Mirror-writing: an experiment and a cognitive model.

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Summary.

Mirror-writing ability was assessed by asking 16 subjects (in a 2 x 2 x 2 design based on sex, handedness and eyedness) to write each of two phrases (their name, and the letters of the alphabet) in upper and in lower case, in each of eight writing conditions (unimanually, using the dominant or non-dominant hand, and writing in the normal or mirror direction; bimanually, with each hand writing in all possible combinations of normal or mirror direction). Skill was assessed by the time taken to write the phrase, and the quality of the writing produced (when viewed in the normal direction). With neither measure was there evidence for Orton's suggestion of homotopic mirror-image transfer of writing ability (i.e. so that mirror-writing with the non-dominant hand would be better than mirror-writing with the dominant hand, or normal writing with the non-dominant hand). Neither was there evidence for particular ease of simultaneous mirror-writing with the non-dominant hand and normal writing with the dominant hand, as Critchley (1928) has suggested. There was no evidence that left-handedness or eyedness related to mirror-writing ability.

The data are best understood in terms of mirror-writing being a spatial or cognitive skill, with different conditions involving different combinations of three separate cognitive transformations of the normal motor output. Estimates of the increased processing times for each transformation are given.

Introduction.

Mirror-writing, the ability to write from right to left, rather than in the normal Western direction from left to right, has been the source of much speculation and interest, albeit often with little empirical support (see e.g. Gordon, 1920; Blom, 1928; Critchley, 1928; de Ajuriaguerra *et al*, 1956; Hecaen and de Ajuriaguerra, 1964; Trueman, 1965; Barsley, 1966; Corballis and Beale, 1976; and Harris, 1980, for reviews).

The earliest report of mirror-writing was in 1698 by Rosinus Lentilus (*Miscellaneus medicopractica Tripartita*), in a left-handed epileptic girl (see Critchley, 1928). Theoretical interest in the neurology of mirror-writing was stimulated by the report of Ireland (1881), who reported Buchwald's observation of three right-handed patients with right-sided hemiplegia who subsequently produced mirror-writing with their left hand, and it was suggested that "when [a right-hander] used the left hand to write there would probably be a tendency to copy the inverse impression or image on the right side of the brain". The first use of this is sometimes attributed to Vogt (1880), although Critchley (1928) cites Erlenmeyer (1879); the hypothesis was also proposed by Lichtheim (1885). More recently Walton (1977) has re-iterated Brain's view that, "we must assume that the education of the right hand in writing involves the unconscious education of the left hand to perform the same movements in the opposite direction" (p.112).

Patients have been reported by Paradowski and Ginsburg (1971) and reviewed by Streifler and Hofman (1976). A separate line of interest concerns the syndrome described by Bauman (1932) of congenital mirror movements of the limbs, particularly the arms; such cases seem primarily to be associated with defects of the spine in the Klippel-Feil syndrome, and with agenesis of the corpus callosum (see Schott and Wyke, 1981).

Modern interest in mirror-writing was stimulated by the theory of Orton (1925), who noted an association between congenital dyslexia and mirror-writing, and he re-iterated Ireland's formulation of a transfer of information between homotopic areas of the cerebral hemispheres, the nature of the transfer across the mid-line resulting in a mirror-image transformation, be it of motor or perceptual engrams. The hypothesis has been carefully examined by Corballis and Beale (1976) who reject the perceptual version of Orton's theory, but conclude that mirror-image transfer of motor learning is a theoretical possibility, and is perhaps supported by the finding of Milisen and van Riper (1939) that transfer of a motor-learning task between hands was easier if the non-learning hand was tested with the mirror-image task. A similar result was also found by Simon (1948) and by Hicks et al (1983). Corballis and Beale also cite the phenomenon of mirror-writing as "consistent with the proposition that motor habits established primarily in one hemisphere tend to be mirror-reversed in the other " (p.72).

Orton (1928) noted that dyslectics, who have a tendency to be left-handed and male, have an increased ability to produce mirror-writing, and suggested that the dyslexia was a consequence of incomplete cerebral dominance, being associated with crossed eye and hand dominance (Orton, 1937). Luchsinger and Arnold (1925) and King (1965) have also suggested that eye-dominance might be related to mirror-writing ability, and Carmichael and Cashman (1932) have stressed the relationship to left-handedness; more recently it has been suggested that the association of mirror-writing with left-handedness is not convincing (Benton, 1975, p.24), although Critchley and Critchley (1978) repeated the suggestion.

