

# Grasping with the eyes of your hands: Haptics and vision modulate hand preference

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**Abstract** Right-hand preference has been demonstrated for visually guided reaching and grasping. Grasping, however, requires the integration of both visual and haptic cues. To what extent does vision influence hand preference for grasping? Is there a hand preference for haptically guided grasping? Two experiments were designed to address these questions. In Experiment 1, individuals were tested in a reaching-to-grasp task with vision (sighted condition) and with haptics (blindfolded condition). Participants were asked to put together 3D models using building blocks scattered on a tabletop. The models were simple, composed of ten blocks of three different shapes. Starting condition (Vision-First or Haptics-First) was counterbalanced among participants. Right-hand preference was greater in visually guided grasping but only in the Vision-First group. Participants who initially built the models while blindfolded (Haptics-First group) used their right hand significantly less for the visually guided portion of the task. To investigate whether grasping using haptics modifies subsequent hand preference, participants received an additional haptic experience in a follow-up experiment. While blindfolded, participants manipulated the blocks in a container for 5 min prior to the task. This additional experience did not affect right-hand use on visually guided grasping but had a robust effect on haptically guided grasping. Together, the results demonstrate first that hand preference for grasping is influenced by both vision and haptics, and second, they highlight how flexible this preference could be when modulated by haptics.

**Keywords** Multisensory · Visuomotor · Touch · Bimanual · Handedness

## Introduction

Many studies have investigated hand preference during visually guided grasping. Tasks that require the use of one hand to pick up an object (i.e., unimanual) have shown that participants will reach and grasp with the hand closest to the object (i.e., ipsilateral; e.g., Annett et al. 1979; Bryden et al. 1994). When the target is located at the midline, however, participants prefer their right hand to pick it up (Bryden et al. 2000; Gabbard and Rabb 2000). This right-hand preference for grasping has been observed when picking up different objects: geometric 3D shapes (Gabbard et al. 2003), cards (Bishop et al. 1996; Calvert and Bishop 1998; Carlier et al. 2006), toys (Bryden and Roy 2006; Sacrey et al. 2012), tools (Mamolo et al. 2004, 2005, 2006), or blocks (Gonzalez et al. 2007; Stone et al. 2013), and it has also been shown in studies that employ bimanual tasks (Fagard and Marks 2000; Stone et al. 2013). An example of a bimanual task is the block-building task, where participants are asked to reproduce an exact copy of a given model using the numerous blocks available from a tabletop. The interaction of the two hands is essential in order to complete the task. Using this task, a marked right-hand preference has been shown, even for contralateral grasps (Gonzalez et al. 2007; Stone et al. 2013). However, all these previous studies have documented hand preference for grasping when vision is available, that is when the movement is guided by vision. To what extent does vision contribute to this right-hand preference?

To our knowledge, no study has investigated hand preference for grasping without vision. Kinematic studies have

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shown differences in hand use when vision is occluded: Peak velocities are lower, maximum grip apertures are larger, overall movement time is longer (Connolly and Goodale 1999; Kritikos et al. 2002; Pettypiece et al. 2010; Schettino et al. 2003; Wings et al. 2003). Even when vision of *one* eye is occluded, individuals reach slower and grasp with less accuracy (Melmouth et al. 2009). These studies emphasize the critical role that vision plays during reaching and grasping movements. Perhaps, it should not be surprising that in the absence of vision, hand preference would also be affected. Studies investigating object recognition without vision (i.e., with hapsis) have shown a left-hand advantage during haptic discrimination (Benton et al. 1978; De Renzi et al. 1969; Fagot et al. 1993; Milner and Taylor 1972; Riege et al. 1980; Tomlinson et al. 2011). For example, Fagot et al. (1993) presented participants with a shape identification task and found that the left hand was better at identifying the correct shape. Similarly, Tomlinson et al. (2011) asked blindfolded participants to lift a dowel with a textured knob and to rate the “coarseness” of the knob on a 3-point scale. After an equivalent number of lifts with each hand, they found that participants were significantly more accurate with their left hand. These studies demonstrate the left-hand advantage during haptic recognition. With this information in mind, one might ask what hand would be used when trying to pick up an object in the dark (e.g., in the middle of the night). Would it be the hand that is used more often for grasping (i.e., right hand) or the one that is more proficient for haptic object recognition (i.e., left hand)? Two experiments were conducted to address these questions.

