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THE RELIABILITY OF SOME MOTOR PERFORMANCE TESTS OF HANDEDNESS*

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Abstract—Twenty male subjects, (10 right-handers and 10 left-handers matched for degree of handedness by questionnaire), were tested on seven different motor tasks on two separate occasions. Test-retest correlations of motor achievement proved significant on all tasks with the preferred hand; in four of the seven tasks with the non-preferred hand, but in only two out of seven instances for the differences in performance between hands.

The results are discussed in relation to the possible influence of training on the motor achievements of the right and left sides, and the importance of reliability of performance measures of handedness is stressed.

TO DICHOTOMOUSLY classify people as either right or left-handed is a convenient but not very realistic method of assessing their manual tendencies, since individuals vary their side of choice according to the task, particularly "left-handers" [1]. It is therefore more usual current practice to determine the consistency of a person's hand preference either by asking him a series of questions concerning which hand he prefers to use in a range of selected activities or by getting him to perform a number of tasks and noting the hand employed in each case. The former method is most practicable with adult subjects [2] whereas the latter is appropriate for young children [3] or sub-human animals [4]. A further method of assessing handedness characteristics is to measure the performance level attained by each hand in turn on a given motor test or range of tests and to determine which hand achieves the better performance. Again, it has been known for some time that, for many people, the more able hand varies from task to task and experiments have been devized to determine why this should be so [5]. However, it has been shown that appreciable discrepancies may arise in the handedness assessments obtained by different methods [1, 6] and that a better relationship may be established between speech laterality and handedness if the latter is based upon motor test scores rather than on subjective self-classification [7].

There is of course, a wide range of motor tasks which may be used to assess the relative performances of the right and left sides and since such tests tend to be very time consuming to administer, some degree of selection must be employed for most practical purposes. In a series of previous experiments [5, 8, 9] evidence has been provided to show that differences between the right and left hands are relatively small and insignificant when the movements involved are simple graded muscle contractions made either for speed or accuracy. However, significant differences between the two sides do occur where the movements involve muscle activity which has to be organized into a temporal sequence and "programmed" to be run

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off without the possibility of correction based on sensory check. Yet differences between the two sides have not been found in such tasks if (a) no training of either side has previously occurred or (b) if both sides have been well practiced but to the same extent. An essential feature of these movements which require the close serial organization of muscle activity appears to be the greater consistency of execution of the individual components which characterizes the more skilled performance and makes the outcome of the action highly predictable [10].

The present investigation was therefore designed to determine the consistency of performances of both the preferred and non-preferred hands (and of the differences between them) on a range of motor tasks. Five tests (some familiar and some relatively novel) were selected as demanding organization of muscle activity into programmed sequences and two others were included which depend on muscular strength and not skill.

METHOD

The performances of 20 male subjects were tested on the right and left sides separately on each of seven different motor tasks. The subjects, whose ages varied from 19 to 42 years, were selected from a much larger sample on the basis of a handedness questionnaire so that half were predominantly right-handed in their hand usage preferences and half left-handed. The questionnaire listed 31 items covering a wide range of activities and is given in Appendix I. To evaluate a subject's handedness characteristics, the number of questions answered as left-dominant were subtracted from those answered as right-dominant and the result divided by the total number of questions asked giving a score between +1 (completely right-handed) and −1 (completely left-handed). The handedness scores of the left-handed subjects in the present study ranged between −0.39 and −1.00, and those for the right-handed subjects were selected to provide a similar distribution from +0.45 to +1.00. The ages of the right and left-handed subjects were matched as closely as possible with respective means of 24.3 and 27.0 years. The subjects were all university students or members of the academic or technical staff.

The tests employed and the procedure used is given below. It will be noted that subjects were given immediate and detailed knowledge of results of their performances on each test in an attempt to maximise and equate incentives across tasks.

1. *Dexterity*

The Crawford Small Parts Dexterity test was used and the subject timed to complete the placing of pins and collars by tweezers for four rows with one hand before repeating the operation with the other hand. One practice row with each hand was allowed before starting the test. The time taken to complete each row was called out to the subject during his performance and he was told the total time taken after finishing the task with each hand.