Mirror-writing with the non-dominant hand has been claimed to be easier if one simultaneously writes forward with the dominant hand (e.g. Critchley, 1928; Bradshaw and Nettleton, 1983).

An alternative hypothesis to the homotopic transfer of information between the hemispheres has been put forward by Corballis and Beale (1976), and re-iterated by Bradshaw and Nettleton (1983), who note that mirror-writing, "can also be easily achieved with the preferred hand alone if you write on your own forehead, or on the underside of a board. This observation suggests that mirror-writing involves a spatial skill (imagining a writing surface from various personal standpoints) rather than a motor skill " (pp. 245-6). This spatial model would imply that mirror-writing with the

non-dominant hand would not be especially privileged, as compared with normal writing with the non-dominant hand. Hicks et al (1983) have proposed that cognitive transfer and motor transfer between the hemispheres may be distinguished; "cognitive or non-motor transfer would be for identical responses, whereas motor transfer would be to mirror-image responses". A crucial question, therefore, concerns whether mirror-writing in normal individuals involves motor transfer, as Orton's theory would predict, or cognitive transfer, as the Corballis and Beale / Bradshaw and Nettleton theory would predict. It must of course be remembered that the mechanisms of mirror-writing in normals and those with brain-damage may be different.

The present study has been designed to ask whether in normal individuals mirror-writing with the non-dominant hand is especially privileged (suggesting homotopic motor transfer) and whether mirror-writing ability is related to the handedness, eyedness or sex of subjects.

In designing our study we had some difficulty in deciding upon an appropriate form of material to be written. We wished to have items which which were well learned, so that subjects would have no memory problems in carrying out the writing task. We also wished to have one item which had been frequently written by the subject, and one which was rarely written as such, although both should be generally well-learned. Eventually we chose the subject's name (preceeded by the

initials) as a well-learned and frequently produced phrase, and the alphabet as a well-learned but rarely produced phrase. Clearly many other phrases could also have been chosen, but these gave some scope for differentiating any effects due to frequency of normal production.

We asked for both upper and lower case examples of each of the phrases, since, in general, upper case phrases are more unusual than lower-case; the cases also differ in their symmetry patterns, typical mirror-reversal problems occurring primarily in lower-case letters (e.g. p and q; b and d).

Method.

16 subjects took part in the experiment, all of whom were undergraduates at Bedford College. Between subject factors of sex, handedness and eyedness, along with order of task, were examined in a balanced 2 x 2 x 2 x 2 design. Handedness was assessed by writing hand, and confirmed by a 28-item handedness questionnaire (McManus, 1979). Eyedness was assessed as sighting dominance.

The subjects were asked to produce writing under 32 conditions; in 16 of the conditions they were writing with both hands at the same time, and hence overall each subject produced 48 separate specimens of hand-writing. On each condition subjects were asked to write either their name or the first half of the alphabet, in either upper-case (non-cursive)

or lower-case (cursive) script in a particular hand combination. The hand combinations are schematised in figure 1 (for a right-hander). Condition 1 consisted of writing with just the dominant hand in a normal direction. In condition 2 the subject was asked to produce mirror-writing with just the dominant hand. Conditions 3 and 4 consisted of normal and mirror-writing respectively with just the non-dominant hand. Conditions 5, 6, 7 and 8 were bimanual, and consisted of all possible simultaneous combinations of normal and mirror-writing with each of the hands. The within subjects variables therefore comprised a balanced design of phrase x case x condition. It must be stressed that in any one bimanual condition subjects were always producing the same phrase with the same case in each hand, albeit perhaps in different directions. The subjects were told that in the mirror-writing conditions they should "attempt to reverse both the word itself and each individual letter, producing a mirror-image, or what is known as mirror-writing". They were also told, "Please try to make your writing as legible, fluent and fast as possible".

The particular condition to be used in a trial was indicated by one of a set of 32 cards, each of which contained a diagram similar to one of those in figure 1. Subjects wrote on a pad of A4 paper using a fine felt-tipped pen. A fresh sheet of paper was used for each condition.

The 32 conditions were randomised in a single random order. Half of the subjects received the conditions in this order and the other half in exactly the reverse order.

Before the experiment proper each subject was asked to provide a control specimen of normal hand-writing, copying Shakespeare's Sonnett 116 from a typed sheet, the first four lines in upper case and the second four in lower case, This process was also repeated at the end of the experiment.

A five-minute break was given to subjects after the 16th condition. The whole experiment usually lasted less than an hour for each subject.

