Size and Quality of Drawings Made by Adults Under Visual and Haptic Control

Magdalena Szubielska, Pawel Augustynowicz, Delphine Picard

Size and Quality of Drawings Made by Adults under Visual and Haptic Control

Magdalena Szubielska[1,*,**], **Paweł Augustynowicz**[1,***], and **Delphine Picard**[2,***]

[1] Institute of Psychology, John Paul II Catholic University of Lublin, Aleje Racławickie 14, 20-950 Lublin, Poland

[2] Aix Marseille Univ, PSYCLE, Aix en Provence, France

[*] To whom correspondence should be addressed. E-mail: magdasz@kul.pl

Postal address: Department of Experimental Psychology, Institute of Psychology, John Paul II Catholic University of Lublin, Aleje Racławickie 14, 20-950 Lublin, Poland

[**] ORCID: 0000-0002-8437-0871

[***] ORCID: 0000-0002-4039-4580

[****] ORCID: 0000-0002-4578-7260

Size and Quality of Drawings Made by Adults under Visual and Haptic Control

Abstract: The aim of the study was twofold. First, our objective was to test the influence of an object's actual size (size rank) on the drawn size of the depicted object. We tested the canonical size effect (i.e. drawing objects larger in the physical world as larger) in four drawing conditions – two perceptual conditions (blindfolded or sighted) crossed with two materials (paper or special foil for producing embossed drawings). Second, we investigated whether drawing quality (we analysed both the local and global criteria of quality) depends on drawing conditions. We predicted that drawing quality, unlike drawing size, would vary according to drawing conditions – namely, being higher when foil than paper was used for drawing production in the blindfolded condition. We tested these hypotheses with young adults who repeatedly drew eight different familiar objects (differentiated by size in the real world) in four drawing conditions. As expected, drawn size increased linearly with increasing size rank, whatever the drawing condition, thus replicating the canonical size effect and showing that this effect was not dependent on drawing conditions. In line with our hypothesis, in the blindfolded condition drawing quality was better when foil rather than paper was used, suggesting a benefit from haptic feedback on the trace produced. Besides, the quality of drawings produced was still higher in the sighted than the blindfolded condition. In conclusion, canonical size is present under different drawing conditions regardless of whether sight is involved or not, while perceptual control increase drawing quality in adults.

Keywords: visual perception, haptic perception, drawing from memory, canonical size, spatial representation

1. Introduction

Drawings of familiar objects produced by humans reveal conceptual information about the objects depicted. This conceptual information mostly includes the basic semantic features of the depicted object (e.g. the head, body, legs and tail of a dog), viewpoint information (e.g. the dog is usually depicted looking to the left side) and size information (e.g. the dog is usually drawn larger than a mouse but smaller than a house). Canonical perspective, or the tendency to prefer one (i.e. more typical) profile over another while drawing familiar objects, has been described by many authors (see, e.g. Kebbe and Vinter, 2013; Picard, 2011; Picard and Durand, 2005; Palmer *et al.*, 1981; van Sommers, 1984) who usually consider that the canonical perspective maximises surface information visible and thereby an object's recognition. Canonical size has been described more recently by Konkle and Oliva (2011; see also Konkle and Oliva 2012a, 2012b for further exploration of the real-world size issue as an automatic property of object representation). They asked young adults to draw 16 different objects from memory (paperclip, key, pet goldfish, apple, hairdryer, running shoe, backpack, computer monitor, German shepherd, chair, floor lamp, soda machine, car, dump truck, single-storey house, lighthouse) that spanned the range of real-world sizes, with two objects at each size rank. Participants had to draw each object separately and were not informed which objects they would need to draw as the next. These authors showed that the drawn size of the object was proportional to the logarithm of the size of the object in the world, thus revealing a canonical size effect in the drawing of familiar objects.

The findings of Konkle and Oliva (2011) were replicated and extended in multisensory research by Szubielska and collaborators (Szubielska *et al.*, 2020; Szubielska and Wojtasiński, 2021). They instructed young adults to draw the same 16 objects of 8 different ranks of physical size in two different conditions: visual (participants drew sighted on normal paper sheets, as in the original study), and haptic (here, participants drew blindfolded on special plastic sheets that produce embossed drawings). These authors found that in both the visual and haptic domain, the size of drawings increased linearly with the logarithm of the physical size of real-world objects, thus indicating the occurrence of the canonical size effect in both the visual and the haptic domains. This interesting finding suggests that the spatial size of familiar objects may be represented in an amodal form in the human brain (Loomis *et al.*, 2013; see also Likova, 2012). Previous research on modality effects showed that both unimodal modality-specific (visual or haptic) and higher-order supramodal mechanisms are simultaneously used in spatial cognition (e.g. Cattaneo, and Vecchi, 2008). Supramodality refers to the representing and processing of specific features of spatial stimuli in a more abstract (amodal) way (i.e. independently of the sensory modality input) (Cattaneo, and Vecchi, 2008; Loomis *et al.*, 2013). However, Cattaneo and Vecchi (2008) did not research explicitly processing and representing the size of objects – in their experiment, the basis for accurate task performance was memorising the locations of targets arranged on the matrices. To the best of our knowledge, no research has been conducted so far directly on supramodality effect with respect to the size as one of the features of spatial stimuli.Research on the production of drawings only with haptic feedback is sparse (for notable exceptions of research on drawings produced by blind adults see: Amedi *et al*., 2008; Kennedy and Juricevic, 2003; 2006a; 2006b and by blind children: Bin and Chuen-Jiang, 2010; Kennedy, 1993; D'Angiulli and Maggi, 2003; Millar, 1975; Szubielska *et al.*, 2016; Vinter *et al.*, 2018). Most research to date has concentrated on tactile perception (and identification) of raised-line drawings by sighted and/or visually impaired participants (Heller, 2002; Heller *et al.*, 1996; Lederman *et al.*, 1990; Pathak and Pring, 1989; Picard *et al.*, 2013; Picard *et al.*, 2014a; Vinter *et al.*, 2020). This literature revealed that identifying raised-line pictures by hand (without sight) is a difficult although not impossible task (for a review, see for instance Picard and Lebaz, 2012) and depends on tactile illustration techniques (for instance, raised lines, thermoforming, and textures; Kalia *et al.*, 2014; Theurel *et al.*, 2013; Thompson *et al.*, 2003) as well as picture size (Wijntjes *et al.*, 2008). We, therefore, know little about how sighted participants draw familiar objects from memory when they are blindfolded (with or without available haptic feedback) and how their drawings compare to drawings produced under a more natural condition of production where sight is allowed and guides the hand movements. In sighted children, we know from Vinter and collaborators (2018) that drawings produced under haptic feedback (using a Swedish drawing kit) contain fewer elements but more disconnected segments and element positioning errors compared to drawings produced under the usual visual condition (using regular sheets of paper). In adults, we know from Szubielska and colleagues (2020) that drawings produced under haptic feedback (using foil for embossed drawings) have a smaller size compared to drawings produced under the usual visual condition (using regular sheets of paper), at least for drawings depicting large objects – apart from a significant global tendency, significant size differences were obtained for size ranks 6 to 8; the authors provided no data about drawing quality. Regarding drawing quality (e.g. elements present and their spatial positioning), we may wonder whether, in adults, haptic feedback could be sufficient to prevent a decline in overall drawing quality (notably the disorganisation of the positioning of graphic elements), thus leading to drawings of comparable quality to those made under visual control.

The comparison between haptically and visually guided drawings is vital for our understanding of the role and specificity of the visual and haptic senses in the control of graphic hand movements. One recurrent drawback of previous research studies comparing visual and haptic drawing production is the lack of control conditions that would permit disentangling two confounding factors. Indeed, most studies contrasted a sighted drawing condition (visual) to a blindfolded drawing condition (haptic). Hence, the material (normal paper versus special plastic sheet – foil for producing embossed drawings) confounded with the perceptual sense involved in the drawing activity. Thus, any difference between visual and haptic drawings could be attributed to material used and visual perceptual feedback, i.e. perceptual condition. Notably, the change of the material may cause changes in the dynamic of the drawing movement (due to the mechanical characteristics of paper versus foil), as well as in the perceptual condition of the drawer (e.g. special foil allows for haptic control and guiding haptically the drawing movement). A more complete and comprehensive approach of how drawings made without visual feedback compared to those made in the typical visual condition (with respect to various parameters such as size or drawing quality) would request the design of four different drawing conditions by crossing material (normal paper versus foil sheet) and perceptual condition (sighted versus blindfolded).

Comparison of visually and haptically guided production of drawings may refer to the functional equivalence of haptic and vision in representing spatial information (Giudice *et al*., 2011; Loomis *et al*., 2013; Ottink *et al*., 2021). Suppose the processing of information about the shape and size of objects is functionally equivalent to touch and vision. In that case, we should not get differences in the size or quality of drawings produced under visual or tactile control. However, some studies have shown that spatial information is processed more accurately through the particular modality, although the results are contradictory – since the accuracy was sometimes higher for vision (Szubielska *et al*., 2021) or for touch (Intraub *et al*., 2015). Due to these conflicting effects, in the current study, we aimed to explore the issue of differences in the quality of drawings produced under visual or haptic control.

1.1. *Scope of the Present Study*

The present study aimed at investigating both the size and quality of drawings produced by sighted adults under visual and haptic control in order to determine whether these parameters are (or are not) affected by the sense involved in drawing production. To that end, the study compares visual and haptic drawings of familiar objects made by sighted adults under four different drawing conditions by crossing the two above-mentioned factors (material and perceptual conditions): (1) sighted/paper (typical condition for drawing activity), (2) sighted/foil (both visual and haptic information is available, however haptic information is likely not useful because of vision dominance), (3) blindfolded/paper (only proprioceptive information is available), (4) blindfolded/foil (haptic feedback available). Importantly, we used a repeated measures design so that participants repeatedly drew the same set of objects under the four different drawing contexts. This was aimed at promoting conservatism in the series of drawings produced (see, e.g. van Sommers, 1984), such that any significant modification in size or quality of drawing across conditions would reveal some external (contextual) factors are affecting drawing behaviour in our participants. If we consider the four drawing conditions of our study, some are typical of normal visual drawing conditions (sighted/paper) while others are more unfamiliar due to a new media for drawing (sighted/foil) or to the lack of vision (blindfolded/paper and blindfolded/foil), with (blindfolded/foil) or without (blindfolded/paper) tactile feedback from the trace produced. Condition sighted/paper served as the baseline drawing condition, where participants drew under visual control on a normal paper sheet. In this condition, drawings of high quality are expected. Condition sighted/foil required participants to produce drawings on foil and permits them to control the drawn process both visually and haptically. Condition blindfolded/paper required participants to produce drawings without visual control or haptic feedback. Finally, condition blindfolded/foil served as the haptic condition in which participants drew blindfolded on foil and could use haptic feedback to control the line produced in relief on the foil.

In line with the findings of previous studies on the canonical size phenomenon (Konkle and Oliva, 2011; Szubielska *et al*., 2020; Szubielska and Wojtasiński, 2021) and the possible amodal nature of the size representation in mind (e.g. Bryant, 1997; Huffman & Ekstrom, 2019; Levine & Schwarzbach, 2018; Szubielska *et al*., 2020; Wolbers et al., 2011), we may predict that the size of drawings in all experimental conditions linearly increases with real-size objects. In other words, we may hypothesise that the canonical size effect transcends perceptual modality.

Also, we may predict the interaction effect of the perceptual condition and material used on the quality of drawings. More specifically, only in the blindfolded condition, the quality should be higher for drawings produced on foil (because of the access to the haptic feedback) than paper (due to the lack of external control of the progress in producing shape; only proprioceptive perceptual information is available). At the same time, in the sighted condition, visual feedback is available both when participants draw on paper and foil, and therefore there should not be a difference in drawing quality between these conditions (likely, visual information is the main modality relevant for drawing – since we hardly ever draw with closed eyes and under only haptic or proprioceptive control).

Summing up, in the current study, we predicted that drawing size would increase linearly with increasing size rank (of the to-be-drawn objects) regardless of the drawing conditions (Hypothesis 1). With regard to quality, on the other hand, we predicted the interaction of factors of the perceptual condition and the material used. More precisely, we predicted higher quality in the blindfolded/foil condition than in the blindfolded/paper condition (Hypothesis 2).

2. Material and Methods

2.1. Participants

We tested a sample of 24 psychology students (12 females; 21 right-handed; aged 20 – 26 years, *M* = 21.88 years, *SD* = 1.48) with normal or corrected-to-normal vision and without motor disabilities.

2.1. Materials

The participants were given white sheets of paper or a Swedish raised-line drawing kit (i.e. a rubber mat with a special foil placed on it to produce embossed graphics) to produce their drawings on using a sharpened pencil (see Fig. 1). Both papers and foils had A4 format and were horizontally arranged.

[Fig. 1 here]

2.3. Procedure

Participants were tested individually in a single session. They were instructed to draw from memory without time limit a single object per sheet of paper/foil, representing: (1) key, (2) apple, (3) shoe, (4) backpack, (5) dog, (6) floor lamp, (7) car, (8) house, i.e. objects of increasing size rank, namely – increasing size in the physical world (in fact, this increase in size is best described by the logarithmic function: Konkle and Oliva, 2011).

Each participant drew in four different blocks: (a) on foil, blindfolded (b) on paper, blindfolded (c) on foil, sighted, (d) on paper, sighted. The order of these blocks was counterbalanced (using twenty-four different orders) across participants. Before drawing on foils, participants were familiarised with a Swedish raised-line drawing kit and were encouraged to draw some lines and shapes, varying the pencil pressure. Importantly, participants were asked to explore the embossed shapes with their non-dominant hand when drawing them with their dominant hand using the raised-line drawing kit. Within each block, eight objects were drawn in random order. The instruction to the participants was to draw the particular object as they usually draw it. There was no time limit for drawing. In the foil, blindfolded condition, participants were encouraged to control the drawing progress with their non-dominant hands. The total number of trials was 32, and the experiment lasted 45 min on average.

All procedures performed in the current study involving human participants are in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The procedure received approval from the Ethical Committee of the Institute of Psychology of The John Paul II Catholic University of Lublin. All participants gave informed written consent before data collection.

2.4. Data Coding

2.4.1. Drawn Size

As in previous studies in this field (Konkle and Oliva, 2011; Szubielska *et al*., 2020; Szubielska and Wojtasiński, 2021), the indicator of the drawn size of the object (in millimetres) was the length of the diagonal of the rectangle bounding the drawing. It is important that each object that was drawn was bounded around by a rectangular box after extraneous objects (e.g. the doormat on which the shoe is placed, the light emanating from a switched-on lamp) are ignored. To measure the diagonals, all drawings were scanned at a fixed resolution, and the boundaries of all the drawings were determined by the first authors of this paper using the Photoshop program. Then, custom software automatically converted the dimension of the bounding box into millimetres using the known resolution.

We identified outliers in participants' drawn size (mean + 3 *SD*s). It was found that in 0.65% of all cases (of a total of 768 drawings), participants produced drawings larger than this cut-off. We replaced these outliers with mean values.

2.4.2. Drawing Quality

Drawing quality was measured in terms of recognisability, level of detail, morphology (i.e. quality of the shape of the graphic components), and topology (i.e. quality of the spatial arrangement between the graphical elements). For the house drawing, for instance, the windows had to be drawn as regular squared or rectangular shapes (correct morphology) and had to be positioned on a single line horizontal to the floor or roof of the house (correct topology). These dimensions were coded by two raters (both females, psychology students, aged 23 and 24 years) who had no knowledge of the aims of the study and visual status of the participants, nor the condition in which the drawings were made. The raters were specifically trained to perform the coding of the data using drawings from our previous studies. In a similar manner to the approach taken in previous research (Vinter *et al.,* 2018), we trained the raters with a different series of drawings until they reached 80% agreement. Training drawings (created both on papers and foil sheets) were derived from previous research on the canonical size effect (Szubielska *et al*., 2020; Szubielska and Wojtasiński, 2021).

In the case of recognisability, the raters were given the name of the to-be-depicted object for each drawing and were instructed to give a rating of 0 when they were unable to identify the object depicted in the drawing, 1 when they identified some parts of the drawing, and 2 when they did not have any problems with assessing what the drawing represented (see illustrations of a key in Fig. 2A).

The level of detail was defined as follows: 0 – low (schematic drawing), 1 – middle (some elements drawn in detail, others schematically), 2 – high (very detailed drawing) (see illustrations of a shoe in Fig. 2B).

Similarly, morphology had to be coded as 0 when the quality of the shape of the graphic components was low, 1 – middle, and 2 – high (see illustrations of a dog in Fig. 2C).

Topology was defined as 0 when there were positioning errors of elements or when elements were disconnected with each other (e.g. backpack straps not touching the backpack), 1 – when these errors were produced sporadically, and 2 – when neither of these errors occurred (see illustrations of a backpack in Fig. 2D).

The raters coded the whole corpus of 768 drawings produced in the current study, with each drawing being presented one after the other, with its title (i.e. the name of the to-be-depicted object), and in random order. In a first step, each rater coded the drawings independently from each other. In a second step, if a discrepancy in coding occurred, the two raters discussed this case until they reached a consensus. We assessed the inter-rater reliability for the coding of each variable using Cohen's Kappa coefficient, which was .66 for recognisability, .58 for level of detail, .63 for morphology, and .55 for topology (all ps < .001). Moreover, we calculated the raters' agreement on coding. The percentage of inter-rater agreement was 81% for recognisability, 76.4% for level of detail, 80.2% for morphology, and 77.2% for topology.

We collapsed data across all size rank conditions of each participant because differences in quality between drawn objects may be quite specific and depend on the selected drawing objects (and this thread is outside the main focus of the current study).

[Fig. 2 here]

3. Results

3.1. Drawn Size

We computed a repeated measures analysis of variance (ANOVA) with the within-participant variables of size rank (8: 1 – key, 2 – apple, 3 – shoe, 4 – backpack, 5 – dog, 6 – floor lamp, 7 – car, 8 – house), perceptual condition (2: blindfolded, sighted), and material used (2: paper, foil), and the dependent variable of drawn size (diagonal measured in mm). Greenhouse–Geisser corrections were used whenever necessary to account for violations of the sphericity assumption in the analyses. Descriptive statistics of drawn size for all experimental conditions are presented in Table 1.

Table 1.

Mean drawn size (diagonals in mm) as a function of material, perceptual condition, and size rank. Standard deviations are presented in parentheses.

	Foil		Paper	
	Blindfolded	Sighted	Blindfolded	Sighted
Size Rank				
1	98.65 (48.22)	110.62 (56.33)	94.46 (47.34)	111.13 (64.90)
2	88.76 (30.18)	121.27 (55.36)	90.65 (42.66)	114.32 (47.80)
3	82.23 (37.55)	91.81 (42.92)	83.82 (40.63)	94.57 (51.62)
4	91.99 (44.78)	112.38 (56.23)	92.91 (40.33)	103.32 (45.54)
5	101.97 (34.53)	118.02 (37.12)	105.62 (29.57)	116.96 (57.98)
6	121.78 (44.21)	139.58 (55.23)	109.92 (45.93)	138.36 (50.18)
7	137.21 (48.03)	154.99 (53.30)	127.30 (48.13)	154.41 (47.86)
8	150.08 (55.93)	173.78 (64.18)	139.37 (60.58)	172.47 (52.52)

The main effect of size rank was significant, $F(7, 161) = 26.59$, $p < .001$, $\eta_p^2 = 0.54$ and best described by a significant linear function, $F(1, 23) = 78.08$, $p < .001$, $\eta_p^2 = 0.77$: participants tended to draw as larger objects that are larger than smaller in the physical world, especially starting with a shoe-sized object and considering larger ones ($M_{key} = 103.72$, SE = 10.34; $M_{apple} = 103.75$, SE = 8.34; $M_{shoe} = 88.11$, SE = 8.15; $M_{backpack} = 100.15$, SE = 9.01; $M_{dog} = 110.64$, SE = 6.73; $M_{floor\ lamp} = 127.41$, SE = 9.21; $M_{car} = 143.48$, SE = 9.01; M_{house} =

158.92, SE = 11.14). A quadratic function also reached significance, $F(1, 23) = 33.68$, $p < .001$, $\eta_p^2 = 0.59$, but explained the results less well than the linear function. The main effect of perceptual condition was also significant, $F(1, 23) = 22.18$, $p < .001$, $\eta_p^2 = 0.49$, with participants producing larger drawings in the visual than blindfolded condition (M_{visual} = 126.75, SE = 9.00; $M_{blindfolded}$ = 107.29, SE = 7.35). These main effects were however qualified by a significant interaction between size rank and perceptual condition, $F(3.82, 87.82) = 2.86$, $p = .030$, $\eta_p^2 = 0.11$.

To investigate this interaction (see Fig. 3), we collapsed data across both material conditions of each participant for each perceptual condition. Then we computed the repeated measures of analysis of variance with the within-participants variables of size rank (8) and perceptual condition (2), followed by post hoc comparisons using Bonferroni adjustments (here and throughout). The pattern of results of these follow-up analyses was the same as for the main effects of size rank and perceptual condition, apart from the size rank 5 (drawings of a dog) – in this case, the post hoc comparison did not yield a significant difference between blindfolded and sighted conditions ($p = .069$). Neither the main effect of material, $F(1, 23) = 0.97$, $p = .335$ nor the interaction of this variable with other factors reached significance (all ps > .072).

[Fig. 3 here]

3.2. Drawing Quality

To analyse the quality of the drawings produced, we computed ANOVAs using the within-subjects variables of perceptual condition (2) and material (2), and the dependent variables of level of detail, morphology, and topology (all treated as the dimensional – local criteria of quality), recognisability (treated as the global quality index, dependent on the coders' knowledge of the drawings' titles), and another drawing global quality index, resulting from the fusion of local criteria (in order to calculate this index we averaged the evaluations on these dimensions). Descriptive statistics and inferential statistics are presented accordingly in Tables 2 and 3.

Table 2.

Drawing quality in terms of recognisability, level of detail, morphology, topology, and global quality (fusion of local criteria) as a function of material and perceptual condition. Standard deviations are presented in parentheses.

CONDITION	Recognisability	Level of detail	Morphology	Topology	Global quality: fusion of local criteria
Foil, blindfolded	1.38 (0.25)	1.13 (0.37)	1.29 (0.22)	1.46 (0.23)	1.29 (0.20)
Foil, sighted	1.76 (0.21)	1.45 (0.36)	1.80 (0.16)	1.97 (0.06)	1.74 (0.18)
Paper, blindfolded	1.21 (0.19)	1.02 (0.34)	1.08 (0.18)	1.12 (0.20)	1.07 (0.16)
Paper, sighted	1.77 (0.20)	1.55 (0.32)	1.76 (0.26)	1.96 (0.06)	1.75 (0.19)

Table 3.

Effects of perceptual condition and material on level of detail, morphology, topology, and global quality indexes of drawings – recognisability and the fusion of local criteria: Inferential statistics.

	Perceptual condition	Material	Perceptual condition × Material
Level of detail	$F(1, 23) = 62.06$, $p < .001$, $\eta_p^2 = .73$	$F(1, 23) = 0.02$, $p = .895$, $\eta_p^2 < .01$	$F(1, 23) = 15.13$, $p < .001$, $\eta_p^2 = .40$
Morphology	$F(1, 23) = 234.89$, $p < .001$, $\eta_p^2 = .91$	$F(1, 23) = 17.05$, $p < .001$, $\eta_p^2 = .43$	$F(1, 23) = 7.49$, $p = .012$, $\eta_p^2 = .25$
Topology	$F(1, 23) = 392.09$, $p < .001$, $\eta_p^2 = .95$	$F(1, 23) = 53.92$, $p < .001$, $\eta_p^2 = .70$	$F(1, 23) = 32.34$, $p = .012$, $\eta_p^2 = .58$
Recognisability	$F(1, 23) = 166.92$, $p < .001$, $\eta_p^2 = .88$	$F(1, 23) = 8.95$, $p = .007$, $\eta_p^2 = .28$	$F(1, 23) = 8.39$, $p = .008$, $\eta_p^2 = .27$
Global quality: fusion of local criteria	$F(1, 23) = 354.46$, $p < .001$, $\eta_p^2 = .94$	$F(1, 23) = 31.51$, $p < .001$, $\eta_p^2 = .58$	$F(1, 23) = 37.59$, $p < .001$, $\eta_p^2 = .62$

3.2.1. Local Criteria of Quality

The analyses on the level of detail variable yielded a significant main effect of perceptual condition and the interaction between perceptual condition and material (see Table 3). Post hoc comparisons showed that, in the sighted condition, the level of detail was higher when drawings were produced on paper than foil (p = .009). In contrast, in the blindfolded condition, the level of detail was slightly lower when participants produced drawings on paper than foil – however, the difference was only marginally significant (p = .070). The level of detail was higher in the visual condition than in the blindfolded condition for both materials (both ps < .001) (see Fig. 4, and illustrations in Fig. 5).

For the dependent variable of morphology, the main effects of perceptual condition and material, and the interaction were significant (see Table 3). Post hoc tests showed that in the blindfolded condition, the morphology local quality was higher for drawings produced on foil than on paper (p < .001), and at the same time, in the sighted condition, the difference between the two material conditions was not significant (p = .273). Moreover, for both material conditions, drawings produced in the visual condition had higher morphology ratings than drawings produced in the blindfolded condition (both ps < .001) (see Fig. 4, and illustrations in Fig. 5).

The results for topology were similar to those for morphology (see Table 3). In the blindfolded condition, topology quality was higher for drawings produced on foil than paper (p < .001), whereas in the sighted condition, the difference between the two material conditions was not significant (p = .185). Moreover, for both material conditions, drawings produced in the visual condition had higher topology ratings than drawings produced in the blindfolded condition (both ps < .001) (see Fig. 4, and illustrations in Fig. 5).

3.2.1. Global indexes of quality

For the dependent variable of recognisability, the analyses showed significant main effects of perceptual condition and material, and interaction of these variables (see Table 3). Post hoc comparisons indicated that, in the blindfolded condition, recognisability was higher for drawings produced on foil than on paper (p = .003). On the other hand, in the sighted condition, the difference between materials used was not significant (p = .704). Moreover, for both material conditions, drawings produced in the visual condition had higher recognisability ratings than drawings produced in the blindfolded condition (both ps < .001) (see Fig. 4, and illustrations in Fig. 5).

[Fig. 4 here]

[Fig. 5 here]

The analysis on another global quality index – being a fusion of local criteria of level of detail, morphology, and topology, showed a similar pattern of results. Namely, the main effects and the interaction effect reached significance (see Table 3). Post hoc comparisons also revealed a similar pattern of results as for recognisability (see Fig. 4). Again, global quality was higher for drawings produced on foil than on paper in the blindfolded condition (p = .033), but in the sighted condition, the difference was not significant (p = .489). Also, for both material conditions, drawings produced in the visual condition had higher global quality than drawings produced in the blindfolded condition (both ps < .001).

4. Discussion

The objective of the current study was to test whether the phenomenon of canonical size occurred under different conditions of drawing from memory (Hypothesis 1). We additionally tested whether the availability (or not) of sight control and the type of material used for drawing (paper/foil) affected drawing quality and hypothesised the better quality of drawings produced on foil than on paper, but only in the blindfolded condition (Hypothesis 2).

Hypothesis 1 was supported because, in all drawing conditions, participants drew objects that are larger in the physical world as larger than objects that have a smaller actual size. It is important to note that the relationship between the size rank and drawn size was best described by a linear function. Hence, we replicated the findings of previous research, which showed that the so-called visual canonical size phenomenon might be present in drawings made not only in the visual (Konkle and Oliva, 2011), but also in the haptic condition (Szubielska *et al.*, 2020; Szubielska and Wojtasiński, 2021). Although a quadratic trend also was significant, the quadratic function explained the results less well than the linear one. In our study, the smallest objects, namely apples and keys, were drawn as relatively large. The quadratic function was not yielded in previous studies (Konkle and Oliva, 2011; Szubielska *et al.*, 2020; Szubielska and Wojtasiński, 2021). Importantly, whereas in these previous studies, two trials (drawing topics) per each condition of the eight size ranks were used (e.g. for rank 8 – house and lighthouse), we used only one trial (drawing topic) per each condition of the eight size ranks (e.g. for rank 8 – house). (Given the number of drawings that the participants had to make in this study, we chose this approach to avoid too many drawings decreasing subjects' motivation to complete the task). It is possible that with more trials associated with the inclusion of an additional object for a given size condition, the averaged drawn size of smaller objects would decrease.

Moreover, our study did not show an influence of the material used for drawing on the presence of the canonical size effect. This may suggest that under different conditions of drawing from memory, participants used the same mental representations of the object they intended to illustrate and used procedural memory, i.e. a specific pattern of movements to be made by the dominant hand, to draw the object in question. In other words, participants rarely changed the drawing scheme due to the automatisation of hand movements (which is similar to automated handwriting movements connected with the stability of kinematic characteristics, cf. Lopez and Vaivre-Douret, 2021; Marquardt *et al.*, 1999). Consequently, looking at the drawings made in different conditions, it is easy to identify that the same person made them (see Fig. 5). From a theoretical perspective, our study contributes to the discussion concerning the potential visual character of the canonical size phenomenon. Konkle and Oliva (2011) suggested that this phenomenon is linked to visual perception. Although it is too early to conclude that the canonical size effect is not visual (for this, it would be necessary to show the occurrence of this effect in people with congenital blindness), our results showed that this effect occurs not only when drawing in visual but also in blindfolded conditions. Therefore, in line with evidence suggesting amodal spatial representations in the human brain (e.g. Wolbers *et al.*, 2011), we may conclude that mental representation of the size of objects in sighted people is amodal. On the other hand, due to a tendency to visualise even non-visual stimuli by blindfolded adults (Pantelides *et al.*, 2016; Szubielska, 2014; Szubielska and Zabielska-Mendyk, 2018; Vanlierde and Wanet-Defalque, 2004), presumably in the haptic conditions, the participants visualised a piece of paper and the object they were to draw on it. In other words, when drawing from memory, participants could, both in the visual and tactile conditions, activate the image of the object in question in their mental imagery (using a visuospatial – or spatial – sketchpad of working memory, for the discussion, see Likova, 2012). Then, they probably attempted to draw the shape activated in their imagery, each time adjusting the proportions of the particular object and the paper/foil sheet to how they 'saw' the size of the object in relation to the frame of the mental image.Our study also revealed another interesting significant effect regarding the drawn size of depicted objects. First, drawn size (apart from the drawings depicting a dog) was larger in the sighted than the blindfolded condition. A similar result was obtained in the previous study on the canonical size effect in the visual and haptic domains (apart from the drawings depicting a key, an apple, a shoe, a backpack and a dog and other drawings of objects characterised by size rank 1 to 5 that were not included in the current study) (Szubielska *et al.*, 2020). Participants in our study may have wanted to have more tactile control over the overall shape that was created on foil, therefore trying to produce drawings that could be embraced with the hand (notably, hand-sized drawings are recommended for tactile graphic design: Edman, 1992). Furthermore, due to the sequential and relatively slow nature of manual perception, the working memory load should be larger in the case of controlling the process of drawing bigger drawings by touch than when producing smaller depictions (Lederman and Klatzky, 1987, 2009; Mazella *et al.*, 2018; Morimoto, 2020; Revesz, 1950; Yoshida *et al.*, 2015). Presumably, the participants produced smaller drawings in the foil haptic condition to avoid overloading their working memory. Interestingly, we noticed that some participants tended to control haptically the drawing production even in the blindfolded paper conditions. They created a kind of boundary using their non-dominant hand and tried to put the whole drawing in such framed space. However, when drawing under proprioceptive control (blindfolded/paper condition), connecting segments and positioning elements appropriately seems more challenging when the sizes of drawings increase. Therefore, in this condition, participants might have decided to produce relatively small drawings of objects with higher size ranks.

Hypothesis 2 was also supported. In line with our hypothesis, the effect of material on general quality (both global and local – apart from the level of detail dimension) occurred in the blindfolded condition but did not in the sighted condition. In the blindfolded condition, drawing quality (apart from the level of detail dimension) was better when foil rather than paper was used, suggesting a benefit of haptic feedback on the embossed trace that was produced. However, the embossed trace left on the foil was quite thick, and at the same time, touch has a relatively low spatial resolution and narrow perceptual field (Dassonville, 1995; Loomis *et al.*, 1991; see also Wijntjes *et al.*, 2008) – which probably made it difficult to draw small elements or details on foil (see also the study with children who drew using fingers on tactile tablet versus pencil on paper and performed worse when using fingers: Picard *et al.,* 2014b). This potential negative effect may have masked the potential positive effect of haptic feedback on the level of detail dimension when drawing blindfolded on foil.

