The Role of Visual and Proprioceptive Information in Mirror-Drawing Behavior

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Abstract. The resolution of visuo-proprioceptive conflicts is studied with regard to the syntactical level of drawing production. We use a distinction made by Meulenbroek and Thomassen (1991) regarding the difference in status between verticals/horizontals and obliques. Adults copied simple horizontal-vertical or oblique patterns in normal and mirror conditions. Results showed that subjects preferred to take into account either a proprioceptive or a visual reference when resolving conflicts. It seems that conflicts are resolved differently through practice as a function of the dominant strategy used. We discuss the importance of visual and proprioceptive information in the syntactical planning of drawing movements.

1. Introduction

The role of visual information in adult handwriting production has classically been studied by means of occlusion of vision with an opaque box. Results show that during graphic production without vision, only occasional errors (e.g. substitution and omission of letters and strokes) and no changes in letter shapes are, in general, recorded (Smyth & Silvers, 1987). It was thus hypothesized that when visual feedback was not available, subjects used compensatory strategies in order to prevent spatial errors in handwriting. An illustration of this point of view was made by Smyth (1989). Specifically, Smyth showed that the use of consistent directions in handwriting movements depends on the ability to visually control spatial locations. Without vision, subjects tended to minimize the number of pen-lifts when writing capital letters in order to avoid spatial errors when repositioning the pen on the paper. This hypothesis concerning the use of compensatory strategies in the absence of vision agrees with Van Doorn's conception (1993). Van Doorn reported that removing visual control during handwriting produced an increment of pen pressure, movement time and writing size in order to ensure accurate shape reproduction. He concluded that subjects compensate for the absence of visual control of the ongoing movement by a more adequate control mode probably relying, for a large part, on kinesthetic (or proprioceptive) information.

Recent experiments with deafferented patients in fact provided additional evidence for the importance of proprioceptive information in movement production. Specifically, the role of proprioception for drawing and handwriting production was studied by Teasdale, Forget, Bard, Paillard, Fleury and Lamarre (1993). They demonstrated that proprioceptive
information is necessary to calibrate the displacement of the hand within the constraint of a graphic space in situations without vision. Teasdale et al. observed that the space between letters and words in handwriting as well as the spatial position of an ellipse in the graphic space in drawing were strongly degraded in the absence of vision for a deafferented patient, but only slightly for normal subjects. However, when vision was available, the deafferented patient and control subjects showed similar performance. These results are consistent with Paillard's observations (1991). Paillard distinguished two components in handwriting. The first is morphokinetic and determines letter shape; it is independent of retroactive control (i.e. visual and proprioceptive). The second component, a topokinetic one, is related to the location of the punctuation marks, as well as to the orientation of the writing lines on the page and letter amplitude. The topokinetic component depends strongly on visual and proprioceptive feedback. These studies demonstrated that for both drawing and handwriting, the displacement of the hand within the constraints of the graphic space depends on afferent information provided by visual as well as proprioceptive systems.

The overall pattern of results suggests that in an "habitual" situation, the organization of graphic behavior relies on a tight integration of visual and proprioceptive cues. Therefore, subjects are able to compensate for the absence of visual information by an increased contribution of proprioceptive processing, while they compensate for the absence of proprioceptive information by an increased contribution of visual processing. However, some authors observed that either visual or proprioceptive control could dominate graphic movement productions. For example, Meulenbroek and Thomassen (1991) suggested that two independent spatial reference systems are involved in straight line production. One system corresponds to the anatomical structure of the effector system and results in preference for obliques, while the second system corresponds to a geometrical system, resulting in a bias for horizontal and vertical orientations. The authors concluded that oblique orientations are strong candidates from a motoric viewpoint with a reduced sensitivity to the availability of visual information, while horizontals and verticals are candidates from a perceptual viewpoint with strong dependence on visual information. Meulenbroek and Thomassen use this theoretical framework to explain that, in their experiment, they observed that the prevalence of visual or proprioceptive control depends on the type of segments to be drawn in a situation where visual and proprioceptive modalities are both available.