In both experiments, participants were tested on the block-building task (Gonzalez et al. 2007; Stone et al. 2013) and hand preference for grasping was documented. In Experiment 1, participants built models sighted and blindfolded (counterbalanced). In Experiment 2, participants received an additional haptic experience (i.e., blindfolded) by manipulating the blocks in a container before completing the task as in Experiment 1.

## Methods and procedures

### Experiment 1: grasping with and without vision

#### Participants

Thirty-eight self-reported right-handed individuals from the University of Lethbridge, between the ages of 18 and 35, participated. Nineteen (eight males) and nineteen (four males) were assigned to the Vision-First and the Hapsis-First groups, respectively. No gender differences were found previously in this task (Gonzalez and Goodale 2009), so no

action was taken to balance the genders. The studies were approved by the local ethics committee, and all participants gave written informed consent before participating in the study. Participants were naïve to the purposes of the study.

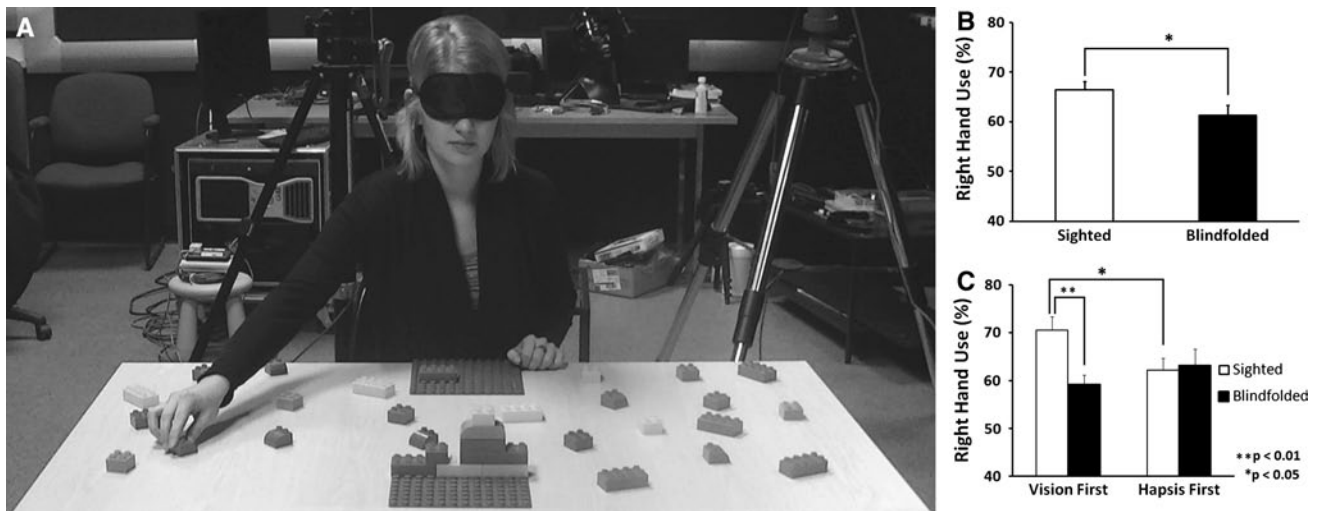
#### Apparatus and stimuli

**Handedness Questionnaire** A modified version of the Edinburgh (Oldfield 1971) and Waterloo (Brown et al. 2006) Handedness Questionnaires were given to all participants (see Stone et al. 2013 for a full version of the questionnaire) at the end of the block-building task. This version of the questionnaire included questions on hand preference for 22 different tasks. Participants had to rate which hand they prefer on a scale of +2 (right always), +1 (right usually), 0 (equal), −1 (left usually), or −2 (left always). Each response was scored as (2, 1, −1, or −2), and a total score was obtained by adding all values. Possible scores range from +44 for exclusive right-hand use to −44 for exclusive left-hand use.

**Block-building task** A total of five models built with MEGA BLOKS<sup>®</sup> were used for the experiment. The blocks ranged in size from 3.1 L × 3.1 W × 2.0 cm H to 6.3 L × 3.1 W × 2.0 cm H. Each model contained ten blocks of various colors and three types of shapes. The blocks that made up the models were scattered on a table with a working space of 122 L × 122 W × 74 cm H 70 L × 122 W × 74 cm H. A strip of clear tape was used to divide the workspace in half, and an equal number of pieces were distributed onto the left and right sides.