This task undoubtedly involves the temporal organization of muscle activity but it is unlikely that any subject would be well-practiced in the total movement patterns acquired. However, some component skills or "sub-routines" [11] such as grasping, reaching and releasing movements may be considered to be relatively highly developed, especially on the preferred side.

2. *Handwriting*

Each subject was required to write the alphabet (as one word) as quickly as possible six times with one hand before repeating the task with the other hand. The time taken to complete the six alphabetic words was noted. One practice word with each hand was allowed before starting the test. The time taken to complete each alphabetic word was called out to the subject while he was writing and he was told the total time taken for the six words after finishing the task with each hand.

This task clearly involves the programming of complex patterns of movement which have been extensively over-trained with the preferred hand and almost never practiced on the other side.

3. *Darts*

Each subject was instructed to throw 10 darts at the centre of a target (dartboard) and the distance of each from the "bull" was recorded, before repeating the task with the other hand. One practice shot with each hand was allowed before starting the test. The subject was able to see his error after each throw.

This task was relatively novel to the (Australian) subjects of this experiment although the action certainly requires the programming of a complex movement pattern.

4. *Tapping*

The number of taps of a telegraph key in a 10 second period was recorded with the subject's forearm supported and the movement made by the hand at the wrist. Two such 10 second periods were administered

for one hand before the task was repeated with the other hand. A few taps of practice were allowed by each hand before the test began. The subject was told the number of taps he had made after each 10 second test period.

This task is unlikely to have been practiced as such by the present subjects although rapid alternation of these antagonistic muscle groups in the movements required in handwriting, hammering and similar activities suggest that they may form well-practiced sub-routines which would also be more highly developed with the preferred hand.

5. *Ratchet*

A hand-held football-style rattle was used comprising a weight at the end of a short arm which swivelled around the handle when this was moved with a rotary motion. A ratchet and counter were suitably mounted on the handle to record the number of rotations made in each of the two five-second periods with one hand before the task was repeated with the other hand. The direction of rotation was always clockwise for the right hand and anticlockwise for the left. A few turns of practice were allowed by each hand before starting the test. The subject was told the number of turns made after each five second test period.

This task requires an extremely complex co-ordination of muscle activity which would be relatively novel to all subjects and little practiced even with the preferred hand.

6. *Hand-grip strength*

An adjustable hand-grip dynamometer was used to record the maximum grip-strength in each of three attempts with one hand before repeating the task with the other hand. One practice try with each hand was allowed before starting the test. The subject was able to observe the results of each pull before the dynamometer was reset to zero for the next test.

This task is not dependent on the temporal organization of muscle activity but instead involves the discrimination, selection and maximum contraction of muscles which contribute to the required movement (ie. primarily finger flexion). Insofar as the preferred hand is used more often than the other side, the preferred hand may be expected to be somewhat stronger but not necessarily more consistent in the performance level achieved.

7. *Grip-strength endurance*

The mean grip-strength value was calculated for each hand in 6 above and the subject was then asked to maintain a value of 80 per cent of this for as long as possible in one further test with each hand. The endurance time was recorded for each side, and the subject told the total length of time (in seconds) he had maintained the required value at the end of each test with each hand.

The muscle requirements for this task are as for 6 above, with an additional demand on the energy reserves of the muscles concerned which again may be expected to be somewhat greater in the side used more often in general activities.

To obtain an estimate of the reliability of each subject's motor performance, all subjects were required to attend laboratory sessions on two separate occasions at least three days apart and to complete the whole series on each occasion. The same order of testing was used for any given subject on each occasion and half of each handedness group started all tasks with the preferred and half with the non-preferred hand. For all subjects, the order of testing on each task was the same (i.e. 1–7 as given above) to avoid the undesirable effects which would results if tasks of dexterity or accuracy were performed after tests of speed, strength or endurance.

RESULTS

The mean performance for each subject (combining both sessions) were calculated for the preferred (better performance) and non-preferred hand on each task and the means for all subjects are given in Table 1 together with the results of a paired comparisons t-test in each instance. As can be seen, all differences between the sides were highly significant ($p<0.001$).

