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Psychomotor Skills for Endoscopic Manipulations:

Differing Abilities Between Right and Left-Handed Individuals

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Objective
The objective of this study was to compare the psychomotor aptitudes relevant to endoscopic manipulations between right-handed and left-handed subjects.

Summary Background Data
There has been little research on the psychomotor performance in relation to minimal access surgery and there are no psychomotor tests to evaluate aspects of psychomotor abilities relevant to endoscopic manipulations.

Methods
A microprocessor-controlled psychomotor tester was developed for objective evaluation of endoscopic performance. The task involved negotiating ten target holes with a probe under videoscopic imaging. Subjects consisted of two groups of 10 medical students: right- and left-handed. After a prestudy familiarization session, each subject performed two test runs with one hand, followed by two runs with the other hand. These test runs were repeated 1 week later. The outcome measures were the total execution time, force on backplate, angular deviations, error rate, and first-time accuracy.

Results
A significant difference in the error rate and first time accuracy was observed between subjects ($p < 0.001$ and $p < 0.001$, respectively) and between the dominant and nondominant hands ($p < 0.001$ and $p < 0.025$, respectively), with no significant change with practice. Right-handed subjects performed better with either hand in terms of error rate ($p < 0.001$) and first time accuracy ($p < 0.001$). Practice improved the execution time ($p < 0.001$) and the degree of angular deviations ($p < 0.02$).

Conclusions
Right-handed subjects perform less errors and exhibit better first time accuracy. The parameters that improve with practice reflect the positive effect of training, whereas others, such as errors rate and first time accuracy which do not, reflect innate abilities.

With the current technology there are three factors that degrade task performance in minimal access surgery (MAS): kinematic restriction, reduced tactile feedback and increased perceptual processing consequent on operating from a displayed indirect image of the operating field.[1] These restrictions contribute to iatrogenic morbidity and indicate the need for adequate training and selection of candidates with the right psychomotor attributes.

In psychomotor research, *ability* is the adaptive capacity, trait, or aptitude that a person brings to a given task; whereas *skill* is the result of applying a specific combination of abilities to a given task.[2] Certain abilities are considered important for endoscopic surgical work. These include control precision, two-hands coordination (ambidexterity), steadiness, aiming, manual dexterity, spatial perception, perceptual processing of indirect images and eye-hand coordination in a magnified virtual field. *Control precision* is common to tasks that require fine, highly controlled muscular adjustments, primarily those in which large muscle groups are involved. *Manual dexterity* involves skillful, well-directed arm-hand movements in manipulating fairly large objects under speed conditions. *Arm-hand steadiness* is the ability to make precise arm-hand positioning movements in which strength and speed are minimized; the critical factor being the steadiness with which such movements are made. *Aiming* is the ability to perform quickly and precisely a series of movements requiring eye-hand coordination. *Two-hands coordination* is the ability to coordinate both hands simultaneously.[3] *Spatial visualization* involves the ability to mentally rotate and manipulate two- and three-dimensional stimulus objects. *Spatial orientation relates to* comprehension of the arrangement of elements within a visual stimulus pattern such that the individual remains unconfused by the changing orientations in which a spatial configuration may be presented. It includes the ability to determine spatial orientation with respect to one's body.[4]

In conjunction with the Department of Medical Physics, we have developed a microprocessor-controlled endoscopic psychomotor tester to evaluate some of these psychomotor attributes and skills. The studies have been conducted in a group of medical students and were designed to compare the performance between right and left-handed subjects and between dominant and nondominant hands.

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MATERIALS

The Dundee Endoscopic Psychomotor Tester

The Dundee Endoscopic Psychomotor Tester (DEPT) consists of a stainless steel probe mounted in a gimbal mechanism, which can be inserted through ten holes set in different planes on a target object consisting of a spatially irregular disk that overlies a flat backing plate (Fig. 1). The system records the spatial coordinates of the tip of the probe, the force exerted by the probe on the back plate and the execution time of the task. The technological details, construction and function of the DEPT are being reported elsewhere. The DEPT interfaces with its controlling personal computer through an Advantech PC MultiLab PCL-711B D/A card (Eagle Electronics, Capetown, South Africa) and records performance data during execution in real time.