#### Procedures

Participants were comfortably seated centrally in front of a table and were instructed to replicate five different models. Participants started the task either sighted (Vision-First group) or blindfolded (by using a blindfold; Hapsis-First group). In the Vision-First group, the 50 blocks that made all five models were available on the tabletop. One model at a time, participants replicated two 10-piece models sighted followed by three 10-piece models blindfolded. In the Hapsis-First group, only 30 blocks were available on the tabletop. Participants were asked to replicate three models blindfolded. After the completion of the three models, the investigator placed back all 50 blocks and allowed the participant to build two models while sighted. This procedure was done to maintain consistency in the number of blocks that participants would use to build each model between the Vision- and Hapsis-First groups. In both conditions, the 10-piece model to be replicated was placed on a building plate directly in front of the participant within arms' reach. Participants were instructed to replicate the model as quickly and accurately as possible on a second



**Fig. 1 a** Photograph of a participant engaging in the building task in Experiment 1. Please note that the participant is blindfolded and cannot see her working space. **b** This graph demonstrates the average right-hand use in percentage for all participants in both the sighted and blindfolded conditions. Note the significant difference in

right-hand use between these conditions. **c** This graph demonstrates right-hand use in percentage for starting condition: Vision-First and Hapsis-First. Both groups are divided into sighted (white bars) and blindfolded (black bars) conditions. Note the significant differences within the Vision-First group and between the sighted conditions



**Fig. 2 a** Photograph of a participant from Experiment 2 manipulating the blocks in a container prior to the building task. **b** This graph demonstrates the average right-hand use in percentage for all participants in both the sighted and blindfolded conditions. Note the significant difference in right-hand use between these conditions.

**c** This graph demonstrates right-hand use in percentage for starting condition: Vision-First and Hapsis-First. Both groups are divided into sighted (white bars) and blindfolded (black bars) conditions. Note the significant differences within both starting conditions and between the sighted conditions

building plate positioned in front of them (see Figs. 1, 2). No other information was given to the participants. Following the replication of the model, both models were removed and a different model to be replicated was provided. The same five models were used for all participants. Starting condition (Vision-First/Hapsis-First) was counterbalanced, and model presentation order was randomized between participants. The task was recorded on a JVC HD Everio

video recorder approximately 160 cm away from the individual with a clear view of the tabletop, building blocks, and participants’ hands.

*Data analysis*

All recorded videos were analyzed offline. Each grasp was recorded as a left- or right-hand grasp in the participants’

ipsilateral or contralateral space. The total number of grasps was calculated to determine a percent for right-hand use (number of right grasps/total number of grasps  $\times$  100). The time in which it took participants to construct each model was recorded on a stopwatch and reported in seconds. Data were assessed, and no violations for homogeneity of variance and normalcy were found prior to analysis. Partial eta-squared values were used to show effect size (ES).

## Results

Means and standard error are reported in percentage and seconds.

**Handedness Questionnaire** All participants self-reported as right handers, and this was confirmed by the Handedness Questionnaire. Overall, the average score on the questionnaire was +30.5 ( $\pm$ 1.0 SE; range +15 to +40) out of the maximum possible score of +44/–44. The Vision-First group scored an average of +31.0 ( $\pm$ 1.6 SE; range +15 to +40), and the Hapsis-First group scored an average of +30.0 ( $\pm$ 1.1 SE; range +18 to +37). The difference between the two groups was not significant ( $p = 0.6$ ).

**Hand use for grasping** Analysis using a 2 (visual availability)  $\times$  2 (starting condition) repeated-measures ANOVA was performed on the percentage of right-hand use for grasping during the task. Visual availability (sighted, blindfolded) was a within-subject factor and starting condition (Vision-First, Hapsis-First) a between-subject factor. Overall, we found a main effect of visual availability ( $F(1, 36) = 6.4$ ;  $p = 0.01$ ; ES = 0.151) as shown in Fig. 1b. Please note that during the blindfolded condition, participants could only use their sense of touch (hapsis) to construct the models. Participants used their right hand significantly more to grasp the blocks when they were sighted ( $66.3 \pm 1.8$  %) than when they were blindfolded ( $61.2 \pm 2.1$  %). There was no main effect of starting condition ( $F(1, 36) = 0.4$ ;  $p > 0.1$ ; ES = 0.01). However, the interaction between visual availability and starting condition was significant ( $F(1, 36) = 9.1$ ;  $p = 0.005$ ; ES = 0.203; see Fig. 1c). Follow-up analysis (pairwise  $t$  test) revealed that in the Vision-First group, right-hand use significantly decreased when participants were blindfolded ( $t(18) = 4.6$ ;  $p < 0.001$ ), yet this was not the case in the Hapsis-First group ( $p > 0.1$ ). In addition, when comparing both sighted conditions, the right hand was used significantly less in the Hapsis-First group ( $t(36) = 2.3$ ;  $p < 0.05$ ; independent-samples  $t$  test). Figure 1c shows that even though in both groups participants were sighted, right-hand use was  $70.5 \pm 2.8$  % in the Vision-First group but only  $62.2 \pm 2.8$  % in the Hapsis-First group. In none of the conditions did hand use decrease to chance level [revealed by performing a pairwise  $t$  test on the values of right-hand