As a check on the reliability of performance from one occasion to the other, product-moment test-retest correlations were carried out on the data for each task and each hand (i.e. preferred and non-preferred according to performance level) and the results are presented in Table 2. Included in this table are similar test-retest correlations of the differences between the sides (e.g. non-preferred minus preferred hand score) on the two occasions of testing. It will be seen that the r values for the preferred hand are highly reliable ($p<0.01$) from one occasion to the other for all except one of the tasks, and are higher than the corresponding figures for the non-preferred hand in five out of seven cases. However, it should

Table 1. Mean performance values of 20 male subjects for each hand on each task together with the results of paired-comparison *t*-tests between sides

Task	Pref†‡	Non-Pref†	*t*
Dexterity (total time in sec)	179.55	211.25	5.99*
Handwriting (total time in sec)	78.82	150.35	9.44*
Darts (av. error of 10 throws in cm)	7.79	10.67	6.37*
Tapping (mean No. in 10 sec)	68.81	60.62	5.80*
Ratchet (av. No. of turns in 5 sec)	15.21	11.55	6.10*
Strength (av. of 3 pulls in kg)	70.15	64.30	5.41*
Endurance (time in sec)	24.10	15.10	5.38*

* Significant at $p < 0.001$.
†Means of trials 1 and 2 combined.
‡ i.e. best-hand performance.

be noted that although the differences in performance level between the sides are positively correlated from one session to the other on all tasks, only the *r* values for handwriting and tapping reach significance ($p < 0.001$).

Table 2. Test-retest correlations between motor performances on Trial 1 and 2 for the preferred (i.e. better) and non-preferred hands and for the differences in scores between the two hands

Task	Pref *r*	Non-pref *r*	Differences between hands *r*
Dexterity	0.56†	0.70*	0.38
Handwriting	0.59†	0.94*	0.94*
Darts	0.60†	0.37	0.15
Tapping	0.79*	0.68*	0.70*
Ratchet	0.68*	0.36	0.25
Strength	0.67†	0.63†	0.34
Endurance	0.45‡	0.33	0.28

* Significant at $p < 0.001$.
† Significant at $p < 0.01$.
‡ Significant at $p < 0.05$.

Finally, in order to facilitate a comparison between the questionnaire evaluation of handedness and an overall assessment of laterality derived from the combined results of the motor tasks, the subject's mean scores on the latter for each side for each task were converted to normalised standard scores [12]. A Spearman rank correlation was then carried out between the subjects' mean differences in motor performance between the two sides and their questionnaire indices of handedness which gave a ρ value of 0.70 (significant at $p < 0.01$).

DISCUSSION

The inadequacy of subjective self-classification of handedness has been emphasized in the investigations of BENTON *et al.* [1] and SATZ *et al.* [7] who have shown that performance on a particular task with each hand by a given subject does not necessarily correspond with

expectation on the basis of that subject's overall view of his laterality characteristics. In their experiments, the lack of concordance between test performance and self-reported handedness was particularly striking for self-classified left-handers since little more than half of these subjects showed superior performance with the left hand on a given task. This discrepancy was presumably due to the variation in hand-preference from one task to another particularly characteristic of the left-handers. In contrast, the left and right-handers of the present study were matched for degree of laterality by questionnaire and it is therefore noteworthy that a reasonably good agreement was found between the overall subjective and objective assessments of handedness.

However, the most important finding of the present study undoubtably relates to the test–retest reliability of the performances on the different motor tasks. Individual differences in achievement on all tasks were significantly consistent for the preferred or better hand from one occasion of testing to the other, but this was true on only four of the tasks for the non-preferred hand. Furthermore, when the difference in mean performance between the two hands is considered, subjects showed significantly consistent differences from time to time on only two of the seven motor tests. Thus for example, those subjects who showed relatively large differences in a given direction in the performance levels achieved by their right and left hands on the handwriting and tapping tasks on the first day, showed similar differences on the second occasion of testing, but such differences between hands were not significantly consistent on any of the other tasks.