System Function

Each run consists of ten target holes. The order in which holes are addressed is by random sequence generated by the system software. The perforated target plate is rotated between 0° and 270°. A light emitting diode situated in close proximity to each target hole lights up to indicate the target hole selected. Starting from the backstop position, the operator aims the probe at the center of the hole and then advances the probe through the center of the hole until it touches the back plate. An error is registered by the system when contact of the probe with the rim of the hole reaches or exceeds a preset time (1 second or more for the present study), or when the subject takes more than 20 seconds to complete one target hole. When an error is encountered, the subject has to reattempt the target hole before proceeding to the next. A full run is completed when the subject has negotiated successfully all the target holes. The Dextest software records the performance data for each individual target hole and for a complete run (Table 1).

SUBJECTS AND METHODOLOGY

Subjects involved in this study were volunteer medical students and consisted of a right-handed and left-handed groups, each of 10 individuals. Both groups were matched for age, year at medical school, sex and vision (corrected).

The endoscopic system used for the study consisted of a Sony monitor (Sony Corp., Tokyo, Japan); a forward viewing Hopkins II telescope (Karl Storz, Tubingen, Germany) and a light source and light cable (Karl Storz, Tubingen, Germany). The telescope was introduced into the DEPT facing the target plate at a distance of 22 cm from its center.

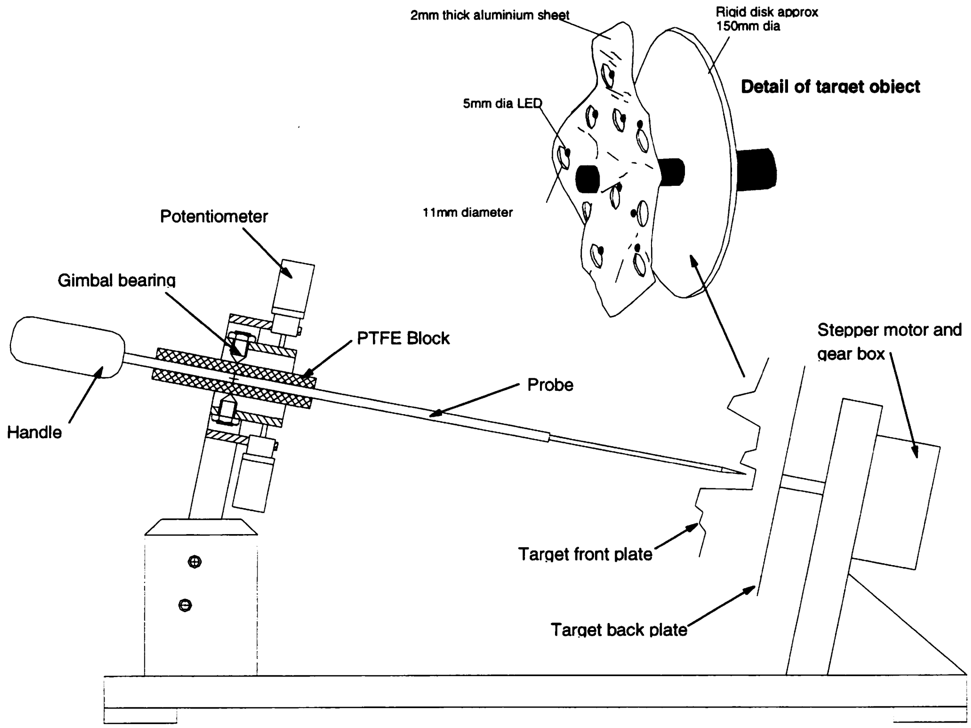

Figure 1. Diagrammatic representation of the Dundee Endoscopic Psychomotor Tester (DEPT).

Each subject had a prestudy session of three complete runs for familiarization with the system. Thereafter, each individual performed two test runs with one hand, followed by two runs with the other hand. The selection of the ''start'' hand (dominant, nondominant) was chosen by random order. These test runs were repeated 1 week later by all subjects involved in the study.

Analysis of Performance Data

The data relating to the total execution time, contact error time, angular deviations, and applied force were normally distributed. Repeated measures analysis of variance was applied to these data to establish the effect on performance of practice (run 1 versus run 4) and dominance (dominant versus nondominant hands) within subjects. The performance between the right-handed and left-handed groups was also compared by repeated measures analysis of variance.

The data on error rate and first time accuracy were not normally distributed. Generalized linear interactive modelling was used to fit a Poisson model to the data in which probability ($R = r/\lambda$) = e − λλr/r where r = observed number of errors, R = population parameter for numbers of errors and λ = mean number of errors. The deviance data obtained from the Generalized linear interactive modelling models were used to generate standardized residuals plots (for fit) and to estimate significance levels. The standardized residuals showed no systematic variation and therefore confirm the applicability of the Poisson model.