use for grasping against 50; Vision-First: ( $t(18) = 3.82$ ;  $p = 0.001$ ; Hapsis-First:  $t(18) = 3.84$ ;  $p = 0.001$ ]. In other words, regardless of the sensory domain being utilized, a right-hand preference for grasping remained. **Number of grasps:** To investigate whether the number of grasps executed between the sighted and blindfolded conditions differed, we conducted a repeated-measures ANOVA with visual availability (sighted, blindfolded) as a within-subject factor and starting condition as between-subject factor. Results showed a main effect of visual availability: Participants executed more grasps per model while blindfolded (13.6) when compared with when they were sighted (10.4;  $F(1, 36) = 58.1$ ;  $p < 0.0001$ ; ES = 0.61). There was no main effect of starting condition ( $F(1, 36) = 0.007$ ;  $p = 0.93$ ) or significant interaction ( $F(1, 36) = 0.002$ ;  $p = 0.96$ ).

**Build times for models** Overall, participants were faster at building models while sighted than while blindfolded ( $F(1, 36) = 44.8$ ;  $p < 0.001$ ; ES = 0.886). During the sighted trials, it took participants in the Vision-First group on average  $29.7 \pm 2.0$  s to complete one model, whereas it took participants in the Hapsis-First group on average  $27.3 \pm 1.4$  s to complete one model. These values were not significantly different from one another ( $p = 0.3$ ). During the blindfolded trials, participants in the Vision-First group completed one model on average  $142.3 \pm 9.5$  s, whereas participants in the Hapsis-First group completed one model on average  $114.1 \pm 9.2$  s. There was a significant difference between these two values ( $t(36) = 2.1$ ;  $p < 0.05$ ; independent-samples  $t$  test).

## Discussion

The results showed a decrease in right-hand use for haptically guided grasping. Participants used their right hand less often to grasp the blocks when blindfolded than when they were sighted. This change, however, was modulated by starting condition. Participants in the Vision-First group used their right hand 70.5 % of the time while sighted, but once they were blindfolded, right-hand use decreased significantly to 59.2 %. On the other hand, participants in the Hapsis-First group demonstrated similar hand preference regardless of visual condition (62.2 % while sighted; 63.2 % while blindfolded). One puzzling finding of these results was the significant decrease ( $\sim 8$  %) in right-hand use in the Hapsis-First group when participants were sighted. In other words, even though participants were locating the pieces and guiding their movements using vision, they used their right hand less often if they have completed the hapsis portion of the task first. Could a brief haptic experience modulate subsequent hand preference for grasping? We tested this suggestion in Experiment 2.

## Experiment 2: grasping with an added haptic experience

### Participants

Thirty-eight self-reported right-handed individuals from the University of Lethbridge, between the ages of 18 and 35, participated. Nineteen (five males) and nineteen (six males) were assigned to the Vision-First and the Hapsis-First groups, respectively. These studies were approved by the local ethics committee, and all participants gave written informed consent before participating in the study. Participants were naïve to the purposes of the study.

### Apparatus and stimuli

All the display material and equipment were the same as in Experiment 1, except that one model was added to the sighted condition. Thus, participants built three models sighted and three models blindfolded.

### Procedures

All procedures were the same as Experiment 1 except that participants were blindfolded and asked to manipulate the MEGA BLOKS<sup>®</sup> in a container (42 L × 30 W × 30 cm H; see Fig. 2a) for 5 min prior to starting the block-building task.

### Data analysis

Data analysis was the same as Experiment 1.

### Results

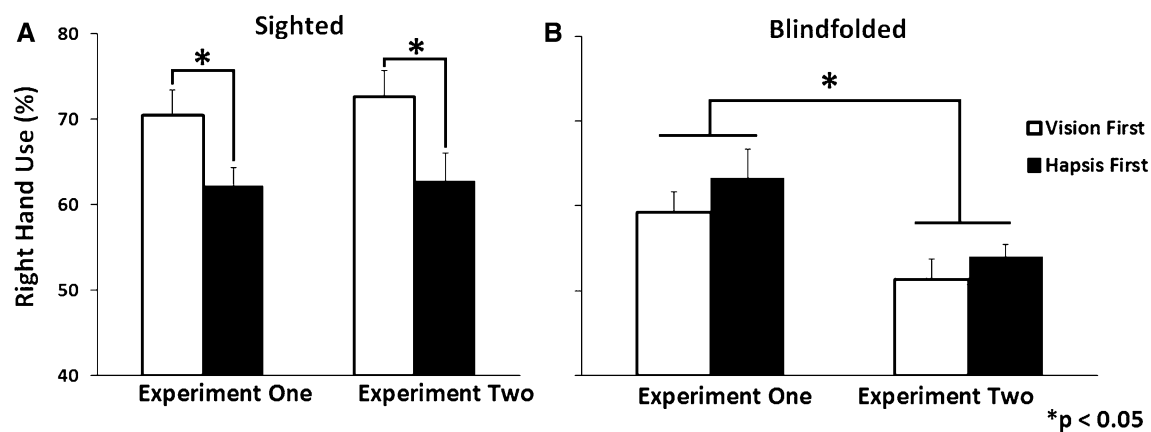
Means and standard error are reported in percentage and seconds.

**Handedness Questionnaire** The average score on the Handedness Questionnaire was +33.5 ( $\pm 1.1$  SE; range: +20 to +44) out of a total possible +44/−44. The Vision-First group scored an average of +32.5 ( $\pm 1.5$  SE; range: +20 to +42), and the Hapsis-First group scored an average of +34.5 ( $\pm 1.7$  SE; range: +23 to +44). The difference between the two groups was not significant ( $p = 0.3$ ).

**Hand use for grasping** Analysis using a 2 (visual availability) × 2 (starting condition) repeated-measures ANOVA was performed on the percentage of right-hand use for grasping during the task. Visual availability (sighted, blindfolded) was a within-subject factor and starting condition (Vision-First, Hapsis-First) a between-subject factor. Overall, we found a main effect of visual availability, as shown in Fig. 2b. Participants used their right hand significantly more

to grasp the blocks while sighted ( $67.7 \pm 2.3$  %) than while blindfolded ( $52.6 \pm 1.9$  %). There was no main effect of starting condition ( $F(1, 36) = 1.4$ ;  $p > 0.1$ ; ES = 0.039) but once again, the interaction between visual availability and starting condition was significant ( $F(1, 36) = 7.3$ ;  $p = 0.01$ ; ES = 0.170). Follow-up analysis (independent-samples  $t$  test) showed that, as in Experiment 1, when comparing both sighted conditions, the right hand was used significantly less in the Hapsis-First condition ( $t(36) = 2.1$ ;  $p < 0.05$ ). In contrast to Experiment 1, however, the reduction in right-hand use when blindfolded was significant regardless of starting condition ( $t(18) = 5.7$ ;  $p < 0.001$ ;  $t(18) = 3.2$ ;  $p < 0.01$ , for the Vision-First and Hapsis-First groups, respectively). The prior haptic experience of touching the blocks blindfolded, thus affected hand preference within its own sensory domain. In contrast to Experiment 1, in Experiment 2, hand use did decrease to chance level, but only for the Vision-First group. Once again, we performed a pairwise  $t$  test analysis on the values of right-hand use for grasping against 50. The results show that for the Vision-First group, these values were not significantly different ( $t(18) = 0.58$ ;  $p = 0.56$ ). However, for the Hapsis-First group, the values were significantly different from 50 % ( $t(18) = 2.6$ ;  $p = 0.015$ ). These results suggest that the brief haptic experience had a different effect on hand use with hapsis depending on the starting condition. If they started with vision, right-hand use was reduced to chance. **Number of grasps:** Again, to investigate whether the number of grasps executed between the sighted and blindfolded conditions differed, we conducted a repeated-measures ANOVA with visual availability (sighted, blindfolded) as a within-subject factor and starting condition as between-subject factor. Results showed a main effect of visual availability: Participants executed more grasps per model while blindfolded (14.1) when compared with when they were sighted (10.3;  $F(1, 36) = 87.1$ ;  $p < 0.001$ ; ES = 0.708). There was no main effect of starting condition ( $F(1, 36) = 0.211$ ;  $p = 0.64$ ) or significant interaction ( $F(1, 36) = 0.92$ ;  $p = 0.34$ ).

