Perceptual and Motor Skills, 1992, 75, 851-866. @ Perceptual and Motor Skills 1992

WHICH HANDEDNESS: PREFERENCE OR PERFORMANCE?[1]

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Summary.- Two ways of measuring handedness, questionnaires and hand-efficiency tests, are compared. A method for combining performance scores of 128 children from different hand-efficiency tests to obtain a single handedness score based on efficiency is presented. Handedness classifications according to different thresholds of preference as well as of performance are shown. To select pure right- or left-handers, it is argued that handedness should be established simultaneously through preference questionnaires and performance tests and that only subjects falling simultaneously into the same category on both measures be kept. Advantages and disadvantages of each classification are discussed as well as the relations between efficiency and motor control of upper limb and hand.

The best way of classifying subjects as right-handed, left-handed, or ambidextrous remains controversial, questionnaires of hand preference being most frequently used in the literature. Even if we consider handedness as a single dimension, from highly right-handed to highly left-handed, there remains the question of whether there are broad or narrow categories within this continuum.

The aims of this study are threefold: (1) to suggest a new way to establish handedness through performance tests, (2) to compare subjects' handedness based on hand preference questionnaires and on hand-efficiency tests, and (3) to relate hand-efficiency acquisition to hand preference and discuss proximal and distal upper arms skills from the scores on the hand-efficiency tests used.

For many decades, questionnaires of hand preference have been used to establish handedness but have been criticized for the number of items included and for varying degrees of bias toward highly learned activities (e.g., writing, drawing, using a spoon or a knife) rather than toward more spontaneous ones (e.g., throwing, dealing cards, opening a jar, carrying a suitcase)(Bryden, 1977; Steenhuis & Bryden, 1989). For scoring, the same weight is given to highly skilled (writing) or unskilled (carrying a suitcase) items. After a period where the only possible responses were “right," “left," or “either," a new trend has emerged wherein the extent of hand preference is assessed. For example, a subject may respond to the question “Which hand do you use for opening a jar?", with possible responses “always left," “mainly left," 1: “either hand," “mainly right," and “always right" (Bryden, 1977; Provins, Milner, & Kerr, 1982).

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Instead of answering questions, subjects may perform each task, material being provided without any laterality bias and experimenter noting the hand used by the subject for each activity.

When we use one hand for a special activity or use it more often than the other for all activities, we develop the skills or the efficiency of that particular hand. Because hand performance is directly related to hand use and, by inference, to hand preference, it is thought that extent of handedness can be established by measuring hand efficiency.

The question of the relationship between hand preference and hand performance is far from being a new one, and it has been tentatively resolved in different manners. Generally, a laterality quotient or hand preference is first established through a questionnaire for each subject who then performs an efficiency test with both hands. Afterwards, comparisons between the two types of scores, preference and performance, are made using primarily the difference on performance between the scores of the right hand and the left one (Annett, 1970, 1976; Annett & Kilshaw, 1983; Benton, Meyers, & Polder, 1962; Borod, Caron, & Koff, 1984; Kilshaw & Annett, 1983; Tapley & Bryden, 1985). A strong preference should be related to a large difference. Apart from the difference between right- and left-hand scores (R -L), other procedures have been suggested, for example, the ratio (R -L)/(R + L) for each efficiency test (see Hiscock, 1988, for review). These ratios, as all ratios, are not satisfactory either as we might get the same ratio from different scores.