Other experiments assessed the respective roles of vision and proprioception when both visual and proprioceptive information are available, but conflictual (e.g. prismatic deviation and mirror deviation tasks). Results from the prism-adaptation (or mirror-adaptation) studies using the prism paradigm are complex. Some studies illustrated that adaptive recalibration concerns mainly the proprioceptive system while other studies reported changes in the visual system. Proprioceptive adaptation implied the dominance of the visual modality when resolving visuo-proprioceptive discordance (Canon, 1971), proprioception being less important for resolving the conflict. An illustration of adaptation including changes in the proprioceptive system when drawing was provided by Lajoie, Paillard, Teasdale, Bard, Fleury, Forget and Lamarre (1992). In a mirror-drawing task of a six-pointed star, Lajoie et al. observed that a deafferented patient had no problems in copying the pattern, while normal subjects had some difficulties in producing fast and accurate movements. Before being able to reach a level of performance similar to that of the
deafferented patient, normal subjects had to learn how to use reversed visual feedback by recalibrating their proprioceptive map.

Proprioceptive adaptation effects were also observed in various skill performance situations (e.g. locomotion, reaching movements). However, results indicated that not all types of exposure condition produce adaptive recalibration of the proprioceptive system. Some types could also induce adaptive recalibration of the visual system. For example, seeing the hand throughout a reaching movement tended to produce proprioceptive adaptation whereas seeing the hand only at the end of the movement resulted in visual adaptation (Uhlbrich & Canon, 1971; Redding & Wallace, 1988). The authors suggested that the nature of the adaptation (visual or proprioceptive) depends on the modality which was used as a source of information for guiding the movement. When the information provided by two sensory modalities is discordant, and if subjects paid strong attention to one specific sensory modality, the adaptation process is recorded only for the other modality. Thus, when control of movement strongly depends on proprioceptive cues (e.g. when vision of the hand is available only at the end of the pointing movement), visual adaptation occurs. On the contrary, when subjects can visually control their movement (e.g. when vision of the hand is available early in the pointing movement), proprioception adaptation occurs, and proprioception probably does not play an important role in resolving the conflict.

Only a very limited number of studies dealing with graphic behavior focus on the distinction between dominance of visual or proprioceptive information, when both types of information are discordant. The previously mentioned mirror-drawing experiment performed by Lajoie et al. (1992) reported the dominance of visual information in resolving the visuo-proprioceptive conflict. However, it has been shown that exposure conditions are likely to force the subjects to attend to either visual or proprioceptive cues. It could therefore be possible that Lajoie et al.'s experiment induced the subjects to favor visual information. To draw a closed figure like a star necessitates that the spatial position as well as the amplitude of each segment be correct in order to ensure accurate shape reproduction. In consequence, the aim of the present study is to examine how subjects resolve visuo-proprioceptive discordance in a mirror drawing task of more simple geometrical figures (i.e. opened figures made up of only 2 or 3 segments) than a star. These figures are composed either of obliques or of horizontal-verticals in order to investigate the difference in status between these segments (Meulenbroek & Thomassen, 1991). Because drawing obliques relies on the anatomical system, the question arises as to whether the proprioceptive system predominates in resolving the conflict. Along the same line, because horizontal and verticals depend on vision, the question is whether the visual system is dominant in resolving the conflict between visual and proprioceptive information.