**Build times for models** Overall, participants were faster at building models while sighted than while blindfolded ( $F(1, 36) = 68.0$ ;  $p < 0.001$ ; ES = 0.901). During the sighted trials, it took participants in the Vision-First group approximately  $27.6 \pm 1.2$  s to complete one model, whereas it took participants in the Hapsis-First group approximately  $26.2 \pm 1.3$  s to complete one model. These values were not significantly different from one another ( $p = 0.4$ ). During the blindfolded trials, participants in the Vision-First group completed one model on average  $139.6 \pm 10.0$  s, whereas participants in the Hapsis-First group completed one model on average  $141.4 \pm 8.5$  s. Again, these values were not significantly different ( $p = 0.8$ ).



**Fig. 3 a** This graph demonstrates right-hand use in percentage for Experiments 1 and 2 while sighted. *White bars* represent the Vision-First groups. *Black bars* represent the Hapsis-First groups. Note the significant reduction in right-hand use for the Hapsis-First group. **b** This graph demonstrates right-hand use in percentage for Experi-

ments 1 and 2 while blindfolded. *White bars* represent the Vision-First groups. *Black bars* represent the Hapsis-First groups. Note the significant reduction in right-hand use in both groups during Experiment 2

**Comparison between Experiment 1 and Experiment 2** To gain a better understanding of how the added haptic experience affected hand use, we directly compared Experiments 1 and 2. Visual availability (sighted, blindfolded) was a within-subject factor, and starting condition (Vision-First, Hapsis-First) and experience (additional haptic experience, no additional haptic experience) were between-subject factors. The repeated-measures ANOVA showed a main effect of visual availability ( $F(1, 74) = 43.3$ ;  $p < 0.001$ ). Participants used their right hand significantly more when they were sighted ( $67.0 \pm 1.4\%$ ) than when they were blindfolded ( $56.9 \pm 1.2\%$ ). There was no main effect of starting condition or experience, but there was a significant interaction between visual availability and starting condition ( $F(1, 74) = 16.2$ ;  $p < 0.001$ ). While sighted, the Hapsis-First group used their right hand significantly less ( $62.5 \pm 2.0\%$ ) than the Vision-First group ( $71.5 \pm 2.0\%$ ). This interaction is illustrated in Fig. 3a. There was also a significant interaction between visual availability and experience ( $F(1, 74) = 10.4$ ;  $p = 0.002$ ). Follow-up analysis (independent-samples  $t$  test) revealed that this interaction was due to the significant reduction in right-hand use during the blindfolded condition when participants had additional haptic experience with the blocks ( $t(74) = -3.3$ ;  $p < 0.05$ ). If participants manipulated the blocks in the container before starting the building task (Experiment 2), they used their right hand  $52.6 \pm 1.7\%$  of the time (see Fig. 3b). Without this experience (Experiment 1), participants used their right hand  $61.2 \pm 1.7\%$  of the time. This was regardless of starting condition as the three-way interaction (visual availability, starting condition, and experience) was not significant ( $F(1, 74) = 0.001$ ;  $p = 0.9$ ).

## General discussion

The series of experiments assessed hand use for grasping with and without vision. Many studies have investigated the kinematics of grasping when vision is occluded (e.g., Connolly and Goodale 1999; Kritikos et al. 2002; Pettypiece et al. 2010; Schettino et al. 2003; Wings et al. 2003), but none, to our knowledge, have assessed whether hand preference is affected when vision is prevented. Participants were asked to replicate 3D block models from a tabletop containing numerous blocks, while sighted and while blindfolded. Hand use for grasping the blocks was documented. The results of Experiment 1 showed that when blindfolded, participants used their right hand significantly less than when they were sighted. Interestingly, starting condition played a significant role in the modulation of hand use. Participants that started the task with vision demonstrated a significant decrease in right-hand use when blindfolded. When compared with participants that started the task with vision, participants that started the task blindfolded displayed a significant decrease in right-hand use while sighted. Experiment 2 investigated the possibility that the haptic experience of touching the blocks without vision had influenced hand use during the sighted portion of the task. To this end, blindfolded participants manipulated the blocks in a container prior to the building task. This haptic experience did not affect right-hand use while sighted regardless of starting condition. The experience, however, significantly affected hand use while blindfolded: When compared to Experiment 1, participants used their right hand less often in both starting conditions. Together, these results demonstrate first that hand preference for grasping is influenced by vision, and second, they highlight

how flexible this preference could be when modulated by hapsis.

