DIVING, ADAPTATION, AND FITTS LAW

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To assess Welford's dual controlling factor interpretation of Fitts' law, 20 scuba divers performed a reciprocal tapping task. In an attempt to separate the two factors, the subjects were tested on land and underwater. This does not change the basic parameters of the task but does put the subjects under informational stress, in that underwater the movement is less ballistic in nature and should require the processing of more information (feedback) in each tap. On land, 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.

Though the area of motor control has advanced rapidly over the last 30 yr, one of the few precise formulations to describe motor performance was devised by Fitts (1954). This formula was subsequently supported by Howarth, Beggs, and Bowden (1971) and Knight and Dagnall (1967) who also demonstrated that the index is maintained even when more force needs to be applied, confirming Fitts original findings.

So that it might provide a better fit to the experimental data, Welford (1960) suggested some revisions be made to the formula, such that

$$MT = K \log_2 (A/W + .5)$$

(1)

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) a faster one concerned with distance-covering and (b) a slower one for "homing onto" the target, represented in the equation as

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

(2)

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-

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component theory was provided by Kerr and Langolf (Note 1) and Beggs and Howarn (1970). Both of these studies utilized movements in the sagittal 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).

Vince (1948) and Keene (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 initiation, is necessary to complete the response, with a concomitant increase in the number of corrections being required. Thus the situation should place 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.

This concept was utilized 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 (i.e., A/W). Tentative support was also given to the Welford et al. (1969) interpretation as movement amplitude did have a disproportionate effect on movement time underwater as compared to on land; however, this may have been due to the use of novice divers or simply the lack of practice underwater. Prior studies in an underwater environment have demonstrated varying degrees of visual adaptation underwater. Ross (1970), investigating curvature distortion underwater in experienced and novice divers, suggested that the experienced divers have acquired a "situation contingent" visual response. There is less information in regard to motor skills. Weltman, Christiansen, and Egstrom (1970) found experienced divers to be more efficient in an underwater construction task than novice divers, though the difference was mainly in work strategy rather than tool manipulation.

Therefore, the purpose of this study was (a) to assess the Welford et al. (1969) dual-controlling interpretation of Fitts' law by manipulating the environmental conditions under which the motor task was performed, and (b) 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 2 yr experience including dives outside the pool. Their ages ranged from 18-24 yr.

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 250 mm and the target width (W) was 2 mm, 6 mm, or 15 mm; thus there were nine 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 nine conditions with one of 10 randomly determined 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 finally were retested on land immediately upon leaving the water; this gave a total of 36 trials. Different sequences were used for each observation on 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 either a 2-min rest (Condition A) or four 20-sec trials of a secondary task (Condition B). The secondary task consisted of following back and forth with a dart a winding path of (5-mm diameter) circles marked on four sheets of clear plastic secured to a second underwater table adjacent to the first. The subject was required to follow the path by striking each circle as quickly as possible. A separate sheet was used for each 20-sec trial. Condition B was intended to provide additional practice on the accuracy component. All subjects performed the complete series of four sequences of the tapping task with Condition A and Condition B, but on separate days one week apart. Half the subjects performed Condition A on the first day and half began with Condition B.

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 strike 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 experiment timed the trials and gave the stop/start signals (given as a tap on the subject's 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, the testing under water was performed in the corner of a heated pool near underwater lights. Thus the subject's head was approximately 6 in. (15.24-20.32 cm) below the surface of the water, and the targets were well lit for the subject. The scorer used a mask to facilitate counting the underwater trials. Prior to any testing, and after familiarization 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 2 x 4 x 9 (group x condition x observation x task) analysis of variance, with repeated measures.

Results

There were no significant differences between the conditions (A or B) or between the two experimental groups (novice and experienced). However, there were significant main effects for observations [F(3,54) = 79.0, p < .01], for tasks [F(6,144) = 635, p < .01], and also a significant observation x tasks interaction [F(24,432) = 15.6, p < .01]. The mean MTs for each of the observations are presented in Table 1, and they show a significant improvement from first to second observation within each environment, most particularly on land.

<table>
<thead>
<tr>
<th>MT</th>
<th>Water 1</th>
<th>Water 2</th>
<th>Land 1</th>
<th>Land 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>608</td>
<td>.05</td>
<td>.01</td>
<td>.543</td>
<td>.01</td>
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<tr>
<td>Water (1)</td>
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<td>.05</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>Water (2)</td>
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<td>.05</td>
<td>.01</td>
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</tr>
<tr>
<td>Land (1)</td>
<td>.502</td>
<td>.05</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>Land (2)</td>
<td>.502</td>
<td>.05</td>
<td>.01</td>
<td></td>
</tr>
</tbody>
</table>

The difference in means for each task (Table 2) show a fairly consistent improvement from the first to second observation within each environment, particularly on land, with the differences between the two environments being greater for the larger amplitudes. Kerr and Langolf (Note 1) questioned whether visual feedback plays a major
Table 2
Mean MTs (milliseconds) for the Nine Tasks