Previous hypotheses specify that the dominant strategy used to resolve the discordance is a function of the type of segments which constitute a figure. However, the dominant strategy could be independent of the characteristics of the segments which make up the figure. In this light, we made the assumption that if vision is dominant, the movement directions as viewed in the mirror should correspond to those used in a "normal" situation. In addition, obliques should be more difficult to produce in the mirror task than horizontal and verticals, because for obliques the conflict implies a multiple choice (combination of up, down, left and right), whereas resolving the conflict implies a binary choice for
horizontal (left versus right) and vertical segments (up versus down; Lajoie et al., 1992). On the contrary, if the visuo-proprioceptive conflict is resolved from proprioceptive cues, performance directions should be maintained, and not be dependent so strongly on the presence of a mirror. Moreover, horizontals and verticals should be the most difficult segments to produce, because they require the participation of both the fingers and the hand, whereas oblique segments are motorically simpler, requiring the participation of either the fingers or the hand (Meulenbroek & Thomassen, 1991). An objective of the experiment was also to investigate the adaptive process in a mirror condition. How do subjects modify their drawing performance when they become more familiar with the new visual and proprioceptive correspondences through practice? Note that our analysis is restricted to syntactical features of drawing production, without considering its kinematic parameters.

2. Method

2.1 Subjects

Sixteen right-handed students at the University of Bourgogne (4 males and 12 females, age mean: 21.5 years) participated in the experiment for course credit. They were not informed of the aims of the study. All subjects were native speakers of French. None of them knew a language using right-to-left handwriting.

2.2 Material

Sixteen items were used in the experiment, composed of either two or three segments, as illustrated in Figure 1.

Regardless of the number of segments, these items are made up of horizontal and vertical segments only ("hv" structure) or of oblique segments only ("ob" structure). The segment length was 1 cm for all items. The models were printed in black ink on 6×6 cm white cards, one model per card, and were presented one at a time.

<table>
<thead>
<tr>
<th>2-segment items</th>
<th>3-segment items</th>
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<tr>
<td>&quot;hv&quot; structure</td>
<td>&quot;hv&quot; structure</td>
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<tr>
<td>&quot;ob&quot; structure</td>
<td>&quot;ob&quot; structure</td>
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Figure 1. Classification of the 2 and 3-segment items used in the experiment. Items were made up of either horizontals and verticals ("hv" structure) or obliques ("ob" structure).
The task was performed on a xy-digitizer (Calcomp) connected to an IBM-PC compatible 486. The xy-coordinates were sampled at a frequency of 100 Hz. Spatial accuracy was 0.2 mm (for technical details, see Teulings & Thomassen, 1979).

2.3 Procedure

Subjects were tested in a single experimental session. Each subject performed in two experimental conditions: (1) in the normal condition (Nor), subjects were able to normally look at their drawing performance; (2) in the mirror condition (MirLe), subjects performed the experimental task by looking in a mirror that was located at the left, at the model, at their hand, and at the trace. An illustration of the experimental set up is presented in Figure 2. In the “MirLe” condition, the left and right directions were reversed; a mask prevented the subject from seeing straight the model and his/her drawing movements. The order of the normal and mirror conditions was counterbalanced across subjects.

In order to familiarize the subjects with the difficulties implied by the mirror task, they were asked first to copy 16 one-segment items (horizontal, vertical and oblique) in the MirLe condition. After familiarization, subjects drew first four series of the eight 2-segment items followed by four series of the eight 3-segment items. The order for each series of 2 and 3-segment items were randomized for each subject. All subjects performed a total of 128 graphic productions (2 conditions by 16 items by 4 trials).

For each item, the direction and sequencing of the drawing movements were recorded. In the coding of movement directions, minor angular deviations were not considered. We were mainly interested in coding whether a vertical, for instance, was drawn in the 90° direction or in the 270° one (Figure 4). The number of errors in segment directions was also recorded. Errors were characterized by a reversal in the direction of an entire segment or by “micro-movements” performed in the wrong direction, compared to one(s) required by the model.

