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The Copying of Complex Geometric Drawings by Sighted and Visually Impaired Children

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Abstract: This study examined the role of visual imagery in the centripetal execution principle (CEP), a graphic rule that is related to the drawing of complex figures that are composed of embedded geometric shapes. Sighted blindfolded children and children with early-onset low vision and early-onset blindness copied raised-line drawings (using only the haptic modality). The results revealed the dominance of the CEP in the sighted and blind groups, but not in the group with low vision. They suggest that the CEP is not determined by visual imagery, but by a more general mechanism that is based on children's perceptual experience.

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Most studies of graphic rules have focused on the "grammar of action" (Goodnow & Levine, 1973), which describes laws that are involved in drawing simple geometric shapes. For example, the start rotation principle, established by Van Sommers (1984), specifies the direction of movements in relation to the position of the pen when one starts to draw a circle. There has been little research on graphic rules that are related to the execution of complex drawings. In this perspective, Osterrieth (1945) showed that the strategy of organizing the drawing of the Rey complex figure using a central large rectangle is the rule that most children follow from age 11. Hauert, Mounoud, and Mayer (1981) attributed the origin of this strategy to proactive control.

More recently, Magnan and her colleagues (Magnan, Aimar, & Baldy, 2000; Magnan, Baldy, & Chatillon, 1999) identified the centripetal execution principle (CEP), a graphic rule for drawing complex figures that are composed of simple geometric shapes following a progression from the periphery to the center (from the outside of the figure to the inside of the figure). The dominance of this strategy was observed in children aged 5 and older in copying drawings and at age 8 and older in reproducing models from memory. This strategy was also stable when the order of the elementary shapes, which were drawn on transparencies, was varied.

Furthermore, in a previous experiment (Bouaziz & Magnan, submitted), we studied the role of vision in the CEP. Six- and 8-year-old children copied complex geometric drawings after a visual or haptic exploration, with or without visual feedback during the execution. The results indicated that if vision contributes to the manifestation of the CEP, it does not explain it, since the dominance of this principle was verified even when the children were deprived of visual information. This finding suggests that the CEP is determined by an amodal mechanism, common to the visual and haptic modalities. In particular, it could be related to visual imagery.

One way to test this hypothesis is to compare blindfolded sighted and visually impaired children in the haptic copying of drawings. Indeed, only sighted people can mentally convert haptic percepts into visual images efficiently. The imaged-mediated model of Klatzky and Lederman (1987) defines this process. The use of visual mediation can make it easier and more economic to integrate and represent the properties of an object, such as the shape, size, or positions of the different parts. Kaski (2002) emphasized that even if visual imagery can facilitate some aspects of perception, the mental representation of tangible objects can take different forms, haptic or semantic, as well as visual.

The results of most studies that have tested the influence of visual status on the performance of imagery tasks have been consistent with the idea that the process of determining visuospatial properties does not depend on visual imagery or visual experience. These studies have shown that blindfolded-sighted and visually impaired (including congenitally blind) participants did not differ significantly in learning a virtual pathway (Cornoldi, Cortesi, & Preti, 1991) or a real environment (Blades, Lippa, Golledge, Jacobson, & Kitchin, 2002; Golledge, Jacobson, Kitchin, & Blades, 2000; Ochaita & Huertas, 1993), the haptic perception of the Müller-Lyer illusion (Heller, Brackett, Wilson et al., 2002), the horizontal (Heller, Brackett, Scroggs, Allen, & Green, 2001), and the perspective (Heller, Brackett, Scroggs et al., 2002).

Kennedy (1997) observed visually impaired adults on different abilities that are related to the properties of haptic pictures (shape, perspective, depth, impression of movement, and perception of contour). He noted many similarities between the blind and sighted participants in the interpretation of pictures. Heller, Brackett, and Scroggs (2002) tested sighted adults who were blindfolded and adults who were visually impaired (including those who were congenitally blind and late blind and those who had low vision) in the haptic identification of pictures representing familiar objects, animals, or parts of bodies, using a multiple-choice paradigm. The results revealed that the mean performances of the blindfolded-sighted and visually impaired participants were not significantly different. Heller et al. (2001)

concluded that visual experience is not necessary for the perception of tangible pictures. Thus, if the manifestation of the CEP is determined by visual imagery, we should note a higher frequency of the CEP in blindfolded sighted children than in visually impaired children--those with early-onset low vision or early-onset blindness. Note that there have been few studies of the influence of visual status on the performance of tasks involving the haptic perception and copying of nonfamiliar drawings, particularly in children.

Method

Participants

The 27 children who took part in the experiment were divided into three equal-size groups as a function of their visual status: those who were sighted, those with low vision, and those who were blind. The children who were visually impaired were recruited from special classes at a school in the area of Lyon, France, and the sighted children came from public schools in the same area. The blind children had lost their vision before age 1. The children with low vision had also become visually impaired before age 1 and varied in the extent of their remaining residual vision, but they all had minimal pattern perception. However, few children with low vision used braille, whereas most of the blind children did. Table 1 presents the characteristics of the children who were visually impaired. The mean age of the three groups was about the same: 9 years, 4 months (*SD* = 19 months), for the sighted children; 9 years, 2 months (*SD* = 22 months), for the children with low vision; and 9 years, 9 months (*SD* = 20 months), for the blind children.

Stimuli and apparatus

The participants haptically explored three raised-line drawings that were composed of four embedded geometric shapes (see Figure 1) successively in a random order. The stimuli were built with a technique in which a sheet with gas between its layers was heated to obtain raised lines. The children could perceive the lines by touching them with their index fingers. This manual exploratory procedure, called "contour following" (Lederman & Klatzky, 1993), is used spontaneously to know the global and exact shape of two-dimensional objects (Symmons & Richardson, 2000).

We used drawings similar to those used by Magnan et al. (1999, 2000), except that all the contact points between the simple shapes that made up the drawings were deleted because it is difficult to extract adjacent shapes by touch. Instead, we introduced a regular free space of about five millimeters (about 0.2 inch) between two consecutive simple geometric shapes. A Swedish raised-line drawing kit was used for the execution. It was composed of a plastic sheet with a granular texture that adhered to a thin rubber surface and a ballpoint pen. The pressure of the ballpoint pen on the sheet produced a durable, thick, raised mark, making it possible to control the execution haptically.

The apparatus that was used for the haptic-reproduction task was composed of a curtain that was fixed to a wooden plank (50 centimeters by 50 centimeters, or about 19 inches by 19 inches) with two compartments (see Figure 2), one for the model (exploration), which was glued on a wooden plate, and one for the raised-line drawing kit (execution). The participants sat in front of the curtain and were asked to touch the model and to reproduce it using the raised-line drawing kit. They could easily reach the haptic model by extending their arms. Before they began the task, the experimenter guided each participant's hand to help him or her locate the two compartments and told the participant that he or she could touch the model as often as he or she wanted to. For each drawing, the experimenter recorded the order adopted by the participants in copying the simple geometric shapes.

Results

We examined the different orders adopted by the participants in copying the elementary figures. Each drawing was composed of four simple geometric shapes, so 24 orders were possible (see Table 2). We could observe that the global frequency of the centripetal order was high (about 57%), whereas the other orders were lower (see Figure 3). Therefore, we focused the data analysis on the number of CEP (between 0 and 3).

The mean frequency of the CEP in the blindfolded sighted, blind, and children with low vision was 2.33 (SD = 1.12), 2.00 (SD = 1.22), and 0.78 (SD = 1.09), respectively. The Kruskal-Wallis test revealed that the effect of visual status was significant ($H[2] = 7.09$, $p < .05$). The Mann-Whitney tests showed that the frequency of CEP was significantly lower in the children with low vision than in the sighted children ($U = 14.00$, $p < .05$) and tended to be higher in the blind children than in the children with low vision ($U = 19.50$, $p < .07$). The difference between the sighted and blind children was not significant.

Discussion

We found a significant effect of visual status on the CEP. The dominance of the CEP was verified in the blindfolded sighted children and the blind children, but not in the children with low vision. Thus, we observed a high frequency of CEP in both the blindfolded sighted children and the blind childen. This result is consistent with the findings of other studies (Heller, 2002; Heller, Brackett, Scroggs et al., 2002; Kennedy, 1993; Kennedy & Merkas, 2000), suggesting that visual imagery (or visual experience) is not necessary for processing visuospatial information.

The perceptual analysis of the blind children of the properties of the stimuli and organization of the execution of the drawings following this analysis were also efficient. This result suggests that the CEP does not depend on the image-mediation process defined by Klatzky and Lederman (1987). Visuospatial information can be represented in different formats, which have a variable weight according to an individual's perceptual experience (Cornoldi & Vecchi, 2000). Whereas the sighted children favored imaged representation and used their visual knowledge to integrate information about haptic percepts, the blind children represented information in a tactile-kinesthetic format and hence engaged in a direct process of haptic percepts without the intervention of visual mediation.

Note that the figures that were used in the experiment are meaningless if they are considered in their globality, but were composed of geometric shapes that the children probably knew, given their age (more than 9 years, on average). It is well known that familiarity plays a crucial role in the identification of novel pictures (Heller, Brackett, & Scroggs, 2002; Heller, Calcaterra, Tyler, & Burson, 1996). The recognition of familiar geometric shapes during the haptic exploration of the stimuli would activate visual representations (that are much more developed and specified than haptic representations) in the sighted children and haptic representations in the blind children. These activations could facilitate the integration of the figurative properties of the drawings.