Moreover, the results showed that participants produced drawings that had higher quality, i.e. were more recognisable, had a higher level of detail, and were better with regard to morphology and topology when they could use vision compared to conditions where they were blindfolded (which seems to contradict the functional equivalence theory, see Giudice *et al*. 2011). Similar results (with regard to recognisability, producing positioning errors and disconnections) were obtained in research with children who produced drawings in visual or blindfolded conditions (Vinter *et al.*, 2018). Producing a good quality drawing requires both drawing skills and ongoing control of the shape created during the drawing process. Under both visual conditions, ongoing shape control was possible without hindrance. By contrast, in the blindfolded condition, it was not possible to control the shape haptically during drawings made on paper (although the drawing process might be monitored by proprioceptive information), and this was limited by the capacity of working memory when producing drawings on foil (Mazella *et al.*, 2018; Yoshida *et al.*, 2015). In our view, creating raised-line drawings without sight control requires both fine drawing skills and the ability to read drawings by touch (i.e. to recognise, to accurately discriminate shapes, and to interpret drawing elements as well as the overall shape). As we mentioned before, reading drawings by touch is not an easy task, especially when the drawings are made with the contour line technique and their size is rather small (Kalia *et al*., 2014; Picard and Lebaz, 2012; Theurel *et al.,* 2013; Thompson *et al*., 2003; Wijntjes *et al.,* 2008) – as was the case in our study.

5. Limitations and suggestions for further studies

The current research has some limitations. Among these, we intend to discuss three issues.

First, the drawing process was not recorded. Hence, we cannot assess the extent to which individual participants used the haptic information and cannot analyse the haptic exploration procedures adopted in the blindfolded condition. However, we observed that some participants made very little use of their non-dominant hand to check the embossed trace when drawing on foil during the task. By contrast, other participants used their non-dominant hand and occasionally paused drawing to use a bi-manual exploration to read the result of the drawing produced so far. Several studies showed that accurate recognisability of an embossed graphic depends on exploratory procedures (D'Angiulli *et al.*, 1998; Magee and Kennedy, 1980; Symmons *et al.*, 2004; see also Wijntjes *et al.*, 2008). And – as we highlighted earlier – producing a drawing under haptic control requires both drawing skills and the ability to read a picture by touch. Furthermore, some blindfolded participants used their fingers or hands as cues even when drawing on paper (i.e. by constructing, with their non-dominant hand, a kind of frame in which they placed the drawing or by marking the starting point with their finger). Blanco and Travieso (2003) showed that hints based on the information provided by fingers/hands are beneficial when performing spatial tasks without sight control.

Second, very limited training in the use of foils for raised-line drawings was provided to the participants. It seems that if the training was more extended and attention was paid to effective strategies for reading convex drawings, the foil might become a more familiar material for the participants, and the difference between the visual and tactile conditions in the quality of drawings made under haptic control might reduce or even disappear.

Third, the within-subjects design may have promoted a high degree of conservatism in participants' repeated drawings across conditions (see van Sommers, 1984), which may have contributed to the absence of effect of the material used. It is possible that different results may have occurred with a between-subject design.

The current research might be developed in at least two directions. First, exploring developmental changes in drawing performance made under visual and without visual control would be interesting. Second, in future studies, it would be beneficial to test adults who are blind, especially in the context of examining the canonical size effect in drawings made from memory.

6. Conclusions

Overall, the present study on adults' drawing from memory indicated that the canonical size effect occurs in both perceptual conditions, thus replicating the findings of previous studies conducted in the visual and haptic modalities (Konkle and Oliva, 2011; Szubielska *et al.*, 2020; Szubielska and Wojtasiński, 2021). In addition to these outcomes, the present study showed that participants produced drawings that had higher quality in the sighted than in the blindfolded condition and in the blindfolded condition when haptic feedback was available.

Funding

The research and work on the article were carried out under a BGF scholarship granted by the French Government (French Embassy in Poland) awarded to MS.

References

Amedi, A., Merabet, L. B., Camprodon, J., Bermpohl, F., Fox, S., Ronen, I., Kim, D. S. and Pascual-Leone, A. (2008). Neural and behavioral correlates of drawing in an early blind painter: a case study, *Brain Res.* **1242**, 252–262. DOI:10.1016/j.brainres.2008.07.088.

Bin, I. and Chuen-Jiang, S. (2010). Examining explanations for differences in two-dimensional graphic spatial representation of cubes among totally blind subjects, *Visual Arts Research,* **36**, 12–22. DOI:10.1353/var.2010.0007.

Blanco, F. and Travieso, D. (2003). Haptic exploration and mental estimation of distances on a fictitious island: from mind's eye to mind's hand, *J. Vis. Impair. Blind.* **97**, 298–300. DOI:10.1177/0145482X0309700505.

Bryant, D. J. (1997). Representing space in language and perception, *Mind Lang.* **12**, 239–264. DOI:10.1111/1468-0017.00047.

Cattaneo, Z. and Vecchi, T. (2008). Supramodality effects in visual and haptic spatial processes. *J Exp Psychol Learn Mem Cogn.* **34**, 631–642. DOI:10.1037/0278-7393.34.3.631.

D'Angiulli, A., Kennedy, J. M. and Heller, M. A. (1998). Blind children recognizing tactile pictures respond like sighted children given guidance in exploration, *Scand. J. Psychol.* **39**,187–190. DOI:10.1111/1467-9450.393077.

Dassonville, P. (1995). Haptic localization and the internal representation of the hand in space, *Exp. Brain Res*. **106**, 434–448. DOI:10.1007/BF00231066.

D'Angiulli, A. and Maggi, S. (2003). Development of drawing abilities in a distinct population: depiction of perceptual principles by three children with congenital total blindness, *Int. J. Behav. Dev.* **27**, 193–200. DOI:10.1080/01650250244000191.

Edman, P. K. (1992). *Tactile Graphics*. AFB Press, New York.

Giudice, N. A., Betty, M. R. and Loomis, J. M. (2011). Functional equivalence of spatial images from touch and vision: Evidence from spatial updating in blind and sighted individuals, *J. Exp. Psychol. Learn. Mem. Cogn.* **37**, 621–634. DOI: 10.1037/a0022331.

Heller, M. A., Calcaterra, J. A., Burson, L. L. and Tyler, L. A. (1996). Tactual picture identification by blind and sighted people: effects of providing categorical information, *Percept. Psychophys.* **58**, 310–323. DOI:10.3758/bf03211884.

Heller, M. A. (2002). Tactile picture perception in sighted and blind people, *Behav. Brain Res.* **135**, 65–68. DOI:10.1016/s0166-4328(02)00156-0.

Huffman, D. J. and Ekstrom, A. D. (2019). A modality-independent network underlies the retrieval of large-scale spatial environments in the human brain, *Neuron* **104**, 611–622.e7. DOI:10.1016/j.neuron.2019.08.012.

Intraub, H., Morelli, F. and Gagnier, K.M. (2015). Visual, haptic and bimodal scene perception: evidence for a unitary representation, *Cognition* **138**, 132–147. DOI:10.1016/j.cognition.2015.01.010

Kalia, A., Hopkins, R., Jin, D., Yazzolino, L., Verma, S., Merabet, L., Phillips, F. and Sinha, P. (2014). Perception of tactile graphics: embossings versus cutouts, *Multisens. Res*. **27**, 111–125. DOI:10.1163/22134808-00002450.

Kebbe, H. and Vinter, A. (2013). How culture, age, and manual dominance affect directionality in drawing side view objects, *J. Cross. Cult. Psychol.* **44**, 160–172. DOI:10.1177/0022022111435098.

Kennedy, J. M. (1993). *Drawing and the Blind: Pictures to Touch*. Yale University Press, New Haven, CT.

Kennedy, J. M. and Juricevic, I. (2003). Haptics and projection: drawings by Tracy, a blind adult, *Perception* **32**, 1059–1071. DOI:10.1068/p3425.

Kennedy, J. M. and Juricevic, I. (2006a). Blind man draws using diminution in three dimensions, *Psychon. Bull. Rev.* **13**, 506–509. DOI:10.3758/bf03193877.

Kennedy, J. M. and Juricevic, I. (2006b). Foreshortening, convergence and drawings from a blind adult, *Perception* **35**, 847–851. DOI:10.1068/p5316.