Figure 2. Illustration of the experimental set up used in the mirror-drawing task. An opaque box was positioned over the papersheet, which prevented the subject from seeing straight the model and his writing hand and pen. An opening at the left of the opaque box allowed the subject to visually control his movement from a mirror located at the left (8 cm) of the sheet.
3. Results

3.1 Analysis of movement directions

The first issue we investigated concerns the suggestion made by various authors regarding the difference in status between vertical/horizontal segments and oblique segments. In the mirror-drawing situation, if the copying movement is mainly visually guided, oblique segments should be more difficult to produce than horizontal and vertical segments. However, if the visuo-proprioceptive conflict is mainly resolved by proprioceptive processing, oblique segments might be easier to produce than horizontal and vertical segments. For each subject and item, the mean frequency of occurrence of verticals [to the top (90°) and to the bottom (270°)], horizontals [to the right (0°) and to the left (180°)] and obliques [from bottom-left to top-right (45°), from top-left to bottom-right (315°), from top-right to bottom-left (225°) and from bottom-right to top-left (135°)] were computed. Note that for the mirror condition, the performed and perceived drawing movements are conflictual, as illustrated in Figure 3. Exceptions are the vertical directions (90°, 270°).

![Diagram showing perceived and performed directions](image)

Figure 3. Illustration of discordance between "performed" and "perceived" movement directions.

In our analyses, performed movements are related to movements realized on the paper sheet, while perceived movements correspond to what the subjects saw in the mirror, some directions being preserved, others not. ANOVAs with Condition (normal vs. mirror) and Block of trials (4 blocks) as within-subject factors were carried out on the frequencies of occurrence of the different performed and perceived movement directions (i.e. on 0°, 45°, 90° and 135°; the remaining directions are complementary). Results for the 2-segment items are presented in Figure 4. Similar results were observed for 3-segment items.
A. Performed directions

B. Perceived directions

Figure 4. Polar representation of the frequency of movement directions as a function of Condition for 2-segment items. Performed (A) and perceived directions (B) are represented.

With regard to performed directions, the mirror condition led to modifications in the oblique directions, $F(1, 15) = 38.76, p < .001$ (45°), $F(1, 15) = 30.06, p < .001$ (135°), as well as horizontal directions, $F(1, 15) = 53.59, p < .001$ (0°). Similar perturbations appeared for perceived directions, $F(1, 15) = 13.38, p < .005$ (45°), $F(1, 15) = 32.84, p < .001$ (135°), $F(1, 15) = 19.56, p < .001$ (0°). Subjects drew less often obliques and horizontals in a left-to-right direction in the mirror condition than in the normal one, but the decrease of right-oriented movements was less pronounced for perceived than for performed directions, suggesting that subjects tended to preserve a “visual syntax” rather than a “motor syntax.”

Although subjects tended to organize syntactically their drawing from a visual point of view, no difference between horizontal-vertical and oblique segments was found in the present study. These results disagree with our expectations that when resolving visuo-proprioceptive conflicts from a visual point of view, the “binary” choice implied in horizontal and vertical segments make them easier to produce than oblique segments, which imply a “multiple” choice. An explanation for these ambiguous results could be that some subjects tended to preserve a “visual syntax” (certainly the majority of subjects in the present experiment), whereas others tended to preserve a “motor syntax.” Such a difference between subjects would be consistent with Paillard’s model (1991). Paillard reported that in the monitoring of handwriting, subjects could make use of two possible strategies, based either on an egocentric proprioceptive reference (i.e. upon information about the movement and position of the body), or on an allocentric visual reference (i.e. upon extraceptive visual information). According to Paillard, subjects can be differentiated as a function of their dominant strategy, when they are confronted with a non-constraining condition. It may be possible that mirror-drawing production of “open” figures, contrary to “closed” figures as used in Lajoie et al.’s experiment (1992), constitutes a non-constraining condition in this sense. In this line of reasoning, subjects could have used either a visual or a proprioceptive strategy. Subjects who reversed movement directions, probably in order to maintain constant the usual visual sequence of movements for a given figure, could have
made use of visual cues. On the contrary, subjects who did not reverse movement directions, could have made use of proprioceptive cues. We thus expect that subjects who did not reverse movement directions had more difficulties when producing horizontal-vertical figures, while those who reversed movement directions had more difficulties when producing oblique figures.

As a consequence, we checked whether the subjects could be divided into 2 groups as a function of the movement directions they performed in the mirror task. The "proprioceptive group" should include subjects who performed movement directions as they did in the normal condition. The "visual group" should correspond to subjects for which performed movement directions were a mirror image of the ones observed in the normal condition, so that the resulting perceived directions were in agreement with those obtained in the normal condition. For each subject, the mean number of occurrence of each direction (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°) produced when drawing in the mirror condition was computed. The data were collected in a 16 (number of subjects) by 8 (number of directions) contingency table. This table was analyzed with a Correspondence Analysis (for details on procedure and analysis, see Greenacre, 1984; Benzécri, 1973). The goal of the analysis was to identify groups of subjects as a function of the reversal or non-reversal of movement directions (performed on the paper sheet). For 2 and 3-segment items, the first factorial axis explained 59% of the variance. This axis divided subjects in two groups. The first group included 11 subjects who, in the mirror condition, performed left-oriented segment directions (135°, 180° and 225°), while the second group included the 5 remaining subjects, who performed right-oriented segment directions (0°, 45° and 135°). The first and second groups were respectively called the "visual" and "proprioceptive" groups.

As mentioned above, subjects from the "visual group" probably reversed the motorically preferred movement directions in order to maintain, visually, a sequence of movements corresponding to the one they observed in the normal condition. Therefore, if the copying movements were mainly visually guided in the mirror task, oblique segments should be more difficult to produce than horizontals and verticals for these subjects. The reverse pattern of results should characterize performance of subjects from the "proprioceptive group." For the 2-segment items, frequency of performed and perceived directions are presented in Figure 5, as a function of the group. Similar results appeared for 3-segment items.

For both "proprioceptive" and "visual" groups, a series of ANOVAs for repeated measures with Condition (normal vs. mirror) and Block of trials (4 blocks) were carried out on the frequencies of occurrence of the different movement directions (i.e. on 0°, 45°, 90° and 135°; the remaining directions are complementary). With respect to performed directions for subjects from the "proprioceptive group," the MirLe condition induced only modifications in the horizontal direction, F(1,4) = 7.97, p < .05. Subjects drew less often left-to-right horizontals in the MirLe than in the normal condition. For the "visual group," the mirror task led to important modifications in the oblique, F(1,10) = 178.14, p < .001 (45°), F(1,10) = 72.81, p < .001 (135°) and horizontal directions, F(1,10) = 54.96, p < .001 (0°). The distribution of movement directions produced in this condition was reversed in comparison to the distribution observed in the normal condition. No other significant effect was revealed by the ANOVAs. In particular, no effect of practice reached significance. However, a contrast analysis showed a linear increase of occurrences of
horizontals drawn to the right (block 1 = 35%, block 2 = 52.5%, block 3 = 50% and block 4 = 65%) for the "propiceptive group" only (p = .061).

**Performed directions**

A. "Proprioceptive group"

- Nor = MirLe
- 90°
- 135°
- 180°
- 225°
- 270°

B. "Visual group"

- Nor = MirLe
- 90°
- 135°
- 180°
- 225°
- 270°

**Perceived directions**

D. "Proprioceptive group"

- Nor = MirLe
- 90°
- 135°
- 180°
- 225°
- 270°

E. "Visual group"

- Nor = MirLe
- 90°
- 135°
- 180°
- 225°
- 270°

Figure 5. Polar representation of the frequency of observed movement directions as a function of Condition for 2-segment items. Performed (A and B) and perceived directions (C and D) are represented separately for the "propiceptive" and "visual" groups.

With regard to perceived directions, subjects from the "propiceptive group" drew horizontals, $F(1,4) = 50.00$, $p < .005$ (0°), and obliques to the right, $F(1,4) = 34.51$, $p < .01$ (45°), $F(1,4) = 370.29$, $p < .001$ (315°), less often in the MirLe than in the normal condition. For subjects from the "visual group," the frequencies of occurrence of the left-to-right horizontals, $F(1,10) = 6.92$, $p < .025$ (0°), and top-left to bottom-right obliques, $F(1,10) = 23.15$, $p < .001$, were slightly inferior in the MirLe than in the normal condition for items made of 2 segments only. The difference between the normal and mirror
conditions marginally reached significance for the top-right to bottom-left oblique production ($p = .074$).

3.2 Analysis of threading performance

Regardless of the number of segments and condition, threading performance (no pen-lifts) occurred in more than 79% of the cases. But we could expect that threading performance nevertheless varies as a function of the drawing condition and item structure, for both the "proprioceptive" and "visual" groups. Thus for both groups, for each subject and each item, the frequency of threading was computed. ANOVAs for repeated measures were performed on these frequencies, using a 2 Condition x 2 Structure x 4 Block of trials factorial design. Results for 2 and 3-segment items are presented in Figure 6 for the "visual group" only. No significant effect was observed for subjects from the "proprioceptive group," threading being applied in more than 97% of the cases whatever the structure and the condition.

![Figure 6. Frequency of occurrence of threading as a function of Condition and Structure ("visual group").](image)

Threading performance was less frequent in the normal condition than in the MirLe condition, $F(1,10) = 10.957, p < .01$ (2-segment items), $F(1,10) = 5.40, p < .05$ (3-segment items), and regardless of the condition, performance varied significantly as a function of the item structure for the 2-segment items, $F(1,10) = 8.59, p < .025$. Items made up of horizontal-vertical segments were less often threaded when vision was available than items with an oblique structure, $F(1,10) = 8.85, p < .025$. For 3-segment items, although threading reached only marginal significance for both Structure, $F(1,10) = 4.48, p = .058$, and the interaction between Condition x Structure, $F(1,10) = 4.47, p = .058$, they followed patterns similar to those observed for items made up of 2 segments.

Because threading constrains movement directions, it is of interest to examine whether performed movement directions for items drawn with pen-lifts showed the same characteristics as those reported in Figure 4A. Forty-two 2-segment items were produced with pen-lifts in the normal condition (35 with a "hv" structure, 7 with an "ob" structure), nine in the mirror condition (7 with a "hv" structure, 2 with an "ob" structure) by 9 subjects (one in the "proprioceptive group" and 8 in the "visual group"). Twenty-nine 3-segment
items were produced with pen-lifts in the normal condition (23 with a “hv” structure, 6 with an “oh” structure), 4 in the mirror condition (2 with a “hv” structure, 2 with an “oh” structure) by 7 subjects (two in the “proprioceptive group” and 5 in the “visual group”). The mean frequencies of occurrence of the different performed movement directions are presented in Table 1 (2-segment items) and Table 2 (3-segment items) as a function of Condition (normal vs. mirror).

Table 1. Percentage of performed movement directions for 2-segment items drawn with pen-lifts as a function of Condition (normal vs. MIrLe).

<table>
<thead>
<tr>
<th>condition</th>
<th>0°</th>
<th>45°</th>
<th>90°</th>
<th>135°</th>
<th>180°</th>
<th>225°</th>
<th>270°</th>
<th>315°</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal</td>
<td>100</td>
<td>85.71</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.29</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>MIrLe</td>
<td>42.86</td>
<td>0</td>
<td>14.29</td>
<td>0</td>
<td>57.14</td>
<td>100</td>
<td>85.71</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2. Percentage of performed movement directions for 3-segment items drawn with pen-lifts as a function of Condition (normal vs. MIrLe).

<table>
<thead>
<tr>
<th>condition</th>
<th>0°</th>
<th>45°</th>
<th>90°</th>
<th>135°</th>
<th>180°</th>
<th>225°</th>
<th>270°</th>
<th>315°</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal</td>
<td>100</td>
<td>90</td>
<td>8.57</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>91.43</td>
<td>100</td>
</tr>
<tr>
<td>MIrLe</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

These results show a pattern similar to the one observed for the whole set of items (see Figure 4A). For 2 and 3-segment items, oblique and horizontal directions were less often performed to the right in the mirror condition than in the normal one. An exception appears for the 135°-315° obliques for 2-segment items only, drawn to the right whatever the condition (Table 1). However, only 2 items were produced with pen-lifts in the mirror task.