During each condition the subject was timed, using an ordinary stop-watch, and recording to the nearest whole second, from first starting writing to the pen(s) finally leaving the paper. This measure we will call the writing time.

The quality of the hand-writing specimens was assessed by two independent judges on a 7-point scale, relative to each subject's control hand-writing specimens, a score of 5 indicating the same overall quality as normal hand-writing. The judges were asked to rate the overall quality and legibility of the writing, without concentrating unduly on local features. Each specimen was assessed singly, the sheets produced bimanually being cut in half, and each specimen assessed separately. All specimens were assessed in the normal direction of writing. In order to prevent judges from knowing

whether a specimen was produced normally or in mirror-image, each specimen was placed with its recto in contact with a plain sheet of paper, and the two sheets of paper placed between glass and back-illuminated, so that the writing was viewed in the normal direction. Each specimen, whether produced normally or in mirror-image, was therefore judged in normal direction, while being viewed through a single sheet of paper. The judges were allowed a continuous view of the control specimens in order to help them make comparative judgements.

Results.

There are two separate dependent variables, the time taken to produce a specimen of writing, and the quality of the writing produced; these will be considered in turn.

i. Time to produce hand-writing specimens.

Analysis of data was was by a repeated measures analysis of variance, with handedness, eyedness, sex and order of presentation as between subject effects, and case, phrase and condition as within subject effects. Only first and second order interaction terms for between subject effects were tested in order to allow an adequate between subject error term. In view of the skewness of the writing times, the dependent variable was the logarithm of the time taken to complete the condition; it was also assumed, at least in the first

instance, that effects would probably work multiplicatively. In view of possible learning or fatigue effects the order in which a condition was carried out was entered as a covariate in all analyses. A small but significant covariate regression was found, (reg. coefficient = .0047, standard error = .00254), subjects tending to get slower as the experiment progressed, the last trial being 1.157x longer than the first.

No significant main effects of handedness, eyedness, sex or order were found.

Hand-writing condition had a highly significant effect upon writing time ($F(7,105)=108.31$, $p<0.001$) (Figure 2). In the unimanual conditions, normal dominant writing was the quickest; dominant mirror-writing and non-dominant normal writing were next quickest, and about equal in speed, and non-dominant mirror-writing was the slowest. Among the bimanual conditions, all were slower than the unimanual conditions and about equal in speed with one another, with the single exception of both hands producing normal writing, which was relatively quicker than the other conditions, and about the same speed as unimanual non-dominant mirror-writing. The seven degrees of freedom associated with writing condition were partitioned *a priori* into separate contrasts. One contrast compared unimanual with bimanual conditions (1+2+3+4 *vs.* 5+6+7+8; see figure 1). Within the unimanual conditions three contrasts examined the effects of dominant *vs.* non-dominant hand (1+2 *vs.* 3+4), normal *vs.* mirror-writing (1+3 *vs.* 2+4) and

the interaction of the latter two effects (1+4 *vs.* 2+3). Within the bimanual conditions, three orthogonal contrasts were considered *a priori*; the effect of the type of writing of the dominant hand (5+7 *vs.* 6+8), the effect of the type of writing of the non-dominant hand (5+8 *vs.* 6+7) and the interaction of these two effects (5+6 *vs.* 7+8). *A posteriori* it became apparent that a more appropriate comparison within the bimanual groups would have been 5 *vs.* 6+7+8. All of the seven *a priori* contrasts were highly significant (lowest F value = 17.84, 1,15 df, $p<0.001$).

Names were written more quickly than the alphabet ($F(1,15)=263.5$, $p<0.001$), and of course in most cases were shorter than the alphabet. The case in which a phrase was written had no main effect upon writing time ($F(1,15)=2.51$, NS), although there was an interaction with phrase ($F(1,15) = 22.09$, $p<0.001$), upper and lower cases names taking equal times (12.8 and 13.0 seconds respectively), while the upper case alphabet (27.6 seconds) took significantly longer than the lower-case alphabet (23.2 seconds).

Writing hand condition showed significant interactions with case of writing ($F(7,105) = 6.24$, $p<0.001$), mirror-writing with the dominant hand being slightly longer in upper than lower case, and with phrase ($F(7,105) = 2.47$, $p<0.05$), the alphabet being slower than the name in condition 6. There was no triple interaction of condition, case and phrase.

Neither handedness, eyedness, sex or order showed significant interactions with the writing hand condition, and neither did handedness interact with condition x phrase, condition x case or condition x case x phrase interactions. Figure 2 shows the mean log.times separately for right- and left-handers. It should be noted that the only visible difference between the handedness groups is in the bimanual condition in which the dominant hand is writing normally and the non-dominant hand is writing in mirror (condition 7), and that it is the right-handers who are quicker, counter to any prediction that left-handers might be better at this task.

ii. Quality of writing produced.