The results demonstrated a decrease in right-hand preference for haptically guided grasping when compared with visually guided grasping. Numerous studies have shown a right-hand preference for grasping during uni- and bimanual tasks (Bishop et al. 1996; Bryden and Roy 2006; Calvert and Bishop 1998; Carlier et al. 2006; Gabbard et al. 2003; Mamolo et al. 2004, 2005, 2006; Sacrey et al. 2012). In the course of our investigations using the block-building task, we have shown the robustness of this preference in right handers and even in some left handers (Gonzalez et al. 2007; Gonzalez and Goodale 2009; Stone et al. 2013). The reduction in right-hand use when vision is unavailable shown in the current study is therefore noteworthy. We consider two possible explanations for this reduction. First, studies have shown a left-hand advantage for object discrimination when guided by hapsis (Benton et al. 1978; De Renzi et al. 1969; Fagot et al. 1993; Milner and Taylor 1972; Riege et al. 1980; Squeri et al. 2012; Tomlinson et al. 2011). Squeri et al. (2012), for example, found that during a passive discrimination haptic task, right handers performed better when they used their left hand. In another haptic discrimination task, Tomlinson et al. (2011) found that the left hand was more specialized for identifying the haptic-related properties of the object (e.g., texture). Based on these studies, it is possible to speculate that when grasping for an object that you cannot see, one would resort to the hand with greater discriminatory abilities (i.e., the left hand). In the current experiments, there was a significant decrease in right-hand use when participants were blindfolded (and an even greater decrease with prior haptic manipulation). It is possible that left-hand use for grasping increased because it was being recruited for the discrimination of the blocks.

A second factor that could have contributed to the reduction in right-hand use for haptically guided grasping is the difference in spatial demands between sighted and blindfolded conditions. Arguably, understanding the spatial characteristics of the environment would be more demanding without vision. In a review on spatial representations, Thinus-Blanc and Gaunet (1997) assert that perceiving the environment without vision takes significantly more cognitive resources than with vision. Millar and Al-Attar (2005) tested participants on a spatial task with and without vision. Participants were presented with a tactile map and asked to remember the location of six landmarks. They traced the map with their right index finger under both conditions. Participants were significantly more accurate when using vision. The authors suggested that spatial demands of the task had a greater effect on haptic condition. A fundamental aspect of the block-building task used in the current experiments is to recognize the spatial arrangement of the blocks

on the tabletop and to construct a spatial map in which to guide their movements. This would be particularly relevant when participants are blindfolded. With these increased spatial demands, it is possible that both hands would be recruited more in order to gain a better understanding of space. Furthermore, it has been suggested that the right hemisphere, which controls movement of the left hand, is responsible for encoding the spatial aspects of the environment (Bartolomeo 2006; Serrien et al. 2006; Vallar 1997; Vogel et al. 2003). One could speculate that increased spatial demands would lead to an increase in left-hand use. Future experiments could investigate whether hand use changes as a function of spatial demands with and without vision.

The next finding, present in both experiments, was the interaction between starting condition and visual availability. That is, in the Vision-First group right-hand use decreased in the subsequent blindfolded part of the task. However, hand use in the Hapsis-First group was not significantly different between the vision and blindfolded condition. This was due to the 10 % reduction in right-hand use during the sighted portion of the task. This is intriguing as in both groups (Vision-First, Hapsis-First), participants were building the same models, performing the task with full vision, and the only difference was that one group had completed the blindfolded condition first. This finding suggests that haptically guided grasping has a powerful effect on subsequent hand use behavior. Other studies have also found interactions between visual and haptic modalities. For example, Wismeijer et al. (2012) found that information in the haptic domain is transferred more readily to the visual domain than vice versa. The authors suggest that learning between the senses depends on its direction (Wismeijer et al. 2012). It is possible that in our experiment, the increase in left-hand use during the haptic portion of the task influenced subsequent hand use in the visual domain. Our results align with Wismeijer and colleagues suggesting that learning can be unidirectional across sensory modalities. Other studies have also shown that information extracted in one sensory modality is later utilized by a different modality. Participants that had received experience identifying the properties of an object either by touch or vision were better at identifying the same property but in the other sensory domain (Förster 2011). This suggests that the initial focus of a task, whether it be in the visual or haptic domain, could be carried over into the next part of the task. Again, we could speculate that increased left-hand use during the haptic portion of the task carried over into the visual condition. The initial focus of the task also seemed to affect build times in the blindfolded condition. In Experiment 1, we found that participants were faster to complete the models if they had started the task with hapsis. That is, it took participants longer to build the models while

