Why the Preferred Hand Taps More Quickly than the Non-preferred Hand: Three Experiments on Handedness*

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ABSTRACT

Three separate experiments pursue the question of why the preferred hand outperforms the non-preferred hand on a simple finger tapping task. Experiment I rules out possible differential effects of fatigue on the differences between hands. Experiment II shows that the single-direction components of the 'up' and 'down' travel of the index finger are not significantly related to tapping speed and contribute little to the performance differences between hands. This is not so for the reversal portion of the tapping movement, where the transition between movement directions is made. This portion contributes significantly to the superiority of the preferred hand. It is suggested that sensory feedback plays a minor role and that the principal factor in the preferred hand's better performance is precision of force modulation. Manipulation of this factor (Experiment III) leads to changes in the magnitude of the preferred hand's superiority.

The question of why the preferred hand comes to be the preferred hand remains unanswered. This is acknowledged in a recent review by Searleman (1977) who states that the problem of even measuring handedness remains unsolved. Some researchers have attempted to approach the concept 'handedness' by attempting to define the characteristics of tasks which yield performance asymmetries. For instance, Provins and Glencross (1968) and Steingruber (1975) feel that task complexity is an important variable contributing to hand performance asymmetries. Flowers (1975) suggests that the degree to which sensory feedback is involved in the guidance of skilled movement is an important factor in performance asymmetries. Kimura (1977) adds another variable, the extent to which postural transitions are required by the task.

An alternative approach lies in the analysis of performance characteristics of the two hands on a given task. The experiments described in this paper examine the difference between the preferred and non-preferred hand on a finger tapping task. Previous work has shown that the preferred hand performs both more quickly and more regularly (Peters & Durding, 1978, 1979a). In this paper, three experiments further analyze between-hand performance differences on this task. Experiment I examines the possible effects of fatigue on the differences between hands. Experiment II breaks the task down into component movements, answering the question of whether between-hand differences emerge when parts of the finger tapping movement are performed or only if the entire movement cycle is performed. Experiment III, based on findings made in Experiment II, tests the prediction that differences between hands can be amplified by manipulation of factors identified in Experiment II as contributing to such differences.

EXPERIMENT I: THE ROLE OF FATIGUE

While strength as such does not appear to be directly related to finger tapping performance (Barnsley & Rabinovitch, 1970), it may contribute indirectly to performance differences between hands: the non-preferred hand may tire sooner than the preferred hand. Experiment I was designed to investigate the effects of fatigue on tapping performance under the conditions which normally yield a clear perform-

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ance difference between the hands. In this experiment, the intertap intervals between each tap for each trial were measured by computer. This allowed an answer to the question of whether fatigue affects the two hands differentially.

Subjects
Twenty-four unpaid volunteers of each sex and handedness combination were used as subjects. All were self-labelled right- and left-handers who were also identified as right- or left-handers on the basis of their responses to a short preference questionnaire (which hand is preferred for writing, holding a hammer, throwing a ball, holding a spoon, comb, and toothbrush).

Apparatus
Subjects performed a finger tapping task on a lever which was connected to a microswitch. The microswitch was connected to a computer which allowed measurement of the duration of intertap intervals. The first tap initiated a 10 sec interval during which all taps were recorded.

Procedure
All subjects were shown how to tap. Only the index finger was to be used with no hand movement and all other digits were to rest on the surface on which the microswitch was mounted. Subjects were instructed to tap as quickly as possible. All subjects performed ten 10 sec trials with each hand, alternating hands from trial to trial. The beginning hand was alternated from subject to subject.

RESULTS AND DISCUSSION
The subjects performed on the motor task and expressed hand preferences in accordance with their self-labelling. As in previous studies (Peters & Durding, 1979a), right-handers as a group achieved a preference score which was close to the possible maximum of, in this case, six (on the basis of a score of 1 for each activity for which a right-hand preference was expressed). Left-handers, also in agreement with previous studies, were slightly less clear in their choices, with an average score of -5.3. These preference scores are a function of using volunteers who are self-labelled right- or left-handers. Right- and left-handers from a randomly drawn sample would have less clearly defined preference scores (Peters & Durding, 1978).

The performance data of the subjects were analyzed by using the duration of the intertap intervals as an indicator of speed of tapping. A lengthening of the intervals towards the end of a tapping trial indicates slowing of movements. Out of a number of possible measures, the contrast between the average of the last 3 intervals of each trial and the average interval for that trial was chosen. Figure 1A shows the results for all sex and handedness groups. Each data point in the figure represents the average over ten trials each for 24 subjects. It can be seen that for all groups the average intertap interval over the last three recorded intervals was longer than the average intertap interval computed for the entire trial. This indicates a slowing of tapping towards the end of the trial. This slowing, as the graph indicates, was similar for the preferred and non-preferred hand. An ANOVA for repeated measures, using the difference between the average intertap interval and the average of the last three intertap intervals per trial for each hand and each subject as variable, showed no significant differences between the preferred and non-preferred hand ($F_{1.23} = .69, \text{n.s.}$). The overall performance of the subjects is in accord with that of larger samples (Peters & Durding, 1979a): males tap faster than females and the differences between hands are smaller for left-handers than for right-handers. The results are in agreement with those of Barnsley and Rabinovitch (1970), who also felt that preferred vs. non-preferred hand performance differences are not due to differential effects of fatigue.

Figure 1B gives an indication of the trends within a trial. Given are the durations for the intertap intervals for the first, second, and third intertap intervals as well as the average of the last three intertap intervals. The values for the preferred and non-preferred hand of all subjects were used to construct these data points. It can be seen that the first intertap interval is con-
FIGURE 1  Comparison of average intertap interval (ITI) with average of last three ITIs per trial (A) and comparison of average first, second, and third ITIs with average of last three ITIs (B). $\bar{X} = \text{average ITI}$, $L_3 = \text{average of last three ITIs}$, $1, 2, 3 = \text{average ITI for first, second, and third ITI in each trial}$, $TX = \text{overall average ITI for preferred and non-preferred hand}$, $MRL = \text{male right-hander left hand}$.

siderably longer than the two succeeding ones, in fact, almost as long as the intervals at the end of the trial. This is a very consistent trend and indicates a 'mini' warm up effect at the beginning of the trial.

It should be noted that the trends for the preferred and non-preferred hands are very similar. The between-hand differences emerge even on the very first intertap interval measured. The slowing of the movement towards the end of the trial cannot be attributed exclusively to peripheral factors. There is a possibility that adaptation of so-called command neurons (Rosenbaum, 1977) may contribute to changes in the duration of intertap intervals.

EXPERIMENT II

In evaluating the significance of the performance differences between the hands on the finger tapping task, the question of what aspects of the task contribute to the differences arises. Specifically, it may be asked whether left/right differences emerge when components of the tapping movement are performed or only when the full cycle of repetitive tapping movements is performed. If the former alternative applies, left/right differences may simply arise in an additive fashion on the basis of asymmetries in the performance in component movements. If the latter alternative applies, left/right performance differences on the task may involve differences in central motor planning and execution of chains of movement. Experiment II was designed to decide between these alternatives.

**Subjects**

Two groups of subjects were used for two phases of Experiment II. All subjects were male right-
Component movement times and tapping times for Group 1, Experiment II

<table>
<thead>
<tr>
<th>N</th>
<th>up</th>
<th>down</th>
<th>up/down</th>
<th>down/up</th>
<th>Taps/10 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>R</td>
<td>15.3</td>
<td>12.9</td>
<td>113.8</td>
<td>135.3</td>
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<tr>
<td>28</td>
<td>L</td>
<td>16.7</td>
<td>15.5</td>
<td>124.4</td>
<td>143.8</td>
</tr>
</tbody>
</table>

* = time in msec, R = right side.
N = number of subjects.

handers and identified as such by the procedures outlined in Experiment I. Group 1 had 28 subjects and Group 2 had 15 subjects.

Apparatus

A finger tapping apparatus similar to the one in Experiment I was used. In addition, an apparatus was used which allowed measurement of individual phases of the tapping movement. This apparatus had two vertical rods, separated by a gap of 5 mm, mounted side by side on a platform. Photocells were attached to the bottom of the rods and to a point 2.5 cm above the bottom pair of cells. The distance between the top and bottom pair of photocells was adjustable.

When performing on this apparatus, subjects would slip a metal thimble over their index finger. A vertical metal blade was attached to the thimble and this blade moved between the vertical rods. When performing finger tapping movements with the blade, the blade interrupted and released the photobeams. The following measurements could be taken:

1. Simple movement from top to bottom. This was the ‘down’ or flexor portion of the movement. In all cases the distance of vertical travel was 2 cm.
2. Simple movement from bottom to top. This was the ‘up’ or extensor portion of the movement.
3. Total movement from top to bottom and back to top. This was the ‘down-up’ portion.
4. Total movement from bottom to top and back to bottom. This was the ‘up-down’ portion.

The difference between 3 and 4 was that movement commenced from an active holding position in 3 and from a resting position in 4.

Procedure

Subjects in Group 1 were familiarized with the apparatus and performed ten trials for each type of movement with each hand. The beginning hand was alternated from subject to subject and the order of conditions performed was counterbalanced. At the end of this test, subjects performed ten 10 sec finger-tapping trials on the tapping apparatus with each hand in order to establishing tapping rates.

Subjects in Group 2 performed on the same apparatus as subjects in Group 1. However, an additional measure was introduced which became available only after Group 1 had finished the experiment. This measure consisted of the reversal time taken for the ‘down-up’ portion. Thus, for the ‘down-up’ portion, four measures could be taken: (1) The time taken to travel from top to bottom, (2) the time taken from arriving at bottom to leaving it, (3) the time taken to travel from bottom to top, and (4) the total time taken for the ‘down-up’ portion. Subjects in Group 2 completed 15 trials on the ‘down-up’ phase with each hand. All 15 trials were given first to one hand, then to the other. The beginning hand was alternated from subject to subject. After this, the subjects also performed on the finger tapping apparatus as in Group 1, in order to establish left and right hand tapping rates.

RESULTS

Table 1 provides the average movement times in msec for the subjects in Group 1, as well as the average tapping rates. An ANOVA for repeated measures carried out for the simple ‘up’ and ‘down’ movements showed a significant main effect for the hands. Thus, the right hand performed more quickly than the left hand ($F(1, 27) = 12.7, p < .0014$). Also, the ‘down’ movement was performed more quickly than the ‘up’ movement ($F(1, 27) = 9.26, p < .005$). A single factor comparison showed that the right hand did not move significantly faster than the left in the ‘down’ movement ($F(1, 27) = 2.8, p < .101$), but it did in the ‘up’ movement ($F(1, 27) = 9.82, p < .0041$).

Thus, the left/right differences for the simple movements emerged significantly only in the ‘up’ portion. An ANOVA for re-
TABLE II
(A) Correlations between overall repetitive tapping performance and performance on isolated portions of the tapping movement, and (B) Correlations between the left and right hand on repetitive tapping and isolated portions of the tapping movement ($N = 28$)

<table>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>up</td>
<td>down</td>
<td>up/down</td>
<td>down/up</td>
<td></td>
</tr>
<tr>
<td>RTAP</td>
<td>.08</td>
<td>.08</td>
<td>-.24*</td>
<td>-.41</td>
<td></td>
</tr>
<tr>
<td>LTAP</td>
<td>.02</td>
<td>.08</td>
<td>-.41</td>
<td>-.52</td>
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</table>

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<thead>
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<th>B</th>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>TAP</td>
<td>up</td>
<td>down</td>
<td>up/down</td>
<td>down/up</td>
</tr>
<tr>
<td></td>
<td>.85</td>
<td>.86</td>
<td>.66</td>
<td>.82</td>
<td>.85</td>
</tr>
</tbody>
</table>

*Correlation coefficients. The negative sign indicates that as the movement time decreases, the number of taps/10 sec increases. $R =$ Right, $TAP =$ Taps/10 sec, up = movement from bottom to top.

peated measures for the compound 'up-down' and 'down-up' movements showed a significant effect for hands ($F (1, 27) = 49.64, p < 3.4 \times 10^{-7}$), and for direction of movement ($F (1, 27) = 16.26, p < .0004$). The right hand was faster than the left in both the 'up-down' ($F (1, 27) = 7.84, p < .008$) and in the 'down-up' ($F (1, 27) = 9.99, p < .009$) movements.

Finally, comparison of the finger tapping rates showed that the right hand tapped significantly faster than the left ($t (54) = 9.98, p < 7.34 \times 10^{-10}$). Table II provides the correlation coefficients between the right and left hand for the various types of movement. It can be seen that these correlations were high and even the lowest correlation coefficient ($r = .66$) was significant ($t (26) = 4.47, p < .0005$). A different result was obtained when the performance on the various component movement tasks was correlated with the finger tapping performance. The correlation coefficients for these comparisons are also given in Table II. There were no significant correlations between the rate of finger tapping and the single direction movements. Three of the four correlation coefficients relating the 'up-down' and 'down-up' movements to tapping rate were significant. These correlation coefficients were not impressive and accounted for only a small proportion of the variance. A cautious interpretation would be that speed of movement on the single direction task was not related to speed of finger tapping. For the compound movements, fast times tended to go along with faster tapping performance.

The results for Group 2 are given in Table III. In the measurements for this group, the single direction 'up' and 'down' times were recorded as the sum of the two measures. It can be seen that the differences between the preferred and non-preferred hand are most clearly expressed in the total movement time (22 msec) and in the time taken to reverse movement (16.5 msec), while the difference between hands in the single direction times was quite small (5.5 msec). The difference between hands in the total movement times was significant ($t = 4.08, p < .001$), as was the difference between hands in the reversal time ($t = 3.06, p < .01$). The difference between hands in single movement times failed to reach significance. Comparison with Table I shows that the total movement time for the preferred hand is similar in Group 1 and Group 2 while the time for the non-preferred hand is somewhat longer for Group 2. It can also be seen that the combined single direction movement times are longer for Group 2 than Group 1.

DISCUSSION

The data show a clear difference between tapping rate were significant. These correlation coefficients were not impressive and accounted for only a small proportion of the variance. A cautious interpretation would be that speed of movement on the single direction task was not related to speed of finger tapping. For the compound movements, fast times tended to go along with faster tapping performance.

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DISCUSSION

The data show a clear difference between

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Reversal</th>
<th>Up + Down</th>
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<tbody>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>R</td>
<td>154.8*</td>
<td>97.3</td>
</tr>
<tr>
<td>16</td>
<td>L</td>
<td>156.8</td>
<td>113.8</td>
</tr>
</tbody>
</table>

| Time in msec, Total = total time measured for down and up movement, Reversal = time taken from arriving at 'down' position to leaving this position, Up + Down = single direction movement times taken to travel down and up combined. |
the speed of extensor and flexor movements (Group 1). If a difference in strength is involved, this factor is not expressed very strongly in movement times: preliminary studies show that the ratio of flexor to extensor strength in moving weight over a pulley is 5:1 or higher, while the ratio of speed amounts to 1.2:1. In addition, the 'down-up' movement was slower than the 'up-down' movement even though the distance travelled was the same. In the former case movement commences from an active holding position while in the latter case movement commences from a resting position.

The results for Group 1 show that the differences between right- and left-hand performance become more pronounced as the movement becomes more complex. Is this trend due to simple additive effects or are the types of movement performed qualitatively different? It is of some interest in this context that the single direction movement performance and the finger tapping performance showed a correlation of close to zero. There was a significant correlation, albeit not very impressive, between the compound movement performance and the finger tapping performance. The factor which the two latter tasks have in common, and which the single direction movement lacks, is that both involve sequencing of component movements.

The results for Group 2 indicate that it is in the transition of the flexor to the extensor movements where the major contribution to the left/right differences lies. The differences in the single direction movement times are quite minor in comparison.

In Group 1, the duration for the single 'up' and 'down' phases added together is 28.1 msec for the right and 30.2 msec for the left hand. However, when the single direction movements are measured within the compound movement (as was done in Group 2), the corresponding times are 37.5 msec for the right and 42.9 msec for the left hand. As the total movement times for either hand do not differ very much for groups 1 and 2, one is left with the conclusion that a trade-off between single direction movement times and reversal times takes place: the penalty in single direction movement time is made up by more efficient reversal times.

EXPERIMENT III

Experiment II showed that the major component contributing to between-hand performance differences in the finger tapping task lies in the reversal phase. Descriptively, the problem may be one of force modulation. If precision of force modulation is a factor which differentiates between hands, then changes in the subtlety of force modulation required should be reflected in changes in tapping performance. This question is the subject of Experiment III.

Tapping performance in Experiments I and II was based on the simple instruction 'tap as quickly as possible.' Subjects were shown how to tap and were cautioned not to tap by producing a well-controlled tremor. As a result, full taps with well-defined endpoints of travel were produced. In Experiment III subjects were instructed to limit the excursion of digit movement to a minimum — moving the finger only far enough to operate the switch. In this way, the arc of movement was less than 5 mm as opposed to over 13 mm in the normal condition. In order to maintain performance, much greater subtlety of force modulation is required in this modified task; the extent of digit travel has to be limited by precise interaction of flexors and extensors, while in the normal condition the extent of 'down' travel is limited by the lever reaching the base plate which produces an external limit to movement rather than an internally programmed one.

If force modulation is indeed an important factor in between-hand performance differences, then the modified tapping task should lead to a disproportionately strong decline of performance for the non-preferred hand.
TABLE IV
Speed and regularity of tapping on Tasks 1 and 2 in Experiment m (results from Task 2 are given in brackets, \( N = 15 \))

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Regularity</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH</td>
<td>176 (182)(^{a})</td>
<td>13.8 (14.8)(^{b})</td>
</tr>
<tr>
<td>LH</td>
<td>188 (201)</td>
<td>17.1 (32.1)</td>
</tr>
</tbody>
</table>

Note \( a = \) duration of average intertap interval in msec, \( b = \) standard deviation of intertap intervals in msec.

Subjects

Fifteen right-handed male subjects were used. Handedness was established as described previously.

Procedure

Subjects were rated on the handedness questionnaire and were then shown how to finger-tap on the apparatus. Each subject then performed 5 trials with each hand on each of the two tasks. Task 1 consisted of 'normal' finger tapping, such as the subjects in the previous experiment had performed. Task 2 consisted of tapping around the pressure point, as described in the introduction of this experiment. Each subject alternated hands from trial to trial and the beginning hand and the task with which the subject began was alternated from subject to subject. All subjects were instructed to perform discrete tapping movements, as opposed to tapping which results from deliberate production of a fast tremor.

RESULTS

The results are summarized in Table IV. An ANOVA for repeated measures showed that, for speed of tapping, there was no significant main effect for task \( (F (1, 14) = 1.49, p < .24) \). Thus, measured over both hands, there was no significant decrement in performance in Task 2 as compared with Task 1. There was a significant main effect for hands \( (F (1, 14) = 25.50, p < .0021) \); the right hand performed faster than the left under both conditions. There also was a significant interaction \( (F (1, 14) = 6.16, p < .025) \) which was entirely due to the left hand performing more slowly in Task 2 than in Task 1. An ANOVA performed for the standard deviation of intertap intervals showed a main effect for task \( (F (1, 14) = 11.89, p < .0039) \). This was due to greater regularity in tapping performance in Task 1. There also was an effect for hands \( (F (1, 14) = 8.34, p < .011) \) due to greater regularity of tapping in the right hand. Finally, there was a significant interaction \( (F (1, 14) = 6.16, p < .025) \), again due to a proportionately poorer performance by the left hand on Task 2.

Figure 2 illustrates the trends described with the help of the record of one of the subjects. Shown is the computer printout of the performance of the two hands for Tasks 1 and 2. Essentially, the computer plots all intertap intervals for a given hand and task in an interval histogram. The flatter the curve, the greater the dispersion of intertap intervals around a central point and the more irregular the tapping. The speed of tapping is given by the mean intertap interval. If can be seen quite clearly that while the performance of the right hand is quite comparable on the two tasks, the performance of the left hand deteriorates markedly in Task 2, both in terms of speed and regularity of tapping. The mean intertap interval can be converted into taps/10 sec in a rough approximation by dividing 1000 msec by the given intertap interval. Thus, an intertap interval of 178 msec corresponds to about 56 taps per 10 sec.