Each specimen of hand-writing produced by each hand (i.e. 48 specimens per subject) was assessed by two independent judges. The correlation between the scores of the judges was 0.684 ($P<0.001$), suggesting that the reliability of judges was adequate. The scores from each judge were averaged to give a single quality score for each specimen, and this score was the dependent variable in an analysis of variance which was similar to that described above except that there were twelve hand-writing conditions rather than eight, and order was not used as a co-variate. These twelve conditions may be described according to the hand doing the writing (dominant vs. non-dominant), the direction of the writing (normal vs. mirror), and the activity of the opposite hand (nothing vs.

writing in the same direction *vs*. writing in the opposite direction), the latter effect being further partitioned into two contrasts, (nothing *vs*. same+different) and (same *vs*. different).

There were highly significant differences between the hand-writing conditions ($F(11,165)=64.28$, $p<0.001$) (figure 3). Irrespective of the activity of the other hand, the dominant hand produced higher quality writing than the non-dominant hand, and mirror-writing was worse than normal writing (irrespective of hand). In general there were only minimal differences between the unimanual and bimanual conditions in which the hands were carrying out the same or opposite tasks. For the unimanual conditions there was a highly significant effect of writing hand ($F(1,15)= 83.07$, $p<0.001$), a highly significant effect of type of writing ($F(1,15)= 30.63$, $p<0.001$), but no interaction between writing hand and writing type ($F(1,15) = 0.02$, NS). For the bilateral 'same' conditions there were effects of writing hand, type of writing and their interaction ($F(1,15) = 120.76$, 25.77 and 24.38 respectively, all $p<0.001$). For the bilateral 'opposite' conditions there were effects of writing hand and writing type ($F(1,15) = 146.21$, $p<0.001$ and 18.49, $p<0.001$ respectively) but no interaction ($F(1,15)=0.0$, NS). Overall unimanual conditions produced better writing than bimanual conditions ($F(1,15) = 44.22$, $p<0.001$) but there was no difference between bimanual 'same' and 'opposite' conditions ($F(1,15)= 0.90$, NS).

There was a highly significant effect of case ($F(1,15)=27.57$, $p<0.001$), lower case writing being of higher quality than upper case, but there was no significant effect of phrase ($F(1,15)=1.68$, NS). There was a significant interaction between case and phrase ($F(1,15)=12.81$, $p<.01$), the difference between upper and lower case alphabet being greater than the that between upper and lower-case name. The condition x case interaction was not significant, although the condition x phrase interaction was significant ($F(11,165)=3.26$, $p<0.001$). The latter was mostly accounted for by a greater difference between dominant and non-dominant hands in the bimanual 'opposite' direction ($F(12,15)= 9.78$, $p<0.001$), for the alphabet than for the name, with smaller effects due to differences in the writing hand x writing type interaction in the bimanual 'opposite' condition ($F(1,15)= 7.39$, $p<0.05$) and between writing hands in the bimanual 'same' condition ($F(1,15) = 5.37$, $p<0.05$). The triple interaction between condition, case and phrase was not significant.

The main effects of handedness, eyedness, sex and order were not significant. Handedness showed a significant interaction with condition ($F(11,11) = 4.09$, $p<0.05$) (Figure 3). This interaction was entirely accounted for by left-handers having a greater difference between dominant and non-dominant hands in the condition in which the other hand was writing in the same direction ($F(1,15) = 13.71$, $p<0.005$). Handedness showed no significant interactions with case, phrase, case x phrase, case x condition, phrase x condition, or

case x phrase x conditions. Eyedness, sex and order showed no significant evidence of interactions with condition, case or phrase.

Discussion.

The present study has found no evidence that mirror-writing ability in normal young adults is related to handedness, eyedness or sex, all factors which Orton had suggested were associated with both mirror-writing and developmental dyslexia. It is of course possible that these factors are predictive of mirror-writing ability in dyslectics, or in groups with organic brain-damage.

Analysis of the ease of writing in various unimanual and bimanual conditions finds no evidence for a privileged position of mirror-writing with the non-dominant hand; rather such writing is more difficult than mirror-writing with the dominant hand, or normal writing with the non-dominant hand. Neither is there evidence for the suggestion of Critchley (1928) that mirror-writing with the non-dominant hand is easier if the dominant hand simultaneously writes in the normal direction, since this condition is more difficult than the one in which both hands are writing in the normal direction. Taken together, and following Hicks Et al (1983), these observations provide support for a 'cognitive' or 'spatial' model of mirror-writing in normals, rather than a 'motor transfer' model.

A simple cognitive model of mirror-writing may readily be produced. It is assumed that the normal writing output has to be transformed in a number of ways to produce the unusual writing conditions described in this experiment. Consider three transformations:-

1. MTRANS: the mirror-image transformation of a motor-sequence.

2. NDTRANS: the transfer of a motor-sequence from the dominant to the non-dominant hand.

3. BTRANS: the transformation necessary to write with both hands simultaneously, rather with than just a single hand.

The eight writing conditions of figure 1 each require different combinations of these three transformations. Normal writing with the dominant hand (1) requires no extra transformations. Mirror-writing with the dominant hand (2) requires MTRANS; normal writing with the non-dominant hand (3) requires NDTRANS; and mirror-writing with the non-dominant hand (4) requries both MTRANS and NDTRANS. Bimanual writing in the normal direction with both hands (5) requires BTRANS and NDTRANS, while conditions 6,7, and 8 all require MTRANS, BTRANS, and NDTRANS. Given such a model, estimates of the times required for each transformation may be found. Using a logarithmic scale (i.e. so that all transformations act multiplicatively) then the three transformations together account for 95.5% of the variance in the eight conditions.

If the present interpretation of mirror-writing in normals as a cognitive rather than a motor skill is correct, then two questions arise. Firstly, why is mirror-writing a consequence of brain-damage, as for instance after hemiplegia? Here we may follow Critchley (1970) and Paradowski and Ginsburg (1971) who have stressed the relative rarity of mirror-writing after hemiplegia, only one out of 41 hemiplegics in Paradowski and Ginsburg's series showing spontaneous mirror-writing. It is possible therefore that mirror-writing is not a consequence of hemispheric damage but is rather a consequence, as in congenital mirror movements, of separate and concomitant damage to the pyramidal system at a more distal level; in such manner the rarity of mirror-writing would be comprehensible, and only a single neuro-pathological mechanism would be required. This would also be compatible with the suggestion of Schott (1980), who described 10 right-handers with damage to the brachial plexus on their dominant side, a majority of whom showed facility in producing mirror-writing; he concluded that "[this type of] mirror-writing is a phenomenon linked not to language but to movement" (p.772), and suggested that normal movements would be symmetrical if it were not for contralateral inhibition of movement (a phenomenon first hypothesised by Westphal (1875)), and that extra-cranial damage might modify this inhibitory system. The strong implication of such theorising is that mirror-writing as a pathological activity is related to peripheral motor or kinaesthetic damage, when it manifests as a movement disorder, whereas in most normal

adults, and in some with central damage, mirror-writing is a cognitive process, which can be associated with functional abnormality.

The second question concerns the reasons for the relative commonness of mirror-writing in the young and the mentally retarded (Walton, 1977). Perhaps the best explanation is that of Fildes (1923) who implies that a cognitive model of mirror-writing is required; "reversed, or 'mirror', writing is only a particular case of a tendency shown by a large proportion of children i.e. the tendency to draw a form in a different position from that in which it is presented " (p.66). That is, the forms may be transformed erroneously in many ways, one of which happens to be consistent with the particular neuroanatomical substrate but could actually have either a cognitive or structural origin (homotopy), whilst other transformations are also relatively common and may only have a cognitive basis. Mirror-writing in the young and the retarded should not therefore be regarded as an ability, but rather as a failure to use an appropriate cognitive transformation, or the using of an inappropriate transform.

In conclusion mirror-writing in normal individuals may best be regarded as a cognitive transformation, either desired or undesired, of a normal behaviour, and it shows no causal relation to the homotopic organisation of the cerebral hemispheres.

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Figure 1. Shows schematically, for a right-hander, the eight writing conditions used in the experiment. The arrow indicates the direction of writing (-----> Normal; <------ Mirror), and the columns marked L and R indicate the activity of right (dominant) and left (non-dominant) hands respectively. An open circle indicates that the hand was not writing. For left-handers the L and R columns should be inter-changed.