blindfolded if they had built the models while sighted first. This suggests that perhaps the visual experience interfered with the subsequent performance of building the models with haptics. Intriguingly, however, this was not found in the second experiment. Future studies investigating visual and haptic interactions that focus on performance time should examine the effects of starting condition on this variable.

Experiment 2 was designed to assess the possibility that touching the blocks blindfolded prior to the building task could lead to the increase in left-hand use seen during the visual condition in the Haptics-First group. Contrary to our prediction, we did not find this to be the case. When comparing Experiments 1 and 2, participants did not further reduce their right-hand use in the visual condition, and hand use between the two experiments was, in fact, virtually identical (Fig. 3a). It is possible that right-hand preference for grasping when vision is available could not reach lower levels (i.e., “floor effect”) and that is why the additional haptic experience did not further decrease its use. The results suggest that other factors, besides the haptic feedback, modulate hand preference across the two sensory modalities. In other words, simply “feeling” the blocks while blindfolded was not sufficient to change hand use in a different sensory domain (vision). Transfer of information between sensory domains has been shown in some studies (Bratzke et al. 2012; Gottfried et al. 1977; Held 2009; Norman et al. 2008; Volcic et al. 2010), but not in others. For example, Newell et al. (2001) showed that participants perform worse when transferring information from one sensory modality to the other (i.e., vision to haptics) than within sensory modalities. In their experiment, participants had to visually or haptically assess a platform in which various wooden objects were placed. For the cross-modal condition, participants studied the platform in one sensory modality and were tested in the other sensory modality. Errors were significantly higher in the cross-modal condition. In our experiment, we did not find that additional experience in the haptic domain (i.e., feeling the blocks in the container) influenced hand preference in the vision domain. However, this additional experience did have a significant impact on hand preference within the haptic domain. That is, hand preference for participants in the Vision-First group was significantly reduced to the point that the right and the left hands were used equally (i.e., 51 % right-hand preference) to grasp the blocks while blindfolded. These results suggest the possibility that there is a transfer of information within the haptic domain. Evidence for transfer within sensory modalities has been shown before (Butler and James 2011; Easton et al. 1997; Hupp and Sloutsky 2011; Reales and Ballesteros 1999) but none have documented a change in hand use or preference.

Regardless of starting condition and compared with Experiment 1, participants in Experiment 2 displayed an additional and substantial reduction in right-hand use when they were blindfolded. This is 10 and 11 % reduction in right-hand use in the Vision-First and the Haptics-First groups, respectively. We speculate that the additional ~10 % decrease in the blindfolded conditions was due specifically to the haptic manipulation of the blocks in the container. The results of some studies have shown that experience within sensory modalities significantly influence subsequent behavior. Craddock and Lawson, for example, conducted an identification task where participants either studied specific objects using vision or using haptics. During the test period, they were asked to identify these objects using haptics only. The group who had used haptics to study the objects were significantly faster at identifying them. These results suggest that experience within one modality affects later performance in the same modality. In our study, the haptic experience of touching the blocks in the container altered hand use while blindfolded. Because participants were blindfolded and used both hands to explore the blocks in the container, it is possible that they adopted the same strategy when presented with the blindfolded condition. It is also likely that if there is a left-hand advantage for haptic discrimination (Benton et al. 1978; De Renzi et al. 1969; Fagot et al. 1993; Milner and Taylor 1972; Riege et al. 1980; Squeri et al. 2012; Tomlinson et al. 2011), a prior exposure to the details of the blocks (in the container) prompted its use.

In conclusion, hand preference for grasping is modulated by vision *and* by haptics. Haptically guided grasping remains lateralized but to a lesser extent than visually guided grasping, particularly if followed by a brief haptic experience. Future research in special populations such as congenitally blind individuals and deafferented patients would bring insight into the sensorimotor control of hand actions and the preferences that follow.

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