Table 1. SCREEN DISPLAY DATA

For each target hole negotiated successfully at the end of a completed run
Total time (sec)
Force applied to rear target plate (g)
Worst case low horizontal angular deviation (units)
Worst case high horizontal angular deviation (units)
Worst case low vertical angular deviation (units)
Worst case high vertical angular deviation (units)
Additional information on a complete run
Total time for all ten target holes
Number of errors
First time accuracy*
Average angular deviations†

* First time accuracy is defined as the number of target holes out of ten where there was no front plate error or time-out error on the initial attempt.
† Angular deviation, 1.0 unit = 0.005°.

RESULTS

Total Execution Time, Angular Deviations, and Applied Force

The data are shown in Table 2. Practice improved the execution time ($p < 0.001$) and the degree of angular deviations ($p < 0.02$ for low horizontal; $p < 0.01$ for high horizontal; $p < 0.01$ for low vertical and $p < 0.001$ for high vertical angular deviations). This improvement

Table 2. EFFECT OF PRACTICE ON EXECUTION TIME, FORCE ON BACK PLATE, AND ANGULAR DEVIATION (MEAN ± SD): 1 UNIT OF ANGULAR DEVIATION = 0.005°

Practice	First Run	Second Run	Third Run	Fourth Run
RHG using right hand				
Total execution time (sec)	39.3 ± 17.0	37.6 ± 16.0	35.5 ± 13.0	31.5 ± 10.8
Total force (g)	4478.6 ± 1137.5	4523 ± 1084	4410.4 ± 1505.5	4712 ± 1845
Worst case low horizontal deviation (units)	416.4 ± 272.1	425 ± 240.8	432 ± 198.6	285 ± 169
Worst case high horizontal deviation (units)	323.9 ± 184	272.6 ± 189.2	188.7 ± 213.2	184.4 ± 162
Worst case low vertical deviation (units)	389 ± 257.7	365 ± 192.2	283 ± 168	288.7 ± 188.8
Worst case high vertical deviation (units)	311 ± 256.4	352 ± 264.7	410.8 ± 258.2	270.6 ± 191.7
LHG using left hand				
Total execution time (sec)	56 ± 15.2	48.3 ± 17.1	40.2 ± 16.7	42.1 ± 17.2
Total force (g)	3124.5 ± 587.2	2951.7 ± 542.7	3574.6 ± 1255.8	3689.4 ± 1709.4
Worst case low horizontal deviation (units)	445.8 ± 236.2	331 ± 230.1	305.6 ± 156.5	348.8 ± 232.7
Worst case high horizontal deviation (units)	273 ± 151.7	265.7 ± 192	250.7 ± 215.3	295 ± 187.1
Worst case low vertical deviation (units)	395.8 ± 264.3	340 ± 153.7	309.6 ± 220.7	351.8 ± 193.5
Worst case high vertical deviation (units)	382 ± 232.1	290 ± 233.1	190.5 ± 183.2	199.6 ± 204.7
RHG using left hand				
Total execution time (sec)	39.2 ± 13.5	35.1 ± 14.8	31.4 ± 13.3	28 ± 9.6
Total force (g)	4340.4 ± 803.2	4477.2 ± 994.3	4584.4 ± 1361.5	4318.9 ± 1281.6
Worst case low horizontal deviation (units)	348.8 ± 156.5	307.5 ± 159.7	306.4 ± 238.9	259.8 ± 183.1
Worst case high horizontal deviation (units)	361.3 ± 130.7	279.2 ± 282.2	197.4 ± 204.2	136.5 ± 242
Worst case low vertical deviation (units)	414.4 ± 214.2	302.9 ± 224.8	275.6 ± 155.6	197.2 ± 139.5
Worst case high vertical deviation (units)	410.6 ± 195	392.6 ± 289.3	180.6 ± 181.9	201.8 ± 163
LHG using right hand				
Total execution time (sec)	52.1 ± 16.3	59.4 ± 14.7	45.5 ± 17.9	36.4 ± 13.2
Total force (g)	3559.6 ± 1210.4	2933.4 ± 686.2	3542 ± 1558.6	3485.8 ± 1296.7
Worst case low horizontal deviation (units)	402.8 ± 176.2	463.8 ± 140.8	404.3 ± 191.7	296 ± 189.3
Worst case high horizontal deviation (units)	251.2 ± 160.9	359.5 ± 200.8	201.4 ± 192.4	182.7 ± 151.5
Worst case low vertical deviation (units)	352 ± 251	320.7 ± 147.6	245.5 ± 162.5	214.2 ± 141.2
Worst case high vertical deviation (units)	363 ± 207.4	434.1 ± 218.4	426.2 ± 317.3	156.8 ± 209.4

RHG = right handed group, LHG = left handed group.

was not significantly different whether the subject was using the dominant or nondominant hand ($p = 0.1$ for the execution time; $p = 0.8$ for low horizontal; $p = 0.4$ for high horizontal; $p = 0.4$ for low vertical and $p = 0.3$ for high vertical angular deviations). There was no significant effect of practice on the force applied on the back plate ($p = 0.4$).

No significant differences were found in the execution time ($p = 0.7$) or the force applied on the target ($p = 0.9$) between the dominant and non-dominant hands. Apart from the worst case low vertical angular deviation ($p < 0.04$), there was no significant change in the degree of angular deviations between the two groups ($p = 0.3$ for low horizontal; $p = 0.6$ for high horizontal and $p = 0.5$ for high vertical angular deviations).

Right-handed subjects performed the task in a shorter execution time ($p < 0.04$) but with more force on the target ($p < 0.02$) than the left-handed group. The improvement in the execution time was not significantly different on using the dominant or nondominant hands ($p = 0.06$) or with practice ($p = 0.1$). Similarly, the increase in the force applied was not significantly different on using the dominant versus the nondominant hands ($p = 0.7$) or with practice ($p = 0.4$). No significant difference was observed between the right-handed and left-handed subjects in the degree of angular deviations ($p = 0.7$ for low horizontal; $p = 0.8$ for high horizontal; $p = 0.97$ for low vertical and $p = 0.9$ for high vertical angular deviations).

Error Rates

Each subject carried out eight runs, total number of runs, 160. The frequency distribution of errors is shown Table 3. The high value of 23 was excluded as this left-handed subject was very nervous during performance of this particular run and had a median of two errors in eight runs. The medians and interquartile ranges for the error rates for both groups using dominant and nondominant hands are outlined in Table 4.

Using the parameter estimates from a Poisson model

Table 3. FREQUENCY DISTRIBUTION OF ERRORS IN 160 RUNS (EIGHT PER SUBJECT)

No. of errors	0	1	2	3	4	5	6	7	23
Incidence	91	34	15	6	8	2	1	2	1

fitting hand and dominance gave the following mean expected number of errors for each group:

Right-handed using dominant hand = 0.29;
Right-handed using nondominant hand = 0.59;
Left-handed using dominant hand = 0.91;
Left-handed using nondominant hand = 1.86.

As expected, a significant difference was observed between the dominant and nondominant hands ($p < 0.001$). The difference in error rate between the right-handed and left-handed subjects was significant ($p < 0.001$), with insignificant interaction of dominance. The effect of practice in reducing error rate was not significant ($p = 0.3$).

Another model was fitted using dominance and the operator rather than fitting hand as these 2 factors were completely aliased. This showed a significant difference between subjects in the error rate ($p < 0.001$).

First Time Accuracy

First time accuracy was on a scale between 7 and 10. For the analysis, this was transformed by (10-x),that is, on to a scale 0–3, with 0 indicating first time accuracy of 10/10, 1 = first time accuracy of 9/10, 2 = 8/10 and 3 = 7/10 target holes. The frequency distribution of the first time accuracy observations is shown in Table 5. The raw data on first time accuracy for the four runs in both groups using dominant and nondominant hands are shown in Table 6.

The parameter estimates from the Poisson model fitting hand and dominance gave the following means (on the original scale) for first time accuracy:

Table 4. ERROR RATES WITH PRACTICE: MEDIAN (INTERQUARTILE RANGE)

Practice	First Run	Second Run	Third Run	Fourth Run
RHG using right hand	0 (0–0)	0 (0–0)	0 (0–1)	0 (0–0)
LHG using left hand	1 (0–2)	0.5 (0–1)	0 (0–2)	0 (0–1)
RHG using left hand	0 (0–2)	0 (0–1)	0 (0–0)	0.5 (0–1)
LHG using right hand	1.5 (0–3)	1 (1–5)	2.5 (1–4)	1 (0–1)

RHG = right handed group, LHG = left handed group.

Table 5. FREQUENCY DISTRIBUTION OF FIRST TIME ACCURACY IN 160 RUNS

Value	10	9	8	7
Incidence	91	48	14	7

Right-handed using dominant hand = 9.77;
Right-handed using nondominant hand = 9.61;
Left-handed using dominant hand = 9.33;
Left-handed using nondominant hand = 8.87.

There was a significant difference between the dominant and nondominant hands ($p < 0.025$) and between right-handed and left-handed subjects ($p < 0.001$) but practice had no effect on first time accuracy ($p = 0.6$).

Another model was fitted using the operator as the factor as opposed to fitting the hand. This demonstrated a significant difference between subjects in first time accuracy ($p < 0.001$).

DISCUSSION

A psychometric or psychological test used for aptitude testing has to be standardized, objective, reliable and valid.[5,6] The DEPT ensures that all subjects are assessed alike in terms of the nature of the test and the instructions, displayed on the screen, to the candidates. Objective real-time scoring by the system software removes the assessor variability. The data on error rate and first time accuracy have confirmed the reproducibility of the test. The DEPT measures a combination of abilities, whereas the established psychomotor tests in current usage measure only a specific ability related to each test. Aspects of face validity include the use of a real endoscopic imaging system and probe movement in the gimble mechanism

Table 6. FIRST TIME ACCURACY, EFFECT OF PRACTICE: MEDIAN (INTERQUARTILE RANGE)

Practice	First Run	Second Run	Third Run	Fourth Run
RHG using right hand	10 (10–10)	10 (10–10)	10 (9–10)	10 (10–10)
LHG using left hand	9 (9–10)	9.5 (9–10)	10 (9–10)	10 (9–10)
RHG using left hand	10 (9–10)	10 (9–10)	10 (10–10)	9.5 (9–10)
LHG using right hand	9 (8–10)	9 (9–9)	8 (8–9)	9 (9–10)

RHG = right handed group, LHG = left handed group.

that reproduces the use of the endoscopic instruments through access ports with the same degrees of freedom. Predictive validity needs future studies to determine the extent to which the assessment obtained by use of the DEPT predicts the level of endoscopic surgical performance. The DEPT satisfies the criteria outlined by Holdsworth (1988) for viable assessment techniques, that is, it is technically sound, economically feasible and acceptable to both candidates and assessors.[5]

The subject's performance with the current version of the DEPT depends on hand to eye coordination, spatial perception, perceptual processing of indirect image information and balance or manipulation of the probe within a magnified field. Control precision and aiming are also required for movement of the probe through the holes, while steadiness is necessary during probe advancement between the target plates. However, the current generation does not evaluate two hand coordination and bimanual dexterity, although this deficiency is being addressed in the next generation of the DEPT.

The data on performance by right- and left-handed subjects obtained in these experiments confirm improvement in certain parameters with training and practice. Execution time and the degrees of angular deviations are significantly reduced with practice. The measurement of the contact force confirmed that the improvement in the execution time is genuine as although the subjects performed the task faster, they exercised the same level of deliberate careful movements. A significant difference in the error rate and first time accuracy was observed between subjects and between the dominant and nondominant hands. However, there was no significant change in these two parameters with practice. This finding is important since it signifies that the DEPT exercises measure the ability of the subjects and at the same time allow for the inconsistency of manual performance over time.

Right-handed subjects performed better with either hand in terms of error rate and first time accuracy than the left-handed individuals. This finding is consistent with reports on psychomotor studies that showed that left-handed people have poorer spatial perception than the right-handed subjects,[7–11] although other studies have not documented this difference.[12–15] The longer execution time by the left-handed subjects with application of less force on the target are in agreement with the reported observations of Schuenman et al. that left-handed surgical residents are more cautious than right-handed counterparts.[16]

In conclusion, objective evaluation of the performance during remote manipulations in a magnified indirect visual field is a practical proposition. Volunteer studies using the DEPT have documented differences in psychomotor abilities between medical students. Certain parameters that improve with practice reflect the positive effect of training and practice, whereas others, such as error rates and first-time accuracy that do not, reflect innate abilities. Right-handed subjects perform less errors and exhibit better first time accuracy than the left-handed individuals. The use of the DEPT for aptitude evaluation in the selection of candidates for careers which require manipulative endoscopic skills merits future investigation.

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