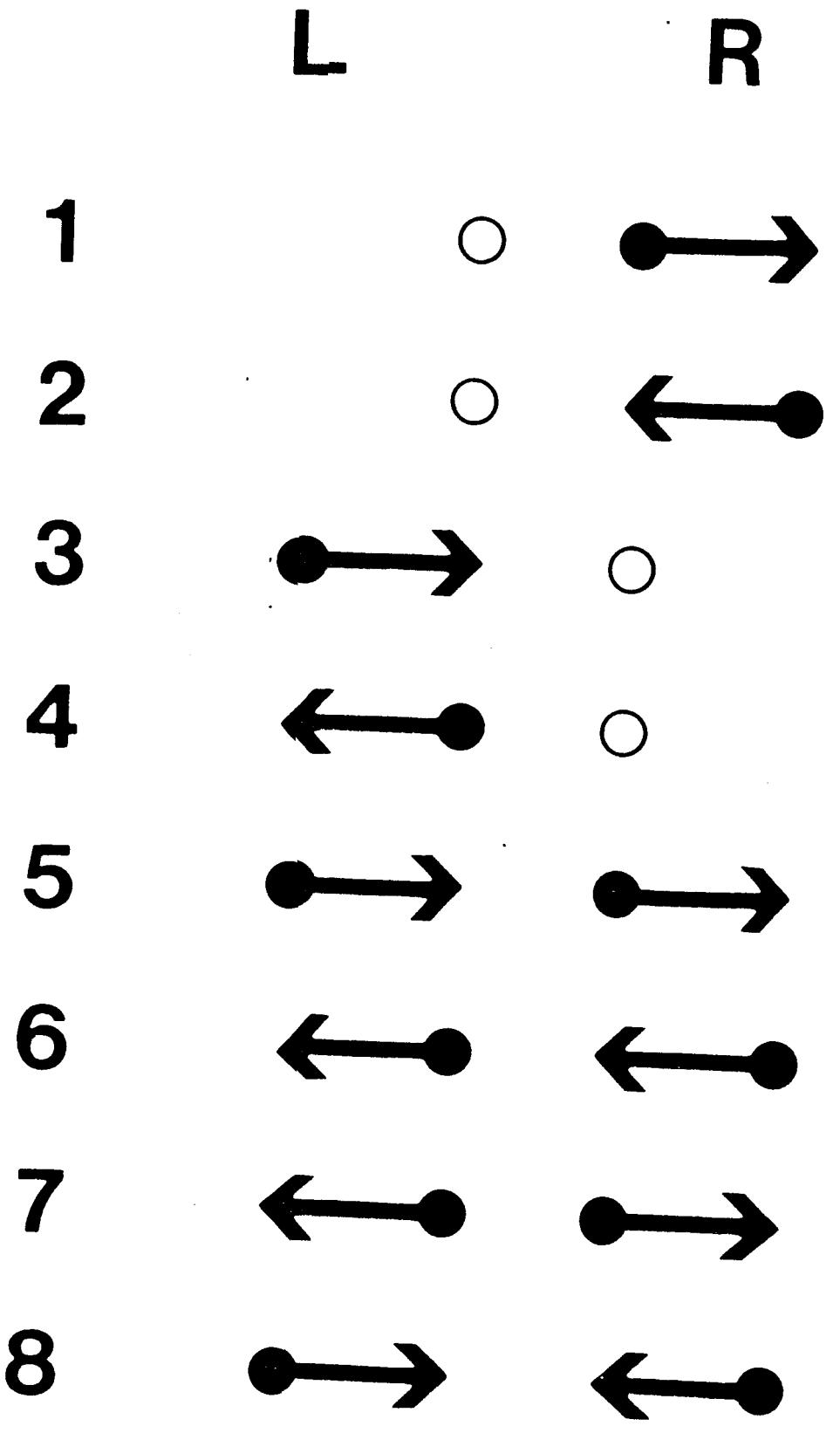
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Figure 2. The ordinate shows the mean log.time to complete each of the eight conditions; the left-hand ordinate shows the time in loge (seconds) and the right-hand ordinate shows the time in seconds on a logarithmic scale. The abscissa shows the activity of the dominant hand; N: normal writing; M: mirror writing; O: Not writing. The three lines on the graph give a similar breakdown, according to the activity of the non-dominant hand (◻◼ ◶● normal writing; △▲ mirror writing; ○● not writing), for right-handers (● ■ ▲) and left-handers (○ ◻ △). For obvious reasons no point is plotted for the case in which neither dominant nor non-dominant hand is writing. Error bars indicate 95% confidence limits for means.