Although it is convenient to use a single efficiency test to calculate the performance differences between right and left hands and relate this difference to the laterality quotient, hand performance cannot be dependent on a single measure but must be related to different efficiency tests (Barnsley & Rabinovitch, 1970). It is no more acceptable to consider that a questionnaire might only include one question than to be satisfied with a unique test of hand efficiency. It bas been argued, for a long time (Fleishman, 1964), that hand efficiency is not a unidimensional trait but a multidimensional one, with independent factors. Considering this premise and using particularly Fleishman's results, Barnsley and Rabinovitch (1970) completed an exhaustive study including 32 different tests for the evaluation of almost all thinkable aspects of hand efficiency. Tests were applied first to 100 adults (17 to 37 years of age) and then to 77 children (6 to 7 years of age). A factor analysis distinguished nine different factors related to hand efficiency, specifically, reaction time, dexterity, stated hand preference, wrist finger speed, aiming, hand stability, arm-movement stability, finger tapping, and grip strength. In the present study, five of these factors (aiming, finger dexterity, tapping, hand stability, and grip strength) which are the most characteristic and reliable for evaluation of hand performance (Annett, 1976; Barnsley & Rabinovitch, 1970; Fleishman, 1964; Provins & Cunliffe, 1972) are considered, using the most valid test for each. One additional test, writing, was added as a single-hand well-learned skill.

Although it is easy to calculate a difference between scores of the two hands on a single test, it is somewhat more difficult to combine many tests to provide a global hand-efficiency score by adding the scores on two or more tests. The differences between hand performances on different tests cannot simply be added, units being not identical.

Based on previous work done with children (Barnsley, 1970; Rigal, 1974), a new procedure for adding scores is suggested hereafter. As the aims of this procedure are (1) to establish, keep, and use the difference between the actual performance by the two hands, (2) to sum the results on different efficiency tests, and (3) to show hand-efficiency evolution through age, we must find a way to combine raw scores to subserve these goals.

METHOD

Subjects

One hundred twenty-eight children were randomly selected among 2500 children from a school board; they ranged from six to nine years of age, with 16 boys and 16 girls for each year of age.

Procedure

Subjects were seen individually, performed first the preference test, then the efficiency tests, starting with the preferred hand.

Tests

Hand preference.-Subjects performed the 10 actions on a questionnaire of lateral dominance based on the Harris (1958) test (Table 1), these actions having high reliability, i.e., consistent use of the same hand to perform the same task (Coren & Porac, 1978).

TABLE 1
QUESTIONNAIRE OF HAND PREFERENCE (HARRIS, 1958)

Experimenter notes hand used by subject to perform the following tasks:	
1. write letter O	6. hammer a nail into a plank
2. throw a ball	7. cut modelling clay with a knife
3. cut paper with scissors	8. unscrew a jar lid
4. erase the letter O	9. deal cards from a pack lying on the table
5. draw a tree	10. grasp a glass on the table
Laterality quotient: R × 10 (R: number of times right hand is used among the 10 items).	

Hand efficiency.-The tests used must evaluate different aspects of hand efficiency such as: (1) *aiming,* in which the subject is scored for the time required to place a dot in each of 40 circles of $^1/_8$ in. in diameter, regularly spaced at $^3/_8$ in.; (2) *linger tapping,* in which the subject is required to tap a mechanical tapper as fast as possible with his forefinger for 15 seconds while holding his arm firm, and the number of taps are counted; (3) *linger dexterity,* in which the subject takes a block from a hole, turns it over, and puts it back in the same hole, using only one hand, and repeats the procedure for 40 blocks, while the time necessary to turn over all blocks is recorded; (4) *arm-hand steadiness,* in which the subject holds a stylus in a hole $^1/_8$ in. in diameter during 10 sec., with the score being the amount of time the stylus is in contact with the edge of the hole; (5) *strength,* in which the subject grips as hard as possible a hand dynamometer, and grip strength is recorded; (6) *handwriting,* in which the subject writes as many times as possible his given name (or Christian name) (which avoids reading skills) in 20 sec., with the score being the total number of letters written.

Each subject performed all the tasks twice with both hands, starting with his preferred hand. The mean of the two trials is considered the score for each hand on each test.

Now, to combine the results on the five first tests, I suggest the following procedure. Once all the subjects have been tested, raw scores for the right and left hands on one particular test (e.g., strength) are first included temporarily into the same distribution and then transformed into *z* scores. Thus, we retain the ability difference between the two hands for each subject as well as the ability difference between subjects. For tests on which a low performance gives a high score (aiming and finger dexterity), *z* scores are multiplied by -1. Then, from these *z* scores, *T* scores [$T = (z \times 10) + 50$] can be calculated for each subject's right and left hands, with all scores being positive to avoid negative and positive scores whose sum could equal zero. The same procedure is applied to each of the tests of hand efficiency used in the study. Data are then ordered in two different ways.

First, on a right (R)- and left (L)-hand basis which allows one to establish handedness on an efficiency foundation and to perform comparisons between right- and left-handed subjects' hand efficiency and stepwise regressions on hand preference, the right-hand *T* scores of each subject for the five different tests are added to obtain a right-hand global score (RHGS); similarly, the left-hand *T* scores can be added to obtain a left-hand global score *f* (LHGS). However, these global hand scores do not provide an absolute value of the subject's performance but rather a relative classification of his performance compared to that of other subjects. The handedness of each subject is then indicated by subtracting the left-hand global score from the right-hand global one (RHGS -LHGS). The differences will be positive for right-handers and negative for left-handers. Moreover, ambidextrous subjects, who obtain equivalent results for both hands can be discriminated from ambilaterals through this procedure: the difference between their hands' performances will be close to 0 with high RHGS and LHGS and a total hands high score (RHGS + LHGS), while ambilaterals will have a small difference score as well as a small sum, being as equally unskilled with one hand as with the other.

Secondly, data and subjects are ordered on a preferred (P) and non-preferred (NP) hand basis. Summing *T* scores for the preferred hand and *T* scores for the nonpreferred one, we get a preferred hand global score (PHGS) and a nonpreferred hand global score (NPHGS). This way; scores for one hand (right-hand for right-handers and left-hand for left-handers) should be generally higher or better than scores for the other hand. Correlations between different efficiency tests (i.e., how scores for preferred and nonpreferred hands correlate), comparisons of hand efficiency between subjects based on age and sex, and factor analyses can all be clone using this classification.

This procedure raises a few legitimate questions. Can we include, in the same distribution, scores of the right-hand and of the left-hand of right-handers and left-handers? Can we add *T* scores for different tests? To answer the first question, one might say that all scores for one test are just “temporarily" included in the same distribution to calculate *z* scores. These scores organize the subject's performance around zero and keep the differences between hands and between subjects. If we were splitting scores into two distributions, a preferred hand one and nonpreferred hand one, two different ability scores could have the same *z* value, preventing any further calculation. Once the *z* scores are known, each one is brought back to its original distribution (right-left; preferred-nonpreferred), and statistics calculated. For the second question, adding *T* scores, one might say that hand efficiency is a composite skill for which summing partial scores will give a score close to the real ability of the subject.

RESULTS

Hand Preference

Scores have been obtained by counting the number of times the right-hand is used to perform one of the 10 actions and then multiplying that number by ten. For scores ranging from 0 to 30, 40 to 60, and 70 to 100, subjects were respectively classified left-handed (10% of the sample), ambidextrous (5%), and right-handed (85%) (Table 1). As a group, girls show a general tendency to be more lateralized than boys, the number of girls in the ambidextrous group being always lower than the boys' group, whatever the thresholds; however, the proportional difference did not reach the necessary value to be significant at $p<0.05$. By applying more restrictive range limits to the sample (e.g., more and more actions have to be performed with the right or the left hand to be considered as right- or left-handed), the proportion of ambidextrous subjects increases notably while the proportion of left-handed persons decreases, lowering to 0 if all actions have to be performed with the left hand (Table 2).

TABLE 2
Handedness Classifications For Different Criteria: Percent

	6 Years			7 Years			8 Years			9 Years			*M*		
	RH	LH	AB	RH	LH	AB	RH	LH	AB	RH	LH	AB	RH	LH	AB
Questionnaire*															
1	84.4	9.4	6.2	87.5	6.2	6.2	84.8	12.5	3.1	84.4	12.5	3.1	85.1	10.2	4.7
2	81.2	6.2	12.5	87.5	3.1	9.4	84.4	9.4	6.2	84.4	12.5	3.1	84.4	7.8	7.8
3	63.5	3.1	34.4	78.2	0.0	22.8	65.6	0.0	34.4	71.8	9.3	18.9	69.5	3.1	27.4
4	40.6	0.0	59.4	40.6	0.0	59.4	40.6	0.0	59.4	50.0	0.0	50.0	43.0	0.0	57.0
Efficiency Threshold†															
5%	87.5	6.2	6.2	78.1	12.5	9.4	75.0	18.7	6.3	81.3	15.6	3.1	80.5	13.3	6.2
10%	84.4	6.2	9.2	75.0	6.2	18.7	75.0	15.6	9.4	78.1	12.5	9.4	78.1	10.2	11.7
20%	78.1	6.2	15.6	71.9	3.1	25.0	71.9	9.4	18.7	75.0	12.5	12.5	74.2	7.8	18.0
30%	62.5	3.1	34.4	62.5	3.1	34.4	62.5	9.4	28.1	65.6	6.2	28.2	63.3	5.5	31.2

Note.—RH: right-handed; LH: left-handed; AB: ambidextrous. All numbers in columns express percentages of subjects in one particular group. One subject equals 3.1% for Columns 6, 7, 8, and 9 years and 7.8% for column "means."
*Questionnaire 1, 2, 3, 4: the limits used with the hand-preference test for differentiating left-handers, ambidextrous, and right-handers are for (1) 0–30, 40–60, and 70–100, respectively; (2) 0–20, 30–70, and 80–100, respectively; (3) 0–10, 20–80, and 90–100, respectively; (4) 0, 10–90, and 100, respectively.
†Efficiency threshold: 5%, 10%, 20%, or 30% of subjects are considered as ambidextrous.

Hand Efficiency

For each test of hand efficiency, raw scores for both hands have been included in the same distribution. None of these is bimodal, and most of them are close to normal including the differences between raw scores (R-L), except for the writing test, on which the left-handed group of children are differentiated clearly from the right-handed one. There is nothing surprising there, as the differences are plotted on a R-L performance basis and it is obvious that on a preferred-nonpreferred hand basis (or absolute right-left differences), the distribution would have been unimodal.

If, for a particular test, we compare the means of the differences between the raw scores, instead of those of the transformed scores, we obtain similar results. The particular differences or similarities are kept at a more global stage in spite of the transformations made. If, instead of making the previous transformations, we compute the differences between the raw scores of right- and left-hand scores for each test, transform these into z scores and finally sum these five z scores, we get a .98 correlation with the hands' difference global score. Both methods give similar results (the sum of the differences equals the difference of the sums), the latter one losing, unfortunately, any information about a whole-hand efficiency.

Correlations between scores for preferred and nonpreferred hand-efficiency tests were .88 for strength, .84 for steadiness, .82 for tapping, .77 for aiming, .74 for dexterity, and .67 for writing. These coefficients are higher for tests where there is not a systematic training bias for one hand than for tests where there is such a bias (e.g., writing). The ratios of nonpreferred/preferred hand scores are higher than .90 for strength (.93), tapping (.95), and dexterity (.97) and are lower for aiming (.73) and steadiness (.75) and also for writing on which they equal .55 at 6 years of age and .42 later on. This suggests that performances of both hands are very close when one ability is not overpractised. Does a high difference between scores for preferred and nonpreferred hands on an efficiency test relate to a high difference on the other tests? It seems that this is not the case, as the correlations between such differences on the five efficiency tests are lower than .25 except for steadiness-tapping (.40); the hand-efficiency tests measure different hand abilities.

Hand efficiency and age.-A three-way analysis of variance was carried out on the factors of age, sex, and hand for each hand-efficiency test. Age had a significant effect on all tests as well as hand. There were no significant interactions between age and sex or age, sex, and hand for any of the efficiency tests ($p>0.01$); there were interactions only for age by hand ($F_{3,120}= 34.34$) and sex by hand ($F_{1,120}= 14.36$) on writing ($p<0.01$). Performances improve regularly with an exception for boys between 7 and 8 years of age for whom there was no significant increase ($p<0.01$)*)* in performance for preferred as well as for nonpreferred hands and for girls whose performances did not improve for two consecutive years between ages 7 and 8, 8 and 9. The performance of the preferred hand is always superior to that of the non-preferred one ($p<0.01$).

Although there was a significant difference ($p < 0.01$) between groups for the preferred and the nonpreferred hand global scores as well as for the sum of the global scores of each hand (preferred + nonpreferred), there was no significant one ($p<0.01$) between the hands' global score differences for various age groups (preferred -nonpreferred scores) (efficiency of both hands being equivalent in each group). This suggests that hand efficiency improves regularly with age for both hands.

Hand efficiency and sex.-An effect for sex is clear on strength and tapping (boys better than girls with both hands) and on writing (girls better than boys with both hands) for each age group ($p<0.01$). On dexterity, girls are better than boys only with the preferred hand. No sex difference was found on aiming and steadiness. Comparisons of differences between raw scores of preferred and nonpreferred hand for each hand-efficiency test showed no significant difference ($p> 0.05$) for age or sex, except on writing where the difference increases with age and is higher for girls than for boys ($p<0.01$). This test is the only one on which the preferred hand is systematically trained and is also the only one on which a significant difference appears between the two hands. Handedness classification obtained from the writing test shows exactly the same number of girls and boys among the right-handers (56) and the left-handers (8), with no ambidextrous children. For global hand efficiency as well as for the differences between global preferred and nonpreferred hand scores, there is no significant difference between boys' and girls' performances ($p<0.01$) (Table 3), but there is one for age, without interaction of age and sex.

Hand efficiency and hand preference.-Any subject whose difference “d" of the global scores for preferred and nonpreferred hands is included between the limits: $0<d<[-1.29 \times (1 + M]$ (where σ is the standard deviation of the differences and M their mean) (10% of the subjects are included under the normal curve below

TABLE 3
GLOBAL HAND EFFICIENCY: CHANGE WITH AGE

Age, yr.	Preferred, P			Nonpreferred, NP			Global P + NP			Difference P – NP		
	Boys	Girls	*M*	Boys	Girls	*M*	Boys	Girls	*M*	Boys	Girls	*M*
6	224.5	231.5	228.0	203.3	201.5	202.4	427.9	432.9	430.4	21.1	30.0	25.6
7	257.2	262.3	259.7	229.3	228.3	228.8	486.5	490.6	488.6	27.9	34.0	30.9
8	275.5	286.1	280.8	242.1	247.5	244.8	517.6	533.6	525.6	33.5	38.6	36.0
9	303.7	290.2	297.0	265.8	251.1	258.4	569.6	541.3	555.4	37.9	39.1	38.5
M	265.2	267.5	266.4	235.1	232.1	233.6	500.3	499.6	500.0	30.1	35.4	32.7

the value -1.29σ) is considered ambidextrous, and right-handed if the difference falls above the limits. For left-handers to appear, differences between right and left global scores must be compiled: negative differences whose absolute values are higher than the previous upper limit will identify left-handers. Applying these limits to this sample, 15 subjects (8 girls and 7 boys) are ambidextrous (12%), 13 left-handed (10%), and 100 right-handed (78%) with equivalent numbers of subjects in each category in each age group. Mean ratios (P -NP)/NP are significantly different ($p<0.01$) between ambidextrous and right- and left-handed children classified through efficiency tests ($F_{2,125} = 33.35$) but not when age or sex are considered. The ratios (P -NP)/(P + NP) will be, of course, lower for ambidextrous than for right- or left-handed subjects, as their P -NP differences are closer to 0. In this sample the ratios (P -NP)/(P + NP) were lower than .025, the sum P + NP being at least equal to 40 times the difference P -NP. As long as there is a significant difference at ($p<0.01$) between the means of the differences P -NP of right- and left-handed and ambidextrous subjects, one could change the limit for separating the three populations according to handedness. If we consider that 20% of the subjects could be ambidextrous, the differences lower than [-.85 x σ + *M*] would apply to them. Doing so, the means are significantly different ($F_{2,125}$=60.36), the right- and left-handed means being higher than the ambidextrous one but not different one from the other.

Different handedness distributions according to four various criteria are found in Table 2. As the questionnaires' classifications 1, 2, and 3 showed 4.7%, 7.8%, and 27.6% of ambidextrous subjects, these classifications were compared with efficiency-based classifications for 5%, 10%, and 30%, respectively. Discordant classifications (significant at $p<0.01$) appeared, with many permutations for subjects in neighbouring groups or not (Table 4). Some subjects classified as right-handers through the preference test appear to be left-handers and vice-versa. Of the 109 children self-classified as right-handers on the questionnaire 1, 5 turned out to be ambidextrous on the 5% performance test and 7 left-handed; 5, classified as ambidextrous, were actually right-handed; and from the 13 self-classified as left-handed, 2 were ambidextrous and one right-handed. But this does not happen when hand preference and writing performance are compared: no right-hander becomes a left-hander and no left-hander becomes a right-hander. These results raise the important question about the tests and the limits used to classify subjects according to their handedness as well as the difficulty of comparing percentages of each category in the population from one study to another.

TABLE 4

COMPARISONS OF PERFORMANCE AND PREFERENCE CLASSIFICATIONS FOR THREE DIFFERENT THRESHOLDS ON EFFICIENCY AND WRITING TESTS (CF. LEGEND OF TABLE 2)

Performance Tests	Preference											
	Preference 30–70:Performance 5%				Preference 20–80:Performance 10%				Preference 10–90:Performance 30%			
	1	2	3	Σ	1	2	3	Σ	1	2	3	Σ
Efficiency												
1. Right	97	1	5	103	94	1	5	100	69	0	12	81
2. Left	7	10	0	17	5	5	3	13	1	1	5	7
3. Ambidextrous	5	2	1	8	9	4	2	15	19	3	18	40
Σ	109	13	6	128	108	10	10	128	89	4	35	128
	Preference 30–70:Writing 5%				Preference 20–80:Writing 10%				Preference 10–90:Writing 30%			
Writing												
1. Right	109	0	3	112	102	0	3	105	61	0	14	75
2. Left	0	13	3	16	0	10	4	14	0	3	6	9
3. Ambidextrous	0	0	0	0	6	0	3	9	28	1	15	44
Σ	109	13	6	128	108	10	10	128	89	4	35	128

In the present sample, differences between global preferred and nonpreferred hand scores were as much as 45% greater for right-handers than for left-handers (35.6 vs 24.6). Right-handers, as a group, tended to be more lateralized than left-handers, the preferred hand being more skilled than the nonpreferred one (Tapley & Bryden, 1985). The mean of the differences is also higher for girls (35.4) than for boys (30.1), although not significantly different ($p>0.05$). The distribution of differences was slightly negatively skewed, which also confirms previous results (Annett, 1972).

Means of total hand-efficiency scores (P + NP) were not significantly different ($p > 0.05$) for right-handed, left-handed, and ambidextrous groups. Subjects who use one hand more often than the other should show a large hand difference on both scores of preference and efficiency: a correlation of only .54 is found between global hand-efficiency score differences and percentages of hand preference; on the other hand, a correlation of .71 is found between hand preference and hand score differences on writing. Even when this relation is quite high, the stated preference for one or the other hand might only correspond to a small difference in efficiency between the two hands.

How are the hand-efficiency tests related? A factor analysis (varimax rotation) done with raw scores for preferred and nonpreferred hands yielded four factors (strength, steadiness, tapping-aiming, and dexterity), with the following respective contributions of proportional variance, 23%, 27%, 28%, and 22%. The tests used do seem to evaluate different dimensions of hand efficiency.

How do raw scores on hand-efficiency tests predict hand preference? The results of a stepwise regression analysis with right- and left-hand scores show that four scores on two tests are most important: left- and right-hand writing, and right- and left-hand aiming. If differences between raw scores are included in the regression instead of raw scores, writing enters the model first ($R = .71$; $R^2 = .51$), with a second and last step for aiming ($R = .74$; $R^2 = .62$). The two tests needing the greatest amount of training are the ones most related to hand preference.

DISCUSSION

Using a battery for hand preference, on which subjects have to perform the tasks instead of just answering which hand they “think" they use more often to do one action or another, avoiding the repetitive effect of questions and monotony of responses, gives a better idea of hand dominance.

Comparing the differences between the scores for preferred and non-preferred hands on the efficiency tests emphasizes similarities in performance or the shift towards a higher score for one hand compared with the other. It appears that boys and girls, as groups, obtain similar difference scores, except on writing on which the difference score is higher for girls than for boys. But, a comparison of the sums of scores for the right and left hands on each efficiency test indicates that boys are better than girls on tapping and strength tests, similar on aiming, and inferior on writing and finger dexterity. There are no systematic differences between boys and girls on efficiency: all depend on the tests and the abilities considered. As a result, one might have to consider total-hand dexterity as well as between-hand differences to get a comp1ete picture of hand efficiency and so of handedness.

If one hand is used more often than the other, the difference in skill should be related to the percentage of use of the preferred hand. When correlations are calculated between right- and left-hand scores on the five efficiency tests and the laterality quotient, only aiming and writing differences are highly correlated with the laterality quotient (.65 and. 71, respectively). Hand preference does not correlate with all hand skills, but mostly correlates with those skills requiring higher control.

To substitute efficiency for preference in establishing handedness, we must develop a single test to assess the overall efficiency of both hands or find a way to combine scores on different tests. The first alternative might be quite hazardous, hand-efficiency being a multidimensional rather than a unidimensional concept. With regard to the second case, that of combined raw scores, we have to be able to compute, at the end, a difference between right- and left-hand scores to assess handedness, and a sum of these same scores to make improvement in efficiency over age stand out.

Are all these calculations worthwhile? Probably so, if one's interest is in selecting pure right- and left-handed subjects. The use of single-task measure or questionnaires may lead to various misclassifications. Some people consider themselves either right- or left-handed, but their performance with the nonpreferred hand actually surpasses that of the preferred one. In this sample, for example, the percentage of subjects misclassified by a questionnaire (1) as compared to efficiency with a threshold of 5% for ambidextrous was close to 14%. According to the questionnaire of hand preference, percentages of subjects classified as right-handers, left-handers, or ambidextrous vary significantly with age and the threshold used. This happens to be similar for efficiency. There is a change in hand efficiency with age: using more v and more one hand at the expense of the other, the difference in efficiency between hands increases for writing but not for other hand abilities (e.g., strength, tapping, etc.).

The threshold for characterizing ambidextrous subjects is purely arbitrary (there is obviously no natural limit for ambidexterity). For handedness questionnaires, right- and left-handers could be those who use consistently the right or the left hand for all actions (Annett, 1970); with such a limit, no subject would have been left-handed in the present study. For efficiency, the range of the difference apart from zero, selected to characterize ambidextrous subjects, may vary to meet the experimenter's goals. If we want to exclude from a study even marginally ambidextrous subjects, we may choose an even higher range *(-z* value closer to 0 in the limits equation) or raise the limit of the (P -N)P(P + NP) ratios. In this sample, all subjects whose hand-efficiency differences were close to zero had total-hand scores close to the mean of their age group.

The Pearson correlation coefficients between hand-efficiency scores for preferred and nonpreferred hands show a general diminishing trend, between gross and fine hand-coordination tests. Strength and finger tapping do not require any fine coordination in muscle contraction, and the performances of the right and left hands are, in this case, highly correlated. On the other hand, aiming, steadiness, finger dexterity, and writing do require fine control. The efficiency of one hand, gained through practice, does not imply efficiency of the other one, especially for writing where correlations between scores for preferred and nonpreferred hands are lower. It might be difficult to find efficiency tests where scores for preferred and nonpreferred hands are not correlated as suggested by Hiscock (1988), unless we only choose highly' learned activities.

These results support the idea of two different muscle-control systems for proximal and distal arm movements (Kuypers, 1978; Healy, Liederman, & Geschwind, 1986), with practice acting more on distal than on proximal control. A similar trend emerges from factor analyses on data from hand- preference questionnaires (Healy, *et al.,* 1986; Steenhuis & Bryden, 1989), where handedness information on everyday activities group together in accordance with this dichotomy. Correlations between scores on different hand-efficiency tests are also rather low, indicating that hand efficiency is a multi-dimensional concept. This is clear with a factor analysis including all tests of hand efficiency using both preferred and nonpreferred hand raw scores. Four different factors emerge: strength, tapping, aiming-writing-dexterity, and steadiness, all fairly representative of abilities needed to perform hand activities adequately. The aiming-writing-dexterity factor assembles two tests using a pen and requiring fine eye-hand coordination to reach high performance; whatever the relation, they share just 36% of common variance. How are these four factors related to those coming from analysis of responses to preference questionnaires?

From the factor analyses performed by Beukelaar and Kroonenberg (1983), Healy, *et al.* (1986), and Steenhuis and Bryden (1989), hand activities might be classified into six different categories: reaching/grasping, using tools/manipulating objects, throwing, carrying, pointing, and bimanual activities. Apart from a general factor requiring the use of one hand, not all of these types of activities require the same amount of fine finger coordination. Using tools and manipulating objects include generally a broad sample of everyday manual activities, some very culturally biased (writing, drawing, painting, etc.), others more culturally independent but related to hand efficiency (striking a match, sewing, peeling vegetables, etc.). They will be “naturally" performed with the “better" hand, the one “having acquired" the best skill as they necessitate a fair amount of finger dexterity (distal muscle control). On the other hand, we find the gross motor-arm activities of throwing and carrying things. This last activity involves the whole body while the hand is used only to grasp the suitcase or the bucket, and when one arm is too tired to hold the object, we change to the other one. Even if we prefer to use one hand rather than the other, both might be used with almost the same efficiency. For throwing (a ball, a javelin, a dart, etc.), even when the whole body is involved, global body coordination is needed with finer control of one shoulder (proximal muscle control). To reach a high performance, training is necessary and one hand is generally preferred to the other. For reaching-grasping (picking up a needle, a marble, a paper clip, a glass, etc.) and painting (button phone or dialing, calculator, showing a far object, etc.), there is a combination of proximal and distal control movements, the first “carrying" the hand towards the object to be reached and the second movement grasping it. Either hand can be used with similar results. Bimanual activities involve, generally, the use of the two hands to hold a single object (rake, broom, spade, shovel, bat, etc.), to use two different objects in combination (fork and knife, nail and hammer, screw and screwdriver, ...), or an object and a tool (potato and peeler, toast and knife, etc.) or to perform a task (winding a watch, cutting paper with scissors, peeling an orange, unscrewing a top from a jar, etc.). These particular activities require a coordination between both hemispheres whose interactions are far from clear in relation to the way the brain controls both hands simultaneously. For this reason, they should be treated separately in questionnaires and not mixed with unimanual tasks. We must keep these features in mind in creating hand-preference questionnaires by including items from each category or favouring one or the other of these. It is interesting to note that none of the questions of hand preference or of the tests of hand efficiency most commonly used are related to “sensory preference" or to hand used to “feel" things or catch information, but only to “motor preference."

Even if there is no simple relationship between preference and efficiency factors, we could relate, from the present study, painting with pointing and tapping, carrying with strength, grasping-manipulating objects with dexterity and writing. So, to answer the title question, only subjects having simultaneously the same performance and preference hand should be included in studies where handedness is a classification variable. If only one method is to be used, efficiency should be considered, in spite of the greater effort involved relative to recording verbal responses to questionnaires: it gives first, the preferred hand and second, a real image of the difference in hand efficiency, gained through practice and associated with preference.

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Accepted August 21, 1992.