked practice with tactile pictures, at least when favorable experimental conditions are gathered (i.e., use of simple 2D drawings, prior information about semantic category). By contrast, D'Angiulli et al. have found much more limited capabilities to make sense of raised-line drawings in sighted children, unlike they were guided in their exploration. The controversy found in this literature probably reflects the task demands and stimulus differences used in the studies. Several (adult) studies have shown that the ability to identify pictures accurately depend on the complexity with which objects are depicted (e.g., Kalia & Sinha, 2011; Lebaz, Jouffrais, & Picard, 2012; Thompson, Chronicle, & Collins, 2003). Namely, using simple or 2D raised-line pictures makes identification easier, compared to using complex or 3D representations. It is also known that providing (adult) participants with semantic information about object category prior to the presentation of a picture makes picture identification easier, as it allows for top-down processes to participate in concert with bottom-up processes during recognition (see Heller, 1989; Heller et al., 1996). Thus, the performance level attained by sighted children in Picard et al.'s study may be due, at least partly, to a more favorable context of perception, at least compared to the one set up in D'Angiulli et al.'s study.

To summarize, beside the role of picture complexity and memory capacities, there may be two important features of haptic picture processing. One is *practice* (or guidance) in exploration which helps extract and integrate tactile shape information efficiently (see D'Angiulli et al., 1998; Magee & Kennedy, 1980). Another important feature of haptic picture processing is *semantic cueing* (see Heller et al. 1996; Pathak & Pring, 1989; Picard et al., 2013), which helps formulate semantically-based hypotheses about object identity. How these two features (practice and semantic cueing) interact during a raised-line drawing identification task is unknown and calls for investigation. This issue is important because the reading of tactile pictures with concomitant semantic cues mimics to a certain extent the natural context of reading tactually illustrated books by visually impaired children, who have developed tactile exploration practice and familiarity with raised-line drawings. In natural settings, these children often have Braille text accompanying simplified pictures (e.g., the Braille text may indicate that "a hungry boy wants to eat a fruit", and the raised-line picture may depict "a banana"): the children can thus use the semantic information to guess what the pictures depict. It is therefore worth testing, under experimentally controlled situations, how visually impaired children respond to simple raised-line pictures when they have semantic information about object category, and how they compare with sighted controls who lack practice with these pictures and who have poorly developed tactile exploration skills. One possibility is that the benefits of semantic cueing add to those of practice, thus resulting in higher performance in visually impaired children compared to sighted controls (hypothesis 1). Another possibility is that semantic cueing competes with practice and compensates for the relative unfamiliarity of sighted children with coding two-dimensional tactual information, thus resulting in a disappearance of the advantage of visually impaired children over sighted controls (hypothesis 2).

We designed the present study to test these hypotheses. To that end, we set up an experimental study in which we compared visually impaired children aged 9-10 years (having prior practice with tactile pictures) and blindfolded sighted children (with no prior practice with tactile pictures) on a raised-line drawing identification task. Prior practice with tactile pictures involved use of tactually illustrated books (i.e., books with braille content and raised-line pictures depicting objects), use of tactile diagrams or maps including braille legends at home and/or at school. The age range (9-10 years) was selected because it involved children who were relatively accustomed to reading tactile pictures due to their acquired experiences with this kind of material at school and at home. The test materials (2D raised-line drawings) and experimental conditions (semantic cueing, no guidance in exploration) were similar to those gathered in Picard et al. (2013). Future comparisons could thus be made between performance levels obtained in this earlier study and the present one (as noted earlier, one main limitation of this field of research is variation in methodologies across studies which limits direct comparison of performance levels). Note that the developmental study by Picard et al. (2013) aimed at determining the influence of age on tactile picture identification in sighted participants, and no comparison was made with visually impaired children. The present study extends that of Picard et al. to a comparison between visually impaired children and sighted controls with a totally different scope (testing how practice and semantic cueing interact). We measured performance levels attained by each group with respect to both identification accuracy and response time to correct naming. We then assessed between-group differences in each parameter. We sought to determine whether children with visual impairments would outperform (hypothesis 1) their blindfolded sighted peers, or whether their advantage over the sighted controls would disappear (hypothesis 2) under conditions of semantic cueing.

METHOD

Participants. Twenty six French children aged 9-10 years took part in the study. They were divided in two groups according to their visual status: the *visually impaired group* (n = 13; 10 boys, 3 girls; Mean age = 121 months, SD = 7) and the *sighted group* (n = 13; 7 boys, 6 girls; Mean age = 122 months, SD = 6). Table 1 shows the characteristics of the visually impaired children. All these children had an early visual impairment (i.e., either congenital or acquired before the age of one). Seven had low vision (best corrected visual acuity below 4/10), five were legally blind (best corrected visual acuity below 1/10), and two were totally blind (light perception at best). The visually impaired children attended specialized care centers for the visually handicapped (Alfred Peyrelongue, and Cival-Lestrade centers). They all had a self-reported moderate practice in using tactile pictures at home or school. The sighted children attended normal schools and were matched for chronological age with the visually impaired children. None of the sighted children had used raised-line pictures prior to the study.

Table 1. Characteristics of the visually impaired children who participated in the experiment.

Participant	Age	Sex	Visual acuity Right Eye	Left Eye	Visual status	Cause of the deficiency
1	9;1	M	-	0.4/10	legally blind	congenital, optic nerve hypoplasia
2	9;3	M	1.2/10	1.5/10	low vision	congenital, glaucoma + aniridia
3	9;3	M	-	-	totally blind	congenital, microphtalmia
4	9;11	M	4/10	2/10	low vision	congenital, hypermetropia
5	10;1	F	3.2/10	1.6/10	low vision	oculocutaneous albinism
6	10;2	M	0.8/10	0.9/10	legally blind	congenital, retinopathy
7	10;2	F	1.2/10	1.2/10	low vision	congenital, albinism
8	10;4	M	< 1/10	1.3/10	low vision	congenital, retinopathy
9	10;4	M	0.5/10	1.5/100	legally blind	congenital, optic nerve atrophy
10	10;6	M	< 1/10	< 1/10	legally blind	neurofibromatosis type 1
11	10;7	M	3/10	-	low vision	congenital, malformation
12	10;7	M	2/10	4/10	low vision	congenital, retinopathy
13	10;11	F	-	-	totally blind	traumatic brain injury

Materials. The test materials were 8 raised-line versions of pictures of common objects taken from Picard et al. (2013) (see Fig. 1). None of the pictures contain any information about the third dimension. According to the French normative measures for pictures established by Alario and Ferrand (1999), the picture set had a high name agreement (percentage of subjects producing the modal name, M = 97.75%, SD = 4.95), and a low level of visual complexity (amount of detail and intricacy of lines, rated between 1 = very simple to 5 = very complex; M = 2.82, SD = 1.18).We used Swell paper and a heating machine to produce the raised-line drawings. The pictures were presented in a booklet showing one picture per page. Maximum picture size was 19 x 25 cm. Because the task had to be performed under the haptic modality with no reliance on vision of any kind, and because children do not tolerate wearing a sleep mask or glasses blinding their eyes as blindfolds, we used an apparatus with an opaque curtain mounted on wood to hide the test material behind the curtain. This apparatus permitted children to put their hands behind the curtain to explore the tactile pictures haptically, without visual access to the pictures. Children could not see close hand movements while exploring the raised-line pictures behind the curtain.

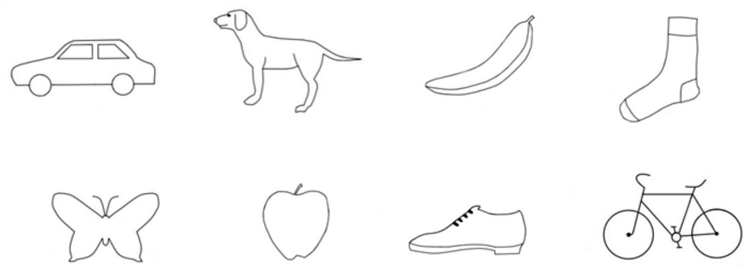

Figure 1. Pictures used in the study (car, dog, banana, sock, butterfly, apple, shoe, bicycle).