<table>
<thead>
<tr>
<th>Task (A/W)</th>
<th>ID</th>
<th>MT (combined)</th>
<th>Land 1</th>
<th>Land 2</th>
<th>Water 1</th>
<th>Water 2</th>
<th>Land</th>
<th>Water</th>
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</thead>
<tbody>
<tr>
<td>50/15</td>
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<td>235</td>
<td>239</td>
<td>217</td>
<td>250</td>
<td>234</td>
<td>228</td>
<td>242</td>
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<tr>
<td>120/15</td>
<td>3.09</td>
<td>386</td>
<td>372</td>
<td>339**</td>
<td>431</td>
<td>403*</td>
<td>356</td>
<td>417</td>
</tr>
<tr>
<td>50/6</td>
<td>3.14</td>
<td>392</td>
<td>393</td>
<td>364*</td>
<td>411</td>
<td>398</td>
<td>379</td>
<td>405**</td>
</tr>
<tr>
<td>260/15</td>
<td>4.15</td>
<td>560</td>
<td>520</td>
<td>481**</td>
<td>634</td>
<td>603*</td>
<td>500</td>
<td>619**</td>
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<td>561</td>
<td>546</td>
<td>508**</td>
<td>612</td>
<td>578**</td>
<td>527</td>
<td>595**</td>
</tr>
<tr>
<td>50/2</td>
<td>4.67</td>
<td>578</td>
<td>594</td>
<td>536**</td>
<td>604</td>
<td>577</td>
<td>564</td>
<td>590</td>
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<td>719</td>
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<td>676</td>
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<tr>
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<td>881</td>
<td>835</td>
<td>780**</td>
<td>971</td>
<td>938**</td>
<td>807</td>
<td>954**</td>
</tr>
</tbody>
</table>

Note: The Welford et al. (1969) formula was used to compute ID, * indicates p < .05, and ** indicates p < .01.

part in aiming in fast movements, but inspection of Table 2 clearly shows that mean MTs were well above the minimum visual correction time of 290 msec of Beggs and Howarth (1970). The error rates of 5.9% (land) and 6.6% (water) were close to the guidelines set for the task.

Regression analysis of the two variables of MT and ID yielded correlations for land and water environments of .91 and .93 respectively, indicating that Fitts law accounted for approximately 85% of the variance of the means in either environment. The regression equations (in milliseconds) for land and water were: MT = 16 + 115 ID; MT = –10 + 137 ID. These equations again indicated the difference between the environments in response to changes in task difficulty. Though the slope coefficient for land was 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 et al. (1969), whereas Fitts (1954) assumed equal weightings. A step-wise regression of MT (in milliseconds) with logA and logW yielded the following equations:

\[
\begin{align*}
\text{Land (1):} & \quad MT = 48 + 114 \log A - 113 \log W \\
\text{Land (2):} & \quad MT = 21 + 109 \log A - 106 \log W \\
\text{Water (1):} & \quad MT = -117 + 158 \log A - 117 \log W \\
\text{Water (2):} & \quad MT = -174 + 153 \log A - 116 \log W
\end{align*}
\]

Thus, while there was no significant difference in the contribution of A and W on land, there was a significant difference (p < .01) in their contribution underwater. These compare with the equations of Kerr and Langolf (Note 1) (for movements in the sagittal plane); they found a significant difference in the slope due to A and W:

\[
MT = -111 + 108 \log A - 70 \log W
\]  

Discussion

The general relationship between MT and the difficulty of the task (ID), as described by Fitts (1954), was demonstrated in this study both on land and underwater. This would appear to justify the original assumption in 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; this was unlike the data of Fitts and Peterson (1964) who showed a practice effect as a decrease in the intercept but not a change in the slope, and it was consistent across the tasks. This change between the environments is mainly a result of the effect of traveling over distance underwater. As the contribution of A and W could be manipulated by changing environments, this confirms the Welford et al. (1969) 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 in tasks which are loaded in favor of one factor do the two processes operate individually.

Alternatively, these data may be explained in terms of the suggestion of Schmidt, Zelaznik, and Frank (in press) that the variability in the movement is a function of the amount of force applied to make that movement. Moving underwater would require much more force with a more sustained contraction than would the more ballistic movement on land. As a result, this would increase the variability of these movements, particularly over the longer distances. Hence, this in turn would necessitate the processing of additional corrections in order to control these movements and longer MTs. However, the increase in ID due to A reduced the information transmission rate underwater by approximately 1 bit/sec at 120 mm and 1.5 bits/sec at 260 mm. This might seem to reflect a slowing of the movement or a compensation for the greater variability in the movement produced by the larger forces generated to move over the longer distances.

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 an equivalent error rate (5.7% and 6.1%). The decrease in MT from Land 1 to Land 2 could be explained as an adaptive effect to controlling movements underwater, or as a practice effect. To assess these possibilities, 10 additional subjects were tested. The procedures used for this testing were the same as those described previously except that all four observations were conducted on land. These data showed a slