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ABSTRACT

The purpose of this study was to assess Welford's dual controlling factor interpretation of Fitts' Law--describing movement time as being a linear function of movement distance (or amplitude) and the required precision of the movement (or target width). Welford's amplification of the theory postulates that two separate processes ought to be distinguished, a faster one concerned with distance covering and a slower one for homing onto the target. Twenty subjects, all scuba divers, were required to perform a reciprocal tapping task. In an attempt to separate the two factors, the subjects were tested on land and underwater. This did not change the basic parameters of the task but did put the subjects under informational stress in that underwater the movement was less ballistic in nature and, therefore, would require the processing of more information (feedback) in order to complete the task. The land data appeared to support Fitts in that the contributions of movement amplitude and precision were approximately equal. However, the relative changes in contribution of these factors to movement time underwater suggests that these parameters do in fact represent separate controlling factors. (Author/MB)

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Movement Precision and Amplitude as Separate Factors

in the Control of Movement

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Movement Precision and Amplitude as Separate Factors in the Control of Movement

Though the area of motor control has advanced rapidly over the last thirty years, we still have few precise formulations to describe motor performance. One such formula, drawing from information theory, was devised by Fitts (1954). He describes movement time (MT) as being a linear function of movement distance, or amplitude (A), and the required precision of the movement, or target width (W), so that:

$$MT = a + b \text{ ID: where ID is the Index of Difficulty}$$

or

$$MT = a + b \log_2 (2 A/W)$$

As this logrithmic relationship between the movement time and the index of difficulty was maintained regardless of whether the subjects used a 1 lb or a 1 oz stylus, Fitts suggested that the movement time is governed more by the central processes controlling and monitoring movement than by any factors of muscular effort. Howarth, Beggs and Bowden (1971) and Knight and Dagnall (1967) also show that the index is maintained even when more force needs to be applied, confirming Fitts original findings.

In 1960, so that it might provide a better fit to the experimental data, Welford suggested some revisions be made to the formula, such that:

$$MT = a + b \log_2 (A/W + 0.5)$$

However, studies by Knight and Dagnall (1967) and Kerr (1973) suggested that either formula was acceptable, with Welford's index giving a slightly better fit to the experimental data.

Thus Fitts Law makes movement time constant for any given ratio between movement amplitude and target width, with proportional changes in either factor producing equivalent changes in movement time. Welford, Norris and Shock (1969), however, felt that two separate processes ought to be distinguished, a faster one concerned with distance covering and a slower one for homing onto the target, represented in the equation as:

$$MT = a + b \log_2 A - c \log_2 W$$

This notion gains heuristic support from Adams (1971) closed-loop theory, where the memory trace selects the initial direction and dimensions of the movement and the perceptual trace guides the completion of the movement. Direct support for the two component theory was provided by Kerr and Langolf (1975) and Beggs and Howarth (1970). Both of these studies utilised movements in the saggital plane, however, a study by Kerr (1975) using a movement in a horizontal plane found no difference between the contribution of the two components of movement amplitude (A) and precision (W).

Ledwith (1970) in looking at the effects of stress on movement control, by reducing the total air pressure in a decompression chamber, found that increases in reaction time were matched by decreases in movement time, resulting in no change in the overall response time. Drawing on this concept of using stress to manipulate the underlying components of a response, it was felt that placing subjects in an underwater environment might allow a similar effect on the two components suggested by Welford; if they are separable.

Vince (1948) and Keele (1973) have indicated that moving to a target involves a series of movements and corrections. By changing the viscosity of the medium, working underwater, subjects are now faced with a situation where a sustained application of force, rather than a ballistic movement, is necessitated to complete the response; with a concomitant increase in the number of corrections. Thus the situation places a greater burden on the central controlling processes in that it requires more information to control the movement, yet the basic parameters of distance and precision remain the same.

If the Welford interpretation is correct in that the response involves two operations, the first of which is simply to get over the target, then the stress condition should increase the contribution of the distance covering factor (movement amplitude) in relation to the homing factor (movement precision). This being due to the increased information processing involved in travelling over distance. If the Fitts interpretation of a single operation is correct then the contribution of the two factors should balance, with there being an overall increase in movement time due to the increased resistence and the general increase in the information load.