3.3 Analysis of Directional Errors

No errors were recorded in the normal condition. For the mirror task, we expected that the number of errors would decrease with practice. Consequently, the mean number of errors was computed for each group as a function of item structure and blocks of trials for 2 and 3 segment items in the mirror task. Results are reported in Figure 7.

Figure 7. Mean number of errors as a function of Structure and Block of trials for both “proprioceptive” (Figure A) and “visual” (Figure B) groups.
For 2 and 3-segment items, ANOVAs were carried out on the mean number of directional errors performed in the mirror condition with Group as between-subjects factor, Structure and Block of trials as within-subjects factors. For 2-segment items, no significant effect of the Group was revealed by the ANOVA ($p > .37$). Results showed that, whatever the group, the number of directional errors significantly decreased through practice, $F(3, 42) = 14.43, p < .001$. Although the Block of trials x Structure interaction reached marginal significance, $F(3, 42) = 2.66, p = .06$, it appeared that errors only decreased for items made of obliques in the "proprioceptive group," while they decreased for both item structures ("hv" and "ob") in the "visual group." For oblique structures, pairwise comparisons (Tukey test) revealed a rapid learning effect (block 1 vs. block 2, $p < .025$) in the "proprioceptive group," while a progressive learning effect (block 1 vs. block 2, $p < .01$; block 2 vs. block 4, $p < .05$) was observed in the "visual group." For horizontal-vertical items, a significant difference between block 1 and block 4 ($p < .05$) was observed ("visual group" only).

For 3-segment items, errors were more frequent in the "proprioceptive group" than in the visual one, $F(1, 14) = 23.93, p < .001$. For subjects from the "proprioceptive group," a significant interaction between Block of trials and Structure, $F(3, 12) = 4.15, p < .05$, showed that errors were more frequent for obliques than for horizontals and verticals in the first and second blocks, whereas the opposite pattern was found in the third and fourth blocks. For subjects from the "visual group," a decrease in the number of errors appeared for oblique structures only (block 1 vs. block 2, block 2 vs. block 3, $p < .05$).

4. Discussion

The primary aim of the present study was to examine how subjects solved visuo-proprioceptive discordance induced by a mirror-drawing task, and how subjects modified their drawing performance through practice. We used a distinction made by Meulenbroek and Thomassen (1991) regarding the difference in status between horizontals/verticals (candidate from a visual point of view) and obliques (candidate from a motoric point of view). Globally, our results do not confirm our expectation that horizontals-verticals could induce proprioceptive adaptation, while obliques could induce visual adaptation. Whatever the segment drawn, the mirror condition led to important modifications on the directions habitually used in the normal condition. Specifically, subjects tended to preserve a "visual syntax" rather than a "motoric syntax." However, contrary to our hypothesis, specific difficulties for mirror-drawing obliques when vision is dominant ("multiple" choice versus "binary" choice, Lajoie et al., 1992) were not observed, oblique figure directions as well as horizontal and vertical figure directions being perturbed in the same manner. These ambiguous results led us to check whether subjects could be classified as a function of the movement directions performed on the paper sheet, favoring either reversed or non-reversed movement directions when resolving the visuo-proprioceptive discordance.

A correspondence analysis carried out on the frequencies of movement directions showed that subjects could be classified in 2 groups as a function of the movement directions realized in the mirror task. The first group was called the "visual group," because of the apparent dominance of visual information for movement control in their behavior, since they tended to reverse performed directions in order to preserve the visually perceived ones. These subjects had difficulties in producing obliques and horizontals. It
could be suggested that biomechanical constraints from the effector system prevent subjects from performing the required directions. Indeed, in the MIRLe condition, perceived directions toward the right imply that subjects performed directions towards the left. This assumption is coherent with the fact that right-handers have difficulties in producing straight lines towards left and top-left (Van Sommers, 1984).