Procedure. A female psychologist served as the experimenter. She observed the children individually a quiet room inside their school or center for blind children. She informed them that she had brought with her a series of tactile pictures of common objects. She told the children that she wanted them to explore each picture by hand so as to identify the objects depicted in the pictures, as accurately and quickly as possible. Children had a maximum of 120 seconds to deal with each picture. This duration corresponded to that used in most previous studies in the field (see Picard & Lebaz, 2012). In order to familiarize the children with the task, two additional raised-line drawings were used for practice. Prior to the presentation of each picture, the experimenter provided the children with the name of the category of the depicted object (fruit for banana and apple; vehicle for bicycle and car; animal for dog and butterfly; clothing for sock and shoe). During the test, the experimenter encouraged the children if necessary, but she gave no feed-back to them, regardless of whether or not the responses were correct. She wrote down the individual verbal responses on a score sheet and recorded responses times to naming using a stopwatch.

RESULTS

We attributed 1 point per picture when children provided the expected name (or a close synonym) of the object. Responses given per picture are listed in Appendix A. We then calculated the number of correct responses (min 0, max 8). We also considered response times to correct naming (i.e., response times for incorrect answers withdrawn, see Lebaz et al., 2012 for a similar analysis). Preliminary analyses indicated that the distribution of the number of correct responses did not deviate significantly from normality (Shapiro-Wilk test, $w = .96012$, $p > .39$), whereas the distribution of response times did (Shapiro-Wilk test, w = .90300, p = .02). Due to our small sample size (N < 30), we used non parametric tests for independent samples to compare the visually impaired and sighted children on their number of correct responses, and on their response times (Mann-Whitney U-tests). We used an alpha level of .05 for all the statistical analyses reported below. Table 2 summarizes the main results obtained.

Table 2. Summary statistics for correct responses and response times to correct naming for each group.

		Visually impaired children	Sighted children
Correct responses	Mean (± SD)	4.15 (± 2.03)	3.00 (±1.53)
	%	51.87	37.50
Response time (sec)	Mean (±SD)	16 (±14)	28 (±14)
	Median	14	26

The results in Table 2 showed that the visually impaired children outperformed the sighted children on their number of correct responses. On the average, the visually impaired children identified 51.87% of the pictures (Mean number correct = 4.15 out of 8 pictures) whereas the sighted children identified 37.5% of the corpus (Mean number correct = 3.00 out of 8 pictures). The between-group difference reached significance (U = 48.5, p = .05). The number of correct responses did not vary significantly according to whether children were blind (totally or legally blind, n = 6, M = 3.70, SD = 2.03) or had low vision (n = 7, M = 4.60, SD = 2.03) (U = 16, ns). The results in Table 2 also showed that the visually impaired children were faster (Median = 14 s) than the sighted children (Median = 26 s) to name the pictures. The between-group difference was significant (U = 33, p = .01). Response time to naming did not vary significantly between blind (Median =

13.5 s) and low vision children (Median = 15.8 s) (*U* = 10, ns). The correlation between individual number of correct responses and response times was not significant (Spearman rank correlation, *r* = -.05, ns). Note that the conclusions remained unchanged when the analysis was run on global response times (including both correct and incorrect answers).

A closer look at the data indicated that the pictures differed greatly in their difficulty of identification. As Fig. 2 shows it, there was a high variability in identification accuracy among the pictures, and some items appeared easier to identify than others (e.g., banana vs. sock). Interestingly, with a few exceptions, items ranked in a similar order of difficulty for each group. Item-based correlation analyses showed a significant and positive correlation between the number of correct responses obtained by the visually impaired and sighted group (Spearman rank correlation, *r* = .70, *p* = .05). This correlation indicated commonalities between groups with respect to difficulties vs. facilities in item identification. Finally, median response times to naming (see Fig. 3) also varied according to items in both groups. Item-based correlation analyses revealed no significant correlation between median response times obtained by the visually impaired and sighted group (Spearman rank correlation, *r* = .36, ns). Item-based correlations between mean number correct and median response times were significant in the visually impaired group only (Spearman rank correlation, *r* = -.85, *p* < .05), not in the sighted group (Spearman rank correlation, *r* = -.15, ns). Thus, in the visually impaired children at least, pictures that were easier to identify were also pictures that were quicker to recognize.