If handedness is defined in terms of the consistency of differences in performance between the two hands, then clearly the test of handwriting is the best single measure of handedness examined here. Certainly it may be considered to be the most highly over-learned of the skill-demanding tasks employed in this investigation and undoubtably the one in which all subjects will have been thoroughly trained with their preferred hand and probably quite untrained with the other. Now, it is well-established that motor skills are highly specific and related to particular patterns of movement [13]. It has also been hypothesized from a review of the evidence, that the recorded differences in motor performance between the sides may be a particular example of this specificity and that they are a result of the combination of an individuals' capacity to acquire skill (genetically determined) and the extent of his previous differential training on the two sides [10]. On this basis, the highly consistent results in the handwriting task conform to expectation. Similarly, the significantly consistent differences in performance between the two sides on the much simpler tapping test may be explained in terms of the previously acquired differential skills of the right and left hands. For although this activity is not one which would be deliberately practiced as such by most people (other than W.T. operators) brief sequences of the alternate contraction of antagonistic muscle groups occur in such a variety of more elaborate movement patterns that the incidental development of such sub-routines would be inevitable and would become more strongly established on the more frequently used side.

Of the three skill-demanding tasks which do not show significantly consistent differences between the sides, both the Darts and Ratchet tests yield reliable results for the preferred hand. Presumably in both cases, although these particular activities were relatively novel to the subjects, some component features of the movement patterns were sufficiently well-practiced in other more familiar throwing and winding movements for a reasonably stable performance to be achieved with the preferred side. However, the inconsistent and significantly poorer performance of the less experienced non-preferred hand would also have

caused the differences between sides to vary appreciably from one occasion to the other and to be similarly unreliable. In contrast, performance on the Dexterity test proved to be significantly consistent from time to time with both hands yet the differences between the sides were not. In other words, while the differences between subjects were reasonably stable from one occasion to the other with either hand considered by itself, performance variations from time to time did not correspond on the two sides. This is perhaps not surprising since the task is a highly complex activity where only particular sub-skills such as grasping and lifting, reaching and releasing would be well developed and practiced movements.

The results of the test of Grip–strength are as predicted with consistent performances recorded for each side separately but with the differences between hands not significantly reliable. Certainly, Grip–strength is related to such stable inter-individual differences as stature and other body dimensions [14] which would be similar for both sides. However, differences in strength between the right and left limbs is less clearly related to such structural features [15] and variations in performance from time to time or from one side to the other may also be influenced by variations in motivation. Undoubtedly, the Grip–strength Endurance measure reflects the level of motivation of the subject [16] but from the present evidence it appears to be of doubtful reliability even with the preferred hand. However, this may well be due to the fact that in the Endurance task the target value could vary from time to time since it was dependent on the mean Grip–strength result recorded in each instance.

From the reliability measures of motor performance described in this report it is clear that not only does the degree of superiority of one hand over the other vary from task to task, but also from one performance to another on all but the most highly practised and skill demanding tasks. For these reasons and because of the specificity of motor skill, it is suggested that a satisfactory performance measure of handedness should comprise a range of tests sampling a variety of skills using tasks which yield performance differences between the sides as reliable as the handwriting task employed in the present experiments. However, this may be somewhat idealistic and impossible to achieve in practice. Clearly, further research on the reliability of performance tests of handedness is required.

APPENDIX I

Handedness Questionnaire*

NAME: DATE:

SEX: AGE:

Please circle the appropriate response for each of the following questions.

1. With which hand do you write?	*Right*	Either	Left
2. In which hand do you prefer to use a spoon when eating?	*Right*	Either	Left
3. With which hand do you throw a ball?	*Right*	Either	Left
4. In which hand do you prefer to hold the toothbrush when cleaning your teeth?	*Right*	Either	Left
5. In which hand do you prefer to hold a tennis racquet?	*Right*	Either	Left
6. If both hands were free, which hand would you use to put the key in a key hole?	*Right*	Either	Left
7. In which hand do you hold the box when striking a match?	Right	Either	*Left*
8. When cutting paper, in which hand do you hold the scissors?	*Right*	Either	Left

* This research was completed before the publication of the Edinburgh Inventory [2] which provides a more desirable standard form of subjective assessment.

9. With which hand do you prefer to use a penknife when sharpening a pencil?	*Right*	Either	Left
10. In which hand do you prefer to hold the pack when dealing cards?	Right	Either	*Left*
11. In which hand do you prefer to hold the rubber when erasing a pencil mark?	*Right*	Either	Left
12. In which hand do you hold the needle when you are sewing?	*Right*	Either	Left
13. When pinning a notice to a notice board, which hand presses in the drawing pin?	*Right*	Either	Left
14. With which hand do you prefer to turn a tap?	*Right*	Either	Left
15. When washing dishes, in which hand do you prefer to hold the dish?	Right	Either	*Left*
16. When pouring tea, in which hand do you prefer to hold the pot?	*Right*	Either	Left
17. With which hand do you use a comb?	*Right*	Either	Left
18. With which hand do you adjust a window blind?	*Right*	Either	Left
19. When buttering bread, which hand holds the bread?	Right	Either	*Left*
20. Which hand do you use to wind a clock?	*Right*	Either	Left
21. In which hand do you prefer to carry a suitcase?	*Right*	Either	Left
22. In which hand do you prefer to hold a jar when unscrewing the lid?	Right	Either	*Left*
23. With which hand do you put a plug into a powerpoint?	*Right*	Either	Left
24. With which hand do you hold a hammer?	*Right*	Either	Left
25. In which hand would you carry or pass a full glass of water?	*Right*	Either	Left
26. In which hand would you hold an apple while you were peeling it?	Right	Either	*Left*
27. Which hand do you prefer to use to remove an object from a high shelf?	*Right*	Either	Left
28. Which hand do you use to draw?	*Right*	Either	Left
29. If catching a ball with one hand, which hand would you use?	*Right*	Either	Left
30. With which hand do you hold the implement steady when using a hand rotary beater or hand drill?	Right	Either	*Left*
31. When feeling material to determine the texture or thickness which hand would you use?	*Right*	Either	Left

Do you suffer from any physical or other handicap which might have influenced your answers to these questions?

Any other comments?

Note on APPENDIX—I.

The answers *in italics* in the above sample questionnaire indicate the responses given by a fully right-handed subject scoring +1.00.

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Résumé—On a soumis vingt sujets masculins (10 droitiers et 10 gauchers appariés, selon un questionnaire, pour leur degré de préférence manuelle) à sept différentes épreuves motrices en deux occasions différentes. Les corrélations test-retest des résultats moteurs se sont révélés significatives sur toutes les épreuves pour la main préférée, dans quatre des sept épreuves avec la main non préférée mais pour seulement deux des sept exemples lorsqu'on considère les différences de performance entre les deux mains.

On discute ces résultats en fonction de l'influence possible de l'entrainement sur les performances motrices des côtés droit et gauche et on souligne l'importance qu'il y a à obtenir des mesures sûres de la préférence manuelle.

Zusammenfassung—20 männliche Probanden (10 Rechtshänder und 10 Linkshänder durch Fragebogen nach Grad ihrer Händigkeit zusammengefaßt) wurden mit sieben verschiedenen motorischen Übungen in zwei Durchgängen untersucht.

Die Korrelation der motorischen Geschicklichkeit des ersten Durchgangs zum zweiten Durchgang war in allen Übungen für die bevorzugte Hand signifikant, in vier der sieben Übungen auch für die nicht bevorzugte Hand. Beim Vergleich beider Hände zueinander zeigten nur zwei der sieben Tests signifikante Korrelationen der Geschicklichkeit zwischen erstem und zweitem Durchgang.

Die Ergebnisse werden im Hinblick auf mögliche Einflüsse von Training auf die motorische Geschicklichkeit der rechten bzw. linken Hand erörtert. Die Bedeutung der Zuverlässigkeit von Messungen bei Händigkeitstest wird betont.