DISCUSSION

Task 2 had a clear effect on non-preferred hand performance, while preferred hand performance remained unchanged in comparison with Task 1. It may thus be argued that precision of force modulation is a significant factor in between-hand performance differences. It must be acknowledged that Tasks 1 and 2 do not only differ in the precision of force modulation but also in the degree of sensory information from the periphery. The greater excursion of the digit in the case of Task 1 provides clearer information about the position of the index finger, both in terms of joint and muscle receptors. In addition, the index
finger comes to a clear stop in Task 1 when it hits the bottom limit of travel. This would provide additional information about the position of the digit through pressure receptors. While an argument, based on reversal times of less than 120 msec, can be made that peripheral feedback is not likely involved in the actual performance of component movements of the finger tapping task, an indirect role of feedback information in the monitoring of performance appears likely. To what extent this factor would account for the performance differences between the hands in Task 2 remains an open question.

In spite of some uncertainty as to what factors contribute most significantly to the between-hand performance differences in Experiment III, the results of this experiment have a very clear applied significance. The rate of finger tapping is one of the more sensitive behavioural indices of brain damage (Reitan & Davison, 1974). According to some authors, the changes in the non-preferred hand tend to be more pronounced than in the dominant hand (Boll, 1974). The results of Experiment III show that the relative difference between the two hands can be increased by manipulating the nature of the tapping movement and it is likely that the tapping movement required in Task 2 would be more sensitive to brain damage than the movement required in Task 1 and would amplify the effect on the non-preferred hand even more.

Experiment III may also account for some discrepancies observed in the literature. McKeever, VanDeventer, and Subaru (1973) and Satz, Achenbach, and Fennell (1967) concluded that finger tapping performance did not correlate well with self-labelling for handedness in left-handers.

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This contrasts with the findings of Peters and Durding (1979a) who found that finger tapping performance correlated highly with hand preference by self-labelling for both left- and right-handers. Peters and Durding also showed that the between-hand performance differences tend to be smaller for left-handers than for right-handers. Experiment 11 shows that the magnitude of the between-hand performance difference is a function of the kind of tapping movement. If the tapping movement involves large movement arcs with well-defined endpoints, the between-hand differences tend to be small and the danger of missing the between-hand differences in left-handers is greater than it is for movements which require some subtlety.

CONCLUSION

Experiment 1 showed that under the conditions used, fatigue is not a significant factor in producing between-hand performance differences. This is in agreement with findings by Barnsley and Rabinovitch (1970) and precludes any simple role of fatigue and strength in such differences. Further support for a dissociation between strength and fatigue and tapping performance is provided by a study on foot tapping (Peters & Durding, 1979b). Right-handers tap more quickly with their right leg even though the left leg, in right-handers, is the stronger leg.

Experiment 11 provides additional support for the contention that peripheral factors are relatively unimportant in producing between-hand performance differences in tapping. The time taken for the reversal portion of the tapping movement is too short to allow for a direct involvement of sensory feedback in the guidance of the reversal. For this reason, a direct role of sensory feedback in preferred vs. non-preferred hand performance differences (Flowers, 1975; Todor & Doane, 1978) can be questioned. Control of the finger tapping movements depends on central pre-
side the primary motor cortex. Anatomical asymmetries underlying performance asymmetries are conceivable in a number of stages of this process.

It has been argued previously that peripheral factors are not likely to contribute substantially to the performance asymmetries observed in finger tapping. If it is true that the processes underlying the formation of the motor idea are not lateralized, then the most likely source of asymmetries is in the processes whereby the movement is preprogrammed and whereby the selection and activation of appropriate neurons occurs.

RéSUMé

Trois experiences differentes cherchent a savoir pourquoi la main preferee surclasse la main non-preferee lors d'une simple tache de tapotement du doigt. L'experience 1 elimine la possibilite des effets differentiels de fatigue sur la difference de performance entre les deux mains. L'experience 1 demontre que les composantes simples de la modulation a 'ascendant' ou 'descendant' de l'index ne sont pas reliees de facon significative a la vitesse du tapotement du doigt et contribuent tres peu a la difference de performance entre les deux mains. Il n'en va pas ainsi pour l'etape du mouvement ou la direction est inversee. Cette etape contribue significativement a la superiorite de la performance de la main preferee, reside dans la precisio de la modulation de la force.

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