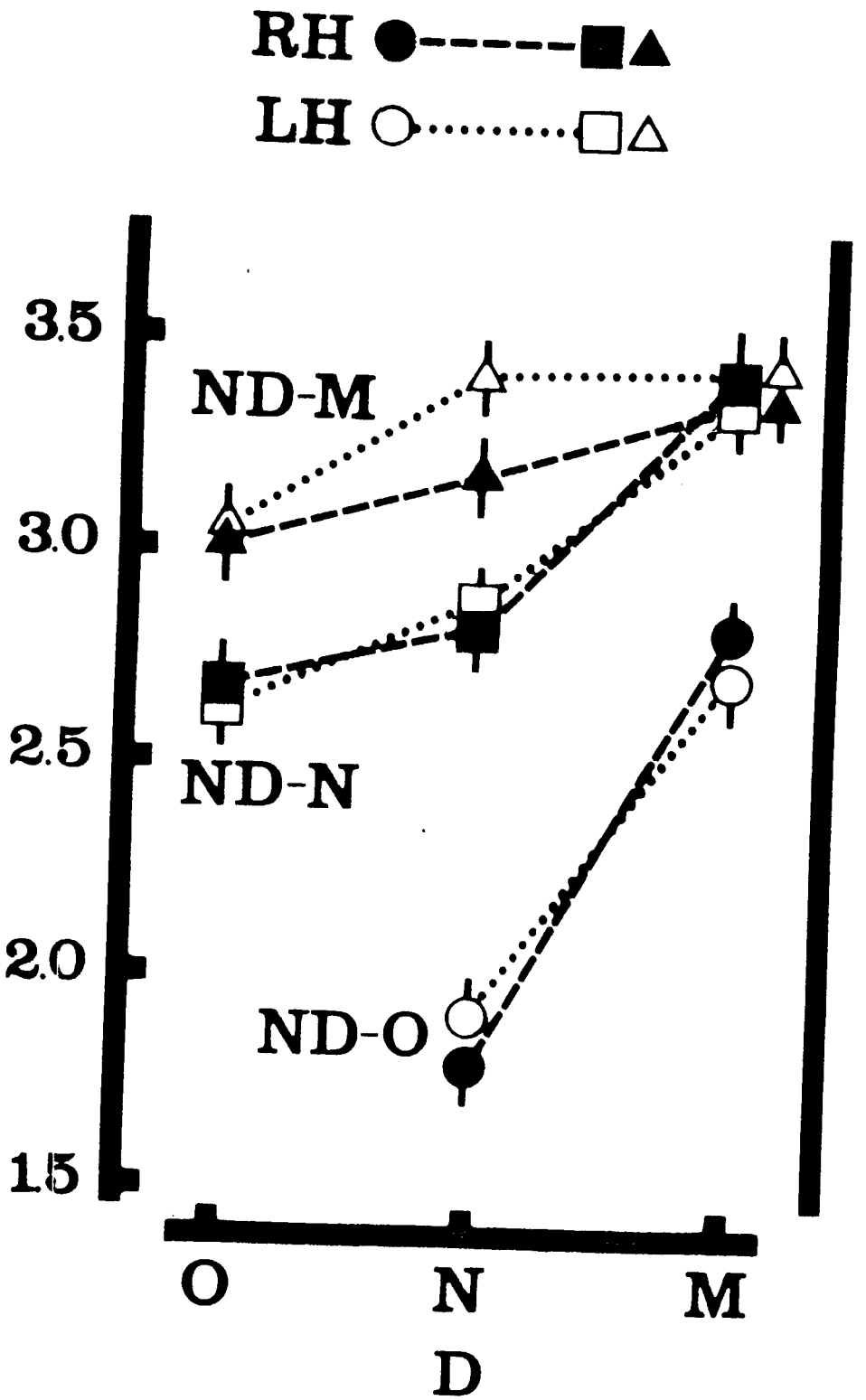
RH
LH
3.5
3.0
2.5
2.0
1.5
ND-M
ND-N
ND-O
O
N
M
D

Figure 3. The ordinate shows the mean quality of writing for each of the twelve types of writing specimen: a scale value of 5 indicates writing of normal quality, relative to the control specimens. The abscissa shows the hand producing the writing (D: Dominant; ND: Non-dominant), and the activity of the other hand (Nothing: other hand not producing writing; Same: other hand producing same direction of writing; Different: other hand producing opposite direction of writing). The solid lines join points representing normal writing conditions, and the dashed lines join points representing mirror-writing conditions. Right-handers are indicated by solid points (●) and left-handers by open points (○).