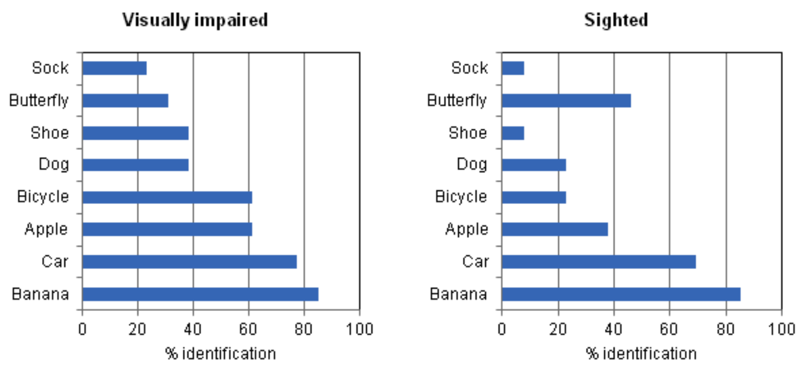

Figure 2. Percent identification for each picture by visually impaired and sighted children.

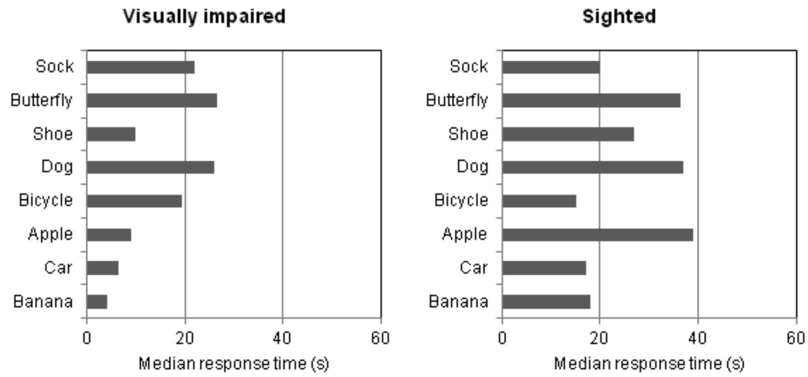

Figure 3. Median response time to correct naming (sec) for each picture by visually impaired and sighted children.

DISCUSSION

This study was aimed to assess how a group of children with early visual impairments (blind and low vision), and moderate practice with tactile pictures, responded to simple raised-line pictures when they have semantic information about object category, and how they compared with sighted controls who lacked practice with these pictures and who had poorly developed tactile exploration skills. This is the first study to draw a comparison between visually impaired and sighted children's ability to identify tactile pictures under conditions of semantic cueing. We sought to determine whether the benefits of semantic cueing (see Heller et al., 1996) would add to those of practice, resulting in higher performance in the visually impaired children compared to the sighted controls (hypothesis 1), or whether semantic cueing would compensate for the lack of practice with tactile pictures in the sighted children, leading to a possible disappearance of the advantage of the visually impaired children over the sighted controls (hypothesis 2).

In line with hypothesis 1, we found that children with early visual impairments (blind and low vision) outperformed their blindfolded sighted peers both on accuracy and response time to correct naming. Under conditions of semantic cueing, these children were able to identify more pictures than the sighted controls (51.87 vs. 37.5% correct), and they were faster to name the depicted objects successfully (14 vs. 26 s). Identification accuracy also varied across the pictures, with some items appearing easier to identify than others, but there were commonalities between the visually impaired and sighted groups with respect to difficulties vs. facilities in item identification. These latter findings support the view that vision and touch may use outline in similar ways to access knowledge of objects' shapes (D'Angiulli et al., 1998; Kennedy, 1993), and that image characteristics play a major role in raised-line picture processing (see Kalia & Sinha, 2011; Theurel et al., 2013). Compared to data reported in an earlier study using similar experimental conditions with sighted participants (Picard et al., 2013), it appears that our group of sighted children aged 9-10 years performed slightly higher than younger peers aged 5-7 years (32.7% correct), but lower than adolescents aged 13-17 years (69.25%). This observation is in line with the view that the ability to identify tactile pictures through haptics improves during childhood and into adolescence in blindfolded sighted humans. Previous studies have shown that under active conditions of exploration (no guidance) congenitally blind children have an advantage over sighted children when asked to identify raised-line pictures without any cue on their identity (see D'Angiulli et al., 1998). The present study shows that this advantage still holds for children with early visual impairments when picture identification is made easier through the provision of prior categorical information. This finding is new and adds to our knowledge on tactile picture processing in children and to our understanding of the mechanisms involved in raised-line picture identification.