This concept was utilised in a study by Kerr (1973), the results of which confirmed the general concept of Fitts Law in terms of the relationship between movement time and the index of difficulty. Tentative support was also given to the Welford interpretation, as movement amplitude did have a disproportionate effect on movement time underwater compared to land, however, this may have been due to the use of novice divers or simply the lack of practice underwater. Ross (1970), looking at curvature distortion underwater in experienced and novice divers, suggested that the experienced divers have acquired a "situation contingent" visual response.

Therefore, the purpose of this study was to assess Welford's dual controlling interpretation of Fitts Law and to investigate the relationship between diving experience and movement control underwater.

Method

Subjects. The subjects were 9 experienced and 11 novice divers who were paid volunteers drawn from university scuba classes. The novice divers were those who had just completed an introductory scuba course in the pool, whereas the experienced divers were those who had a minimum of two years' experience including dives outside the pool. The ages ranged from 18 to 24 yrs.

Apparatus. The apparatus consisted of pairs of targets marked on thin sheets of clear plastic, 8.5 x 11 in. (21.6 x 27.9 cm). These sheets were secured to the top of a white table, four per subject on each table, and the subjects sat on a broad 10 in. (25.4 cm) bench to allow for support of the air tanks on land. A duplicate of this apparatus was weighed down and used underwater. Subjects performed a reciprocal tapping task over the complete range of the index of difficulty, where movement amplitude (A) was 50 mm, 120 mm or 260 mm and the target width (W) was 2 mm, 6 mm or 15 mm; thus there were 9 combinations of A and W. The tapping was performed with a dart, the feathers of which had been removed to facilitate movement through the water.

Procedure. The subjects were tested on all 9 conditions with one of 10 chance sequences being arbitrarily assigned to each subject. Subjects first completed one sequence on land, were then placed underwater where they completed two more sequences and finaly were retested on land immediately upon leaving the water: giving a total of 36 trials. Different sequences were used for land and underwater and the second sequence performed in each environment was the reverse of the first. The two test sequences underwater were separated by a 2 min. rest.

Each trial lasted 20 sec. with a 10 sec. intertrial interval. The subjects were instructed to start with the dart over the first target and on the command "go" to strik the two targets alternately, making as many marks as possible while ensuring that each mark was within the target. The total number of marks was counted by an assistant while the experimenter timed the trials and gave the stop/start signals; which were given as a tap on the subjects head. The subjects were instructed to maintain a maximum of 5% error.

For the testing the subjects wore full scuba equipment without wet suits. To protect against temperature changes without restricting movement, subjects wore a combination of T-shirt and large plastic bag. The testing underwater was performed in the corner of the heated pool by the underwater lights, thus the subjects head was approximately 6-8 in. (15.24 - 20.32 cm) below the surface of the water. The scorer used a mask to facilitate counting the underwater trials. Prior to any testing, and after familiarisation with the task, all subjects had one complete practice session, performing 18 trials underwater and 18 trials on land. Movement time was calculated as the total number of movements (marks) made in each trial divided by 20. The data were submitted to a 2 x 4 x 9 (Group x Observation x Task) analysis of variance, repeated measures design.

Results

There were no significant differences between the two experimental groups, but there were significant main effects for observations, $F(3,54) = 39.6$ $p < .01$, for tasks, $F(8,144) = 593$, $p < .01$, and also a significant Observation x Tasks interaction, $F(24,432) = 7.1$, $p < .01$. The means MT's for each of the observations are presented in Table 1, and show a significant improvement from first to second observation within each environment, most particularly on land.

Insert Table 1 about here

The difference in means for each task, Table 2, show a fairly consistent improvement from Water 1 to Water 2, with the exception of the easiest and hardest task. On land the improvement is greater, in particular, this can be seen in movements to the smallest target, 2 mm. However, when comparing land to water, Table 3a, it is clear that the main differences lay in the greater effect of A on MT underwater. This influence can be seen in Table 2 where the difference between the first and second observation for targets of similar ID (for ID see Table 3b) is higher for the smaller W on land but higher for the greater A underwater. Kerr and Langolf (1975) questioned whether visual feedback plays a major part in aiming in fast movements, but inspection of Table 3b clearly shows that mean MTs are well above the minimum visual correction time of 290 msec. of Beggs and Howarth (1970).