Konkle, T. and Oliva, A. (2011). Canonical visual size for real-world objects, *J. Exp. Psychol. Hum. Percept. Perform.* **37**, 23–37. DOI:10.1037/a0020413.

Konkle, T. and Oliva, A. (2012a). A familiar-size Stroop effect: real-world size is an automatic property of object representation, *J. Exp. Psychol. Hum. Percept. Perform.* ***38***, 561–569. DOI:10.1037/a0028294.

Konkle, T. and Oliva, A. (2012b). A real-world size organization of object responses in occipitotemporal cortex, *Neuron* **74**, 1114–1124. DOI:10.1016/j.neuron.2012.04.036.

Lederman, S. J. and Klatzky, R. L. (1987). Hand movements: a window into haptic object recognition, *Cogn. Psychol.* **19**, 342–368. DOI:10.1016/0010-0285(87)90008-9.

Lederman, S. J. and Klatzky, R. L. (2009). Haptic perception: a tutorial, *Atten. Percept. Psychophys.* **71**, 1439–1459. DOI:10.3758/APP.71.7.1439s.

Lederman, S. J., Klatzky, R. L., Chataway, C. and Summers, C. (1990). Visual mediation and the haptic recognition of two-dimensional pictures of common objects, *Percept. Psychophys.* **47**, 54–64. DOI:10.3758/bf03208164.

Levine, S. M. and Schwarzbach, J. V. (2018). Cross-decoding supramodal information in the human brain, *Brain Struct. Funct.* **223**, 4087–4098. DOI:10.1007/s00429-018-1740-z.

Likova, L. T. (2012). Drawing enhances cross-modal memory plasticity in the human brain: a case study in a totally blind adult. *Front Hum Neurosci.* **6**, 44. DOI:10.3389/fnhum.2012.00044.

Loomis, J. M., Klatzky, R. L. and Giudice, N. A. (2013). Representing 3D space in working memory: spatial images from vision, hearing, touch, and language, in: S. Lacey and R. Lawson (Eds.), *Multisensory Imagery*, pp. 131–155. Springer Science + Business Media. DOI:10.1007/978-1-4614-5879-1_8.

Loomis, J. M., Klatzky, R. L. and Lederman, S. J. (1991). Similarity of tactual and visual picture recognition with limited field of view, *Perception* **20**, 167–177. DOI:10.1068/p200167.

Lopez, C. and Vaivre-Douret, L. (2021). Influence of visual control on the quality of graphic gesture in children with handwriting disorders, *Sci. Rep.* **11,** 23537. DOI:10.1038/s41598-021-02969-7

Magee, L. and Kennedy, J. (1980). Exploring pictures tactually, *Nature* **283,** 287–288. DOI:10.1038/283287a0.

Marquardt, C., Gentz, W. and Mai, N. (1999). Visual control of automated handwriting movements, *Exp. Brain Res*. **128**, 224–228. DOI:10.1007/s002210050841

Mazella, A., Albaret, J.-M. and Picard, D. (2018). The development of haptic processing skills from childhood to adulthood with using two-dimensional material, *Can. J. Exp. Psychol.* **72**, 48–57. DOI:10.1037/cep0000121.

Millar, S. (1975). Visual experience or translation rules? Drawing the human figure by blind and sighted children, *Perception* **4**, 363–371. DOI:10.1068/p040363.

Morimoto, T. (2020) The nature of haptic working memory capacity and its relation to visual working memory, *Multisensory Res.* **33**, 837–864. DOI:10.1163/22134808-bja10007.

Ottink, L., Hoogendonk, M., Doeller, C.F., Van der Geest, T. M. and Van Wezel R. J. A. (2021). Cognitive map formation through haptic and visual exploration of tactile city-like maps, *Sci. Rep.* **11,** 15254. DOI: 10.1038/s41598-021-94778-1.

Palmer, S. E., Rosch, E. and Chase, P. (1981). Canonical perspective and the perception of objects, in: J. Long and A. Baddeley (Eds.), *Attention and Performance IX,* pp. 135–151, Lawrence Erlbaum Associates, Hillsdale, NJ.

Pantelides, S. N., Kelly, J. W. and Avraamides, M. N. (2016). Integration of spatial information across vision and language, *J. Cogn.Psychol.* **28**, 171–185. DOI: 10.1080/20445911.2015.1102144.

Pathak, K., & Pring, L. (1989). Tactual picture recognition in congenitally blind and sighted children, *Appl. Cogn. Psychol.* **3**, 337–350. DOI:10.1002/acp.2350030405.

Picard, D. (2011). Impact of manual preference on directionality in children's drawings, *Laterality* **16**, 24–34. DOI:10.1080/13576500903140610.

Picard, D., Albaret, J.-M. and Mazella, A. (2013). Haptic identification of raisedline drawings by children, adolescents and yound adults: an age-related skill, *Haptics-e* **5**, 24–28.

Picard, D., Albaret, J.-M. and Mazella, A. (2014a). Haptic identification of raised-line drawing when categorical information is provided: a comparison between visually impaired and sighted children, *Psicológica* **35**, 277–290.

Picard, D. and Durand, K. (2005). Are young children's drawings canonically biased? *J. Exp. Child Psychol.* **90***,* 48–64. DOI:10.1016/j.jecp.2004.09.002.

Picard, D. and Lebaz, S. (2012). Identifying raised-line drawings by touch: a hard but not impossible task, *J. Vis. Impair. Blind.* **106**, 427–431. DOI:10.1177/0145482X1210600705.

Picard, D., Martin, P. and Tsao, R. (2014b). IPads at school? A quantitative comparison of elementary schoolchildren's pen-on-paper versus finger-on-screen drawing skills, *J. Educ. Comput. Res.* **50**, 203–212. DOI:10.2190/EC.50.2.c.

Picard, D. and Vinter, A. (2005). Development of graphic formulas for the depiction of familiar objects, *Int. J. Behav. Dev.* **29***,* 418–432. DOI:10.1177/01650250500206117.

Revesz, G. (1950). *Psychology and Art of the Blind*. Longmans Green, London.

Symmons, M. A., Richardson, B. L. and Wuillemin, D. B. (2004). Active versus passive touch: superiority depends more on the task than the mode, in: *Touch, Blindness, and Neuroscience*, S. Ballesteros and M. A. Heller, (Eds.), pp. 179–185, Universidad Nacional de Educacion a Distancia, Madrid.

Szubielska, M. (2014). Strategies for constructing spatial representations used by blind and sighted subjects, *Studia Psychol.* **56**, 273–285.

Szubielska, M., Niestorowicz, E. and Marek, B. (2016). Drawing without eyesight. Evidence from congenitally blind learners, *Roczniki Psychologiczne/Ann. Psych.* **19**, 659–680. DOI:10.18290/rpsych.2016.19.4-2en.

Szubielska, M. and Wojtasiński, M. (2021). Canonical size in haptic drawings, *Perception* **50**, 97–100. DOI:10.1177/0301006620983697.

Szubielska, M., Szewczyk, M, and Möhring, W. (2021). Differences in adults' spatial scaling based on visual or haptic information, *Cogn Process*. DOI:10.1007/s10339-021-01071-0.

Szubielska, M., Wojtasiński, M., Biedroń, K., Bobel, M. and Chudziak, N. (2020). Canonical size for real-word objects in drawings performed under haptic control, *Roczniki Psychologiczne/Ann. Psych.* **23**, 191–200. DOI:10.18290/rpsych20232-5.

Szubielska, M. and Zabielska-Mendyk. E. (2018). Memorizing 2D tactile right-angle-shapes by congenitally blind and sighted adults, *Studia Psychol.* **60**, 137–149. DOI: 10.21909/SP.2018.03.758.

Theurel, A., Witt, A., Claudet, P., Hatwell, Y. and Gentaz, E. (2013). Tactile picture recognition by early blind children: the effect of illustration technique, *J. Exp. Psychol. Appl.* **19**, 233–240. DOI:10.1037/a0034255.

Thompson, L. J., Chronicle, E. P. and Collins, A. F. (2003). The role of pictorial convention in haptic picture perception, *Perception* **32**, 887–893. DOI:10.1068/p5020.

Vanlierde, A. and Wanet-Defalque, M. C. (2004). Abilities and strategies of blind and sighted subjects in visuo-spatial imagery, *Acta Psychol.* **116**, 205–222. DOI: 10.1016/j.actpsy.2004.03.001.

van Sommers, P. (1984). *Drawing and Cognition: Descriptive and Experimental Studies of Graphic Production Processes*. Cambridge University Press, Cambridge, England.

Vinter, A., Bonin, P. and Morgan, P. (2018). The severity of the visual impairment and practice matter for drawing ability in children, *Res. Dev. Disabil.* **78**, 15–26. DOI:10.1016/j.ridd.2018.04.027.

Vinter, A., Orlandi, O. and Morgan, P. (2020). Identification of textured tactile pictures in visually impaired and blindfolded sighted children, *Front. Psychol.* **11**, 345. DOI:10.3389/fpsyg.2020.00345.

Wijntjes, M. W. A., Lienenm, T., van Verstijnen, I. M. and Kappers, A. M. L. (2008). The influence of picture size on recognition and exploratory behaviour in raised-line drawings, *Perception* **37**, 602–614. DOI:10.1068/p5714.

Wolbers, T., Klatzky, R. L., Loomis, J. M., Wutte, M. G. and Giudice, N. A. (2011). Modality-independent coding of spatial layout in the human brain, *Curr. Biol.* **21**, 984–989. DOI: 10.1016/j.cub.2011.04.038.

Yoshida, T., Yamaguchi, A., Tsutsui, H. and Wake, T. (2015). Tactile search for change has less memory than visual search for change, *Atten. Percept. Psychophys.* **77**, 1200–1211. DOI:10.3758/s13414-014-0829-6.

Figure captions

Figure 1. Example usage of a Swedish raised line drawing.

Figure 2. Examples of drawings rated by the raters as 0, 1, and 2 (from the left) in the dimension of recognisability (A), level of detail (B), morphology (C), and topology (D). All presented drawings were performed in the paper, blindfolded condition. (For greater visibility, all drawings were cropped from A4 format.)

Figure 3. Drawn size as a function of perceptual condition and size rank. Error bars indicate ±1 SE.

Figure 4. Drawing quality in terms of level of detail (A), morphology (B), and topology (C), recognisability (D), and the global quality index – being a fusion of local criteria (E) as a function of perceptual condition and material. Error bars indicate ±1 SE. * = statistically significant (for ps < .05); ** = statistically significant (for ps < .01); *** = statistically significant (for ps < .001); NS = non-significant.

Figure 5. Examples of drawings of a dog and a house produced in each drawing condition: sighted, paper (A), blindfolded, paper (B), sighted, foil (C), and blindfolded, foil (D) by the same participant.

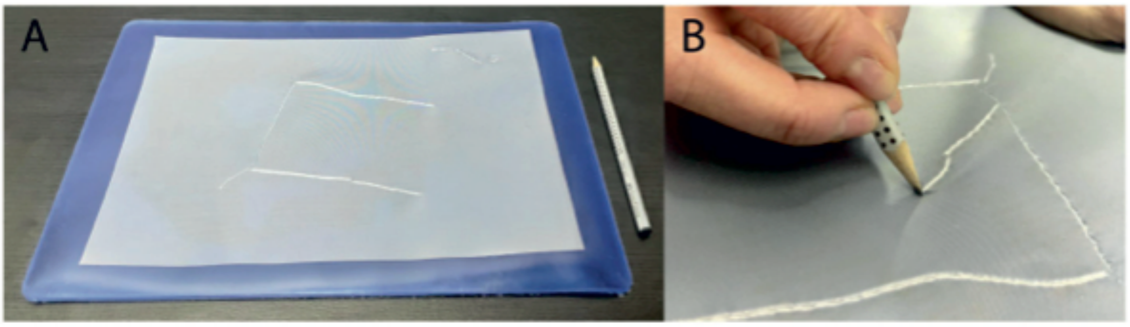

Figure 1. Materials used in the study — special rubber mat, foil, pencil (A) and example usage of a Swedish raised line drawing kit (B).

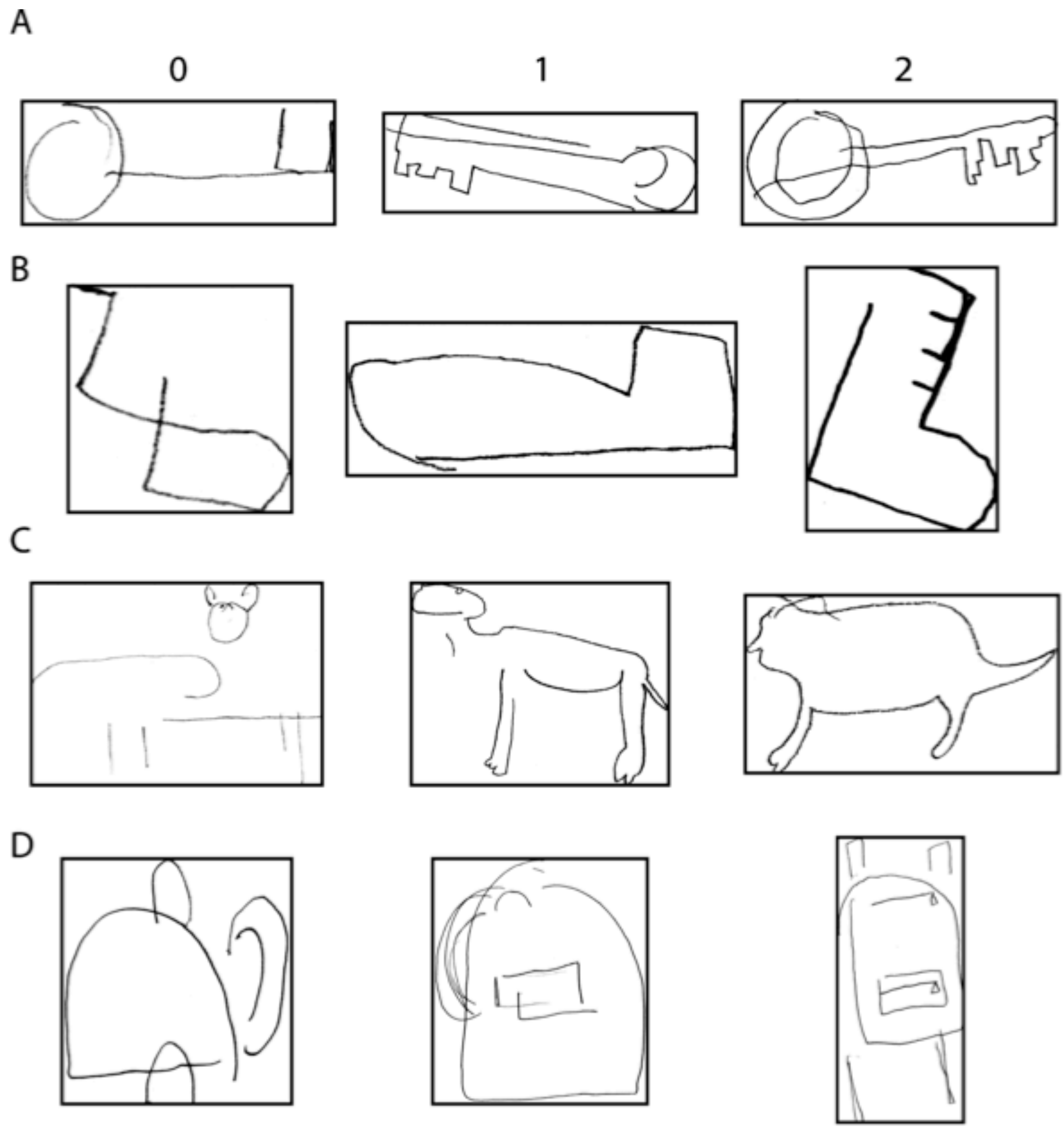

Figure 2. Examples of drawings rated by the raters as 0, 1 and 2 (from the left) in the dimension of recognisability (A), level of detail (B), morphology (C) and topology (D). All presented drawings were performed in the paper, blindfolded condition. (For greater visibility, all drawings were cropped from A4 format.).

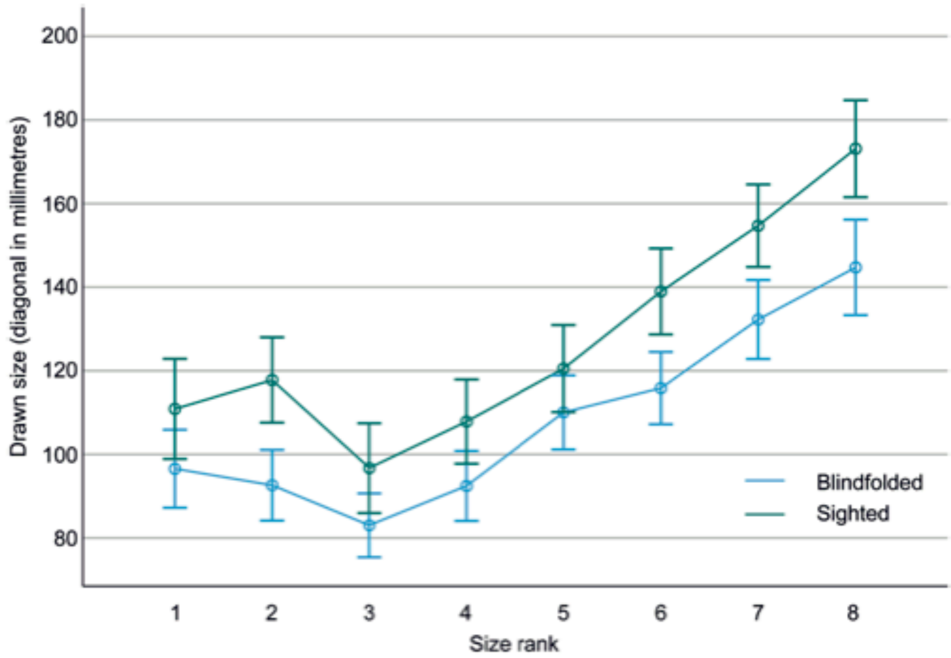

Figure 3. Drawn size as a function of perceptual condition and size rank. Error bars indicate ±1 SE.

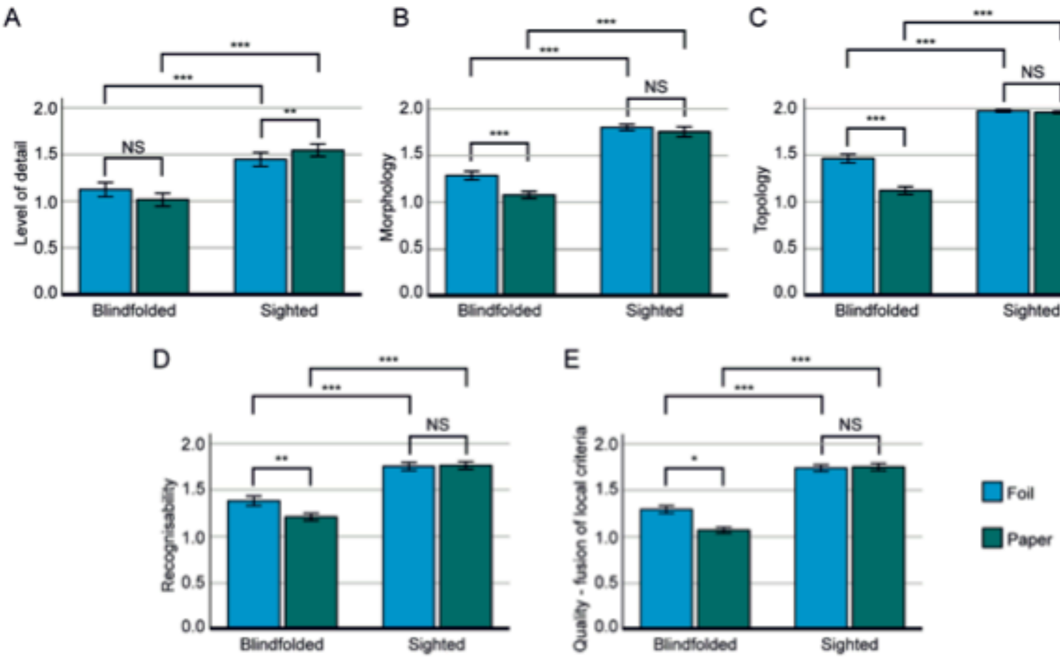

Figure 4. Drawing quality in terms of level of detail (A), morphology (B) and topology (C), recognisability (D) and the global quality index — being a fusion of local criteria (E) as a function of perceptual condition and material. Error bars indicate ±1 SE. *, statistically significant (for $ps < 0.05$); **, statistically significant (for $ps < 0.01$); ***, statistically significant (for $ps < 0.001$); NS = non-significant.

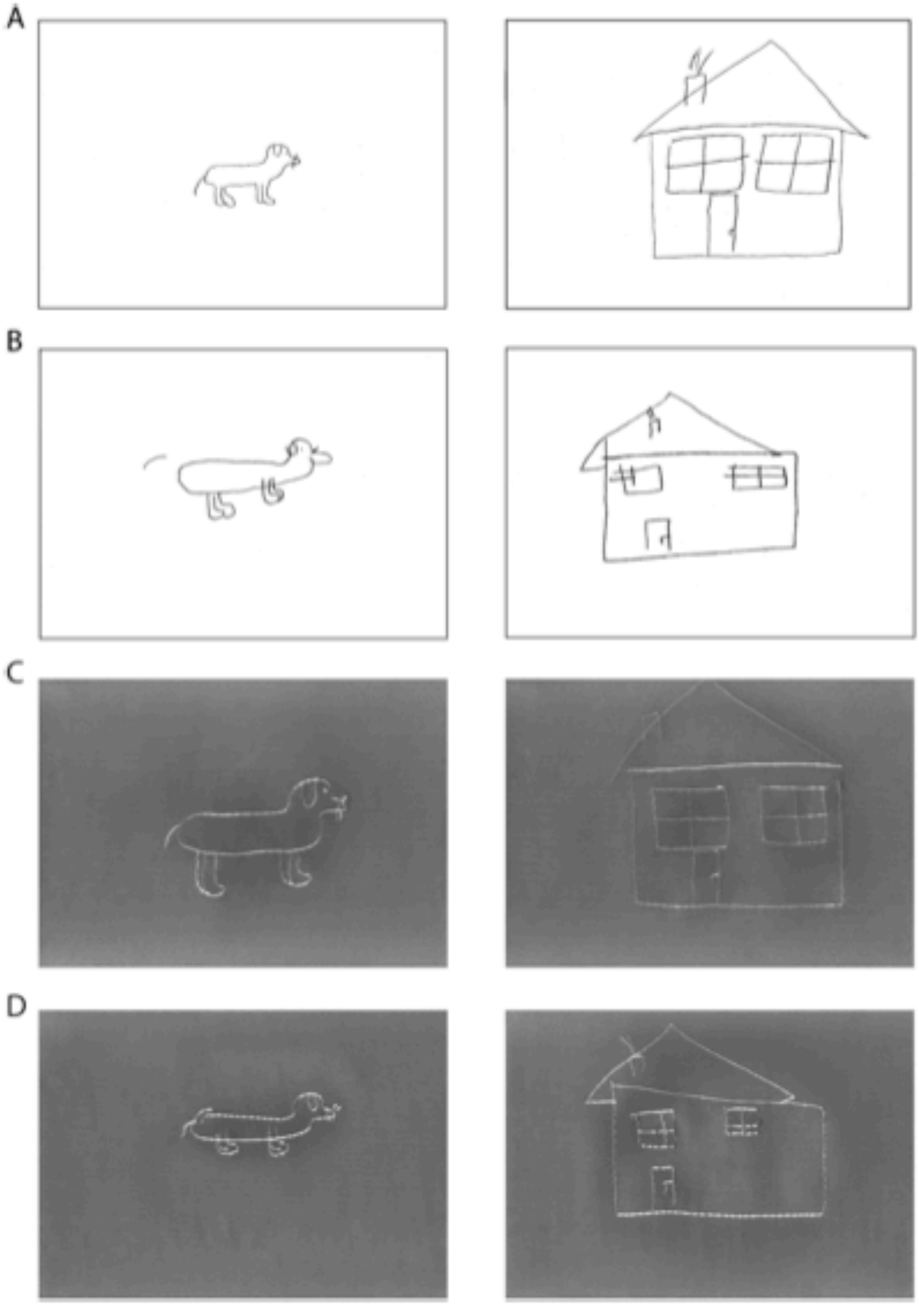

Figure 5. Examples of drawings of a dog and a house produced in each drawing condition: sighted, paper (A), blindfolded, paper (B), sighted, foil (C) and blindfolded, foil (D) by the same participant.