Raised-line picture identification can be regarded as involving both bottom-up processes (encoding and integration of tactually perceived information) and top-down processes (formulation of hypotheses about object identity) (see also Lederman, Klatzky, Chataway, & Summers, 1990). These processes are likely affected by a variety of factors, internal and external to the observer. Prior practice with tactile pictures is a factor internal to the subject that may play a very important role in the encoding of tactually perceived information: subjects with higher practice are likely to have developed more efficient exploration skills (see D'Angiulli et al., 1998; Dulin & Hatwell, 2006). Semantic cueing is a factor external to the subject that may play a very important role in the formulation of hypotheses about object identity: the provision of semantic information (category name) about the depicted objects prior to the presentation of each picture made picture identification easier, as shown in adults at least (see Heller, 1989; Heller et al., 1996). It is likely that the children of our study, irrespective of their visual status, have formulated hypotheses about object identity on the basis of the available semantic information. These hypotheses might have been used to guide hand movements toward the research of confirmatory cues in the raised-line drawing (e.g., when children were told that the picture depicted a vehicle, they might have assumed that it could be a car, and searched for wheels in raised-line picture). Children with visual impairments had moderate practice with tactile pictures, which implied more efficient hand movements and haptic exploration skills (D'Angiulli et al., 1998; see also Rovira, Deschamps, & Baena-Gomez, 2011; Vinter, Fernandes, Orlandi, & Morgan, 2012). By contrast, the sighted controls had no prior practice with tactile pictures and lack efficient exploratory skills with 2D raised-line materials. The finding that the visually impaired children outperformed the sighted controls in our task suggests that these children benefited from both semantic cueing and superior exploration skills. By contrast, in the sighted children, semantic cueing may not have been sufficient to compensate for their encoding difficulties.

To conclude, we suggest that due to developed haptic exploration skills (acquired by practice with 2D raised-line materials) children with early visual impairments have an advantage over sighted children in terms of the rapidity with which they explore raised-line pictures by hands and the accuracy with which they identify them, even when the task is facilitated by the provision of semantic cues. What this study does not tell is how visually impaired children would have responded if no semantic information was provided on the raised-line pictures, as we did not manipulate the presence of semantic cues. In the future, it might be worth comparing performance of visually impaired children on raised-line identification tasks with and without prior categorical information, so as to measure the exact benefit of semantic cueing. Also, we ignore which components of haptic exploration skills are crucial to a successful processing of raised-line pictures. This issue is important if we want to get a full understanding of the mechanisms involved in the extraction and integration of tactile shape information. Accordingly, future research might look at ways to measure several likely components of 2D haptic processing skills in children with and without visual impairments (e.g., haptic scanning skills for raised lines or dots, haptic discrimination skills for raised-line shapes, haptic memory span for raised-line shapes...), so as to determine which of these components actually helps extract and integrate tactile shape information efficiently in raised-line materials.

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APPENDIX A

Responses given per pictures.

Pictures	Correct responses	Incorrect responses
Car	Car	Don't know, elevator, train, tractor, helicopter, plane, truck
Dog	Dog	Don't know, cat, rabbit, horse, dolphin, bear, fish, pigeon, bird, eagle, ant
Banana	Banana	Don't know, zucchini, carrot, lettuce
Sock	Sock	Don't know, pants, t-shirt, skirt, sweater, shoe, boot, shirt, dress, coat
Butterfly	Butterfly	Don't know, bee, wasp, dog, bird, snake, giraffe, fish, pigeon
Apple	Apple	Don't know, strawberry, pear, tomato, pineapple, carrot, melon
Shoe	Shoe	Don't know, t-shirt, hanger, pants, overalls, scarf, hat, jacket, skirt
Bicycle	Bicycle, bike	Four-by-four, tractor, truck, motorbike, elevator, train, plane, car

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