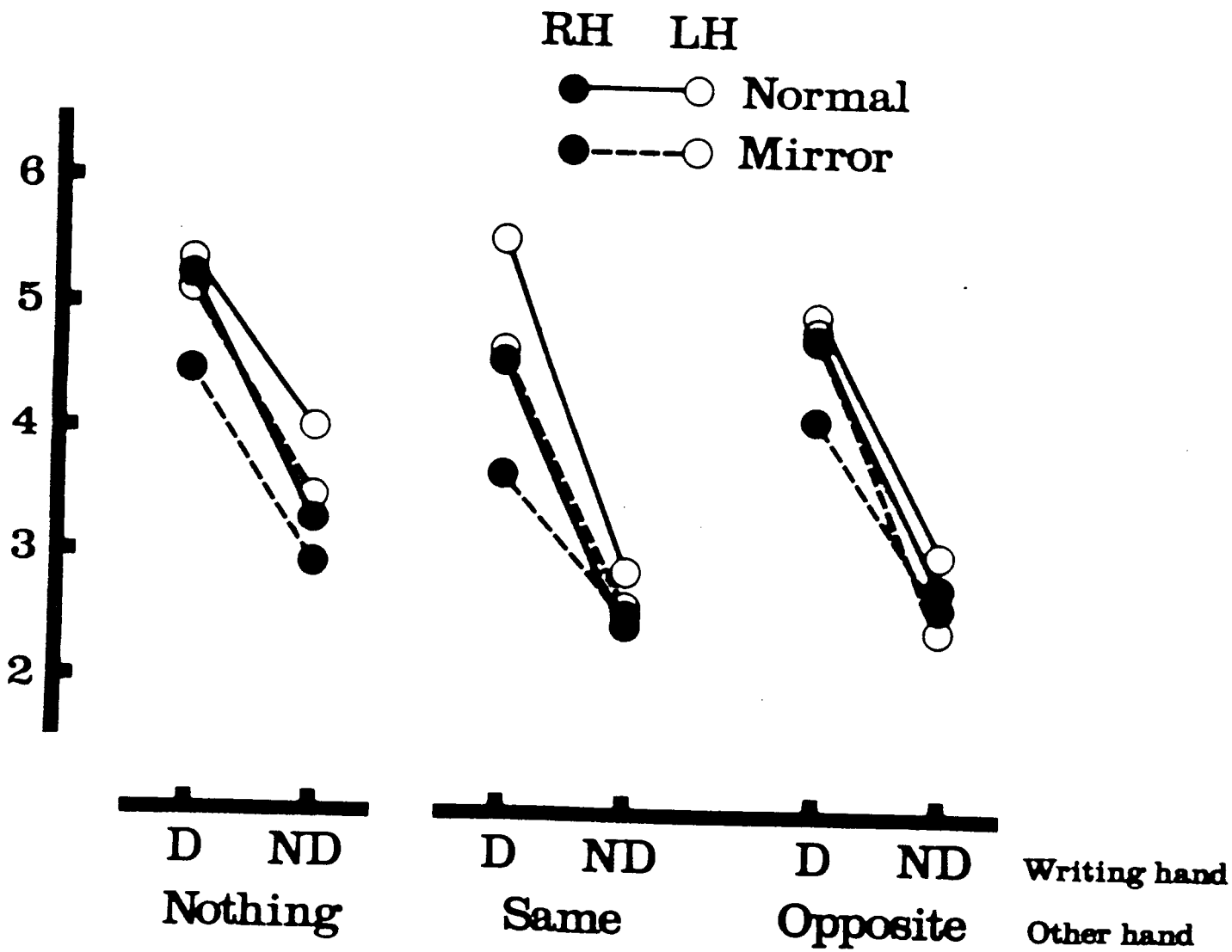
RH LH
Normal
Mirror
6
5
4
3
2
D ND
Nothing
D ND
Same
D ND
Opposite
Writing hand
Other hand

Table 1.

Condition	Dom. Hand	Non-dom.hand	Geometric Mean time	Transformations required	Increased performance time
1	Normal	-	6.30	PRACT	1. x
2	Mirror	-	15.55	MTRANS	2.47 x
3	-	Normal	14.10	NDTRANS	2.17 x
4	-	Mirror	20.51	MTRANS, NDTRANS	3.36 x
5	Normal	Normal	17.55	BTRANS, NDTRANS	2.87 x
6	Mirror	Mirror	29.61	MTRANS, BTRANS, NDTRANS	4.44 x
7	Normal	Mirror	28.93	MTRANS, BTRANS, NDTRANS	4.44 x
8	Mirror	Normal	26.39	MTRANS, BTRANS, NDTRANS	4.44 x