The second group was called the "propiroceptive group," because of the apparent dominance of proprioceptive information for movement control. Subjects performed graphic movements as they did in the normal situation, the resulting perceived movements being reversed in comparison to the normal condition. These subjects had difficulties in performing left-to-right horizontal only. It could be difficult for subjects to ignore visual information when producing the motorically most complex segments, i.e. the horizontals (Meulenbroek & Thomassen, 1991), and this may explain why the frequency of perceived horizontals in the left-to-right direction was important at the beginning of the task. This result also lends some support to Meulenbroek and Thomassen's conception (1991) regarding the distinction between the anatomical (oblique) and geometrical (horizontal-vertical) systems of reference. Recall that the geometrical system is expected to be more sensitive to visual feedback than the anatomical system. Further studies should investigate this point of view. When the mirror is located in front of the subject performing non-reversed movement directions, we would like to see whether vertical segment production requires visual guidance, like the horizontals did in the MIRLe situation.

The differentiation in 2 groups of subjects on the basis of movement directions performed in the mirror condition is also adequate for the normal condition, as revealed by the analysis of threading. Subjects who apparently based themselves on visual cues tended to favor preferred directions rather than threading when drawing horizontals and verticals, while it was the reverse for those who probably based themselves on proprioceptive cues, strongly applying threading whatever the item structure. In consequence, performance obtained from the "visual group" may confirm the assumption that graphic production of horizontals and verticals depends on a geometrical system of reference and is more sensitive to visual information than obliques (Meulenbroek & Thomassen, 1991).

The secondary aim of the present study was to examine how the resolution of visuo-propiroceptive discordance takes place by means of time-series analysis. Results reported how subjects learned to reorganize new visuo-proprioceptive correspondences through practice as a function of their preferred drawing movement directions. It appears that performance of subjects from the "propiroceptive group" evolved through practice with an increase of the production of the right-oriented horizontal directions. For subjects from the "visual group," no learning effect was observed with regard to movement directions, visually guided directions being strongly present from the beginning of the task. These results suggest that when visual and proprioceptive information are discordant, adaptive recalibrations of the visual system are more difficult to perform than adaptive recalibrations of the proprioceptive system. To disregard proprioceptive information should thus be easier than to disregard visual information, in a mirror-drawing task where visual information is not strongly perturbed.

Modifications of mirror-drawing performance through practice were also revealed by an analysis of directional errors. We noted a practice effect for oblique items whatever the group of subjects. However, errors rapidly decreased for the "propiroceptive group," while
the decrease was gradual for the "visual group." These observations suggest that subjects who reversed movement directions performed on the paper sheet needed more trials to learn new correspondences between visual and proprioceptive information than subjects who did not reverse movement directions. These results lend further support to the hypothesis that obliques are strongly affected by the resolution of visuo-proprioceptive discordance from visual cues (multiple choice, Lajoie et al., 1992), while they are motorically simpler to produce when the conflict is resolved from proprioceptive cues (Menkenbroek & Thonnassen, 1991). We expected that the number of errors would be greater for the horizontal-vertical structure than for the oblique structure when subjects belong to the "proprioceptive group." Results did not confirm this expectation. In the first block of trials, errors were significantly more frequent for items made up of obliques. Because the visual modality is not profoundly perturbed in a mirror-drawing task, it may be that vision plays a role at the beginning of the task for the "proprioceptive" subjects, but that their preferred dominant strategy leads them to ignore visual information through practice.

In conclusion, this study showed that different subjects make use of different strategies in the planning of syntactical features of mirror-drawing movements, probably based either on proprioceptive information or on visual information (Paillard, 1991). It also appears that both groups reorganize differently the new visuo-proprioceptive correspondences through practice. With regard to the references that subjects probably take into account in each group (either proprioceptive or visual references), it appears that specific difficulties depend on the item structure. Subsequent studies could be undertaken in order to investigate further the difference in drawing behavior between the "visual" and "proprioceptive" groups. Movement execution should differ at the kinematic level and probably also with respect to the spatial accuracy of graphic production.

References

The Role of Visual and Proprioceptive Information in Mirror-Drawing...