However, the dominance of the CEP was not verified in the children with low vision, who seemed to have more difficulty organizing the copying of the drawings. These children could have had a lesser ability to process and analyze the haptic stimuli than could the sighted and blind children. Kennedy (1997, p. 77) reported that people with late-onset blindness "would benefit from a double advantage: they are more accustomed to pictures than early blind people, and they are more accustomed than sighted people to use touch." Our results show that this was not the case for the children with low vision, who adopted the CEP less often and were less organized in copying the drawings than were the blind children. But these two results may be compatible, considering the fact that the quality of the visual experience could be better in persons with late-onset blindness than in those with early-onset low vision. Thus, the children with low vision could have developed specified visual representations, whereas the children with low vision could not use their visual knowledge efficiently. However, Heller et al. (2001) reported that individuals with low vision performed better than did those with late-onset blindness, those who were congenitally blind, and those who were sighted and wore blindfolds in the haptic perception of the horizontal. There may be two reasons for these opposite results.

First, the participants with low vision in our experiment were children, whereas the participants in the Heller et al. (2001) experiment were adults. Thus, the adults with early-onset low vision could have developed haptic representations because they had used touch to perceive patterns for a long time. In contrast, the children with low vision could not develop specified haptic representations because their exposure to haptic perception was poor (note that only two of the nine children with low vision used braille). Thus, the children with low vision would not have built up specific haptic knowledge, contrary to the blind children (eight of the nine blind children regularly used braille). This difference could explain the significant variation between the two groups in their organization of the execution of the drawings or in the adoption of the CEP. To support this hypothesis, we divided the visually impaired children into two groups as a function of their practice of braille. The Mann-Whitney test showed that the children who used braille adopted the CEP more often than did the children who did not use braille ($U = 5.00$, $p < .01$).

Second, the efficiency or success of the participants with low vision in the haptic water-level problem used by Heller et al. (2001) and the participants' difficulty in the haptic reproduction of drawings that were composed of embedded geometric shapes could be attributed to the different skills that are needed to perform these two tasks. Heller et al. suggested that the participants with low vision were "better able to ignore the distracting effects of the tangible surroundings" (p. 607) in the haptic perception of the horizontal, but in the haptic reproduction task, the adoption of the CEP depended on a global perceptual analysis of the properties of the stimuli. Hence, the children with low vision may have had difficulty processing visuospatial information in a holistic way. They excluded some parts of the drawings and thus built uncomplete representations of the drawings. The fact that they ignored the surroundings helped them in the haptic perception of the horizontal but caused difficulty in the haptic analysis of the visuospatial characteristics of the stimuli, which determines the organization of the execution of the drawings.

Heller et al. suggested that low vision could help individuals maintain postural stability in processing spatial reference information in the haptic perception of the horizontal. One problem could be that persons with low vision who have had poor visual and haptic experience could favor or use only these postural cues because they do not trust their visual and haptic representations, which are not specific. This problem could explain why the CEP frequency was lower in the children with low vision than in the sighted and blind children.

Conclusion

The results of our experiment suggest that the CEP is not determined by visual imagery. In the haptic reprodution of complex figures that are composed of embedded geometric shapes, the children with early-onset blindness were able to analyze the properties of the stimuli efficiently and thus to organize the copying of the drawings. Visual images are only one type of representation that can be used to integrate visuospatial properties in haptic tasks. Tactile-kinesthetic representations are another type of representation that can be activated efficiently.

The preferential use of the visual or haptic format to represent visuospatial information depends on the participants' perceptual experience. That vision is much more developed than touch in sighted persons explains their preference for using visual mediation (Klatzky & Lederman, 1987). Since children with early-onset blindness are much more familiar with haptic percepts than are sighted children, their haptic experience would make possible a direct (with no mediation), efficient process of haptic percepts. Moreover, it is conceivable that the children with early-onset low vision who were not familiar with the use of touch did not develop specific haptic representations and could not use the visual mediation process efficiently because of their imprecise visual representations. It appears that the perceptual experience of children constitutes a main factor in the manifestation of the CEP.

Implications

The data presented here support the early use of tactile graphics in the instruction of children who are visually impaired. We noted that the CEP frequency was higher when the children used braille than when they did not. Haptic exploration would make the representation of spatial information and the interpretation of tactile drawings possible and easier. Nevertheless, tactile drawings have to be suited to haptic perception. Indeed, it is well known that haptic exploration is less efficient and accurate than is visual exploration in analyzing the spatial properties of objects (Gentaz & Rossetti, 1999; Loomis, Klatzky, & Lederman, 1991).

In this study, the analysis and interpretation of the stimuli may have been possible because the different parts could be clearly extracted and distinguished by the introduction of free spaces between them. The presence of contact points would make the representation of the drawings much more difficult and confused (we tested some children in this situation and found that the task was extremely complex for them). One solution could be to establish specific norms in the use of tactile graphics that would be simple cues that are easy to extract and recognize haptically. Moreover, we used drawings that were composed of geometric figures that we thought the children knew and therefore could be coded verbally. Doing so may have made it easier for the children to integrate and interpret the tactile stimuli, which would probably have appeared more difficult with drawings that were composed of unfamiliar abstract figures.

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