Insert Tables 2 & 3 about here

Regression analysis of the two variables of MT and ID yeilded correlations for the four observations of .91, .91, .92 and .92, indicating that Fitts Law accounted for approximately 84 percent of the variance of the means in either environment. The regression equations for land and water were:

$MT_L = 117.8\ ID + 10.1$ msec: $MT_W = 135.4\ ID - .3$ msec

These equations again indicate the difference between the environments in response to changes in task difficulty. Though the slope coefficient for land is somewhat higher than that produced by Fitts (1954), it is in line with the earlier study of Kerr (1973), and may reflect differences inherent in the task.

In terms of the contribution of A and W differential weightings were assigned by Welford, whereas Fitts assumed equal weightings. A step-wise regression of MT with $\log_2 A$ and $\log_2 W$ yeilded the equations:

Land (1):

$$MT = 68 + 115 \log_2 A - 120 \log_2 W:$$

Land (2):

$$MT = 15 + 111 \log_2 A - 107 \log_2 W$$

Water (1):

$$MT = -205 + 161 \log_2 A - 111 \log_2 W$$

Water (2):

$$MT = -148 + 148 \log_2 A - 113 \log_2 W$$

Thus while there is no significant difference in the contribution of A and W on land, there is a significant difference, $p < .01$, in their contribution underwater. These compare with the equations of Kerr and Langolf (1975), for movements in the saggital plane, who found a significant difference in the slope due to A and W:

$$MT = -111 + 108 \log_2 A - 70 \log_2 W$$

Discussion

Though there was a practice effect over observations and an increasingly strong difference in MT as A increased (land vs water), the actual decrease in MT from Land 1 to Land 2 was manifested in an improved ability to deal with the smaller targets. This was achieved while still maintaining the same error rate. It is difficult to explain, but there appears to be an adaptive effect whereby practice underwater improves the efficiency or accuracy of the distance covering process, and in turn simplyfies the task of homing onto the target; the greatest room for improvement being on the most difficult targets. This phenomenon is similar to the "situation contingent" response of experienced divers described by Ross (1970), except in this case the effect was true for both novice and experienced divers.

The general relationship between MT and the difficulty of the task (ID), as described by Fitts Law, was demonstrated in this study both on land and underwater. This would appear to justify the original assumption that the underwater environment did not change the relationship of the basic parameters of the task. However, the change of environment did produce a significant change in the slope coefficients, unlike Fitts and Peterson (1964) who showed a practice effect as a decrease in the intercept but not a change in the slope; i.e. it was consistent across the tasks. Subsequent analysis indicates that this change between the environments is mainly as a result of the increased processing time involved in travelling over distance underwater. As the contribution of A and W could be manipulated by changing environments, this confirms Welford's suggestion that two separate controlling processes are involved. However, under normal circumstances it would appear that these two factors are balanced or are part of the same higher order operation, and only under stressful situations or in tasks which are loaded in favour of one factor do the two processes operate individually.

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Table 1

Significant Differences for Mean MT's of the Four Observations[a]

	Water (1)	Water (2)	Land (1)	Land (2)
MT	612	583	555	505
Water (1)	-	.05	.01	.01
Water (2)		-	.05	.01
Land (1)			-	.01
Land (2)				-

[a]MT in msec

Table 2

Differences in MT for Each Task: From First to Second Observation

a) Land 1 vs Land 2:[a]

	Target Width		
Amplitude	2	6	15
50	71.9**	39*	26.4
120	69.4**	41.2**	31.3*
260	72.7**	55.2**	42.4**

[a] MT in msec

* $p < .05$

** $p < .01$

b) Water 1 vs Water 2:[a]

	Target Width		
Amplitude	2	6	15
50	28.6	15.5	12.9
120	21.1	35.7*	22.4
260	59.7**	27.4	36.7*

[a] MT in msec

* $p < .05$

** $p < .01$

Table 3

Mean MT's for the Nine Tasks[a]

a) Differences Between Land and Water:

	Target Width		
Amplitude	2	6	15
50	24.05	22.85	25.55
120	67.05	58.85	56.75
260	122.80	114.50	118.65

[a]MT in msec

b) MT for Land and Water Combined and the ID:

	Target Width		
Amplitude	2	6	15
50	587 (4.67)	395 (3.14)	240 (1.92)[b]
120	722 (5.92)	555 (4.36)	395 (3.09)
260	890 (7.01)	727 (5.44)	559 (4.15)

[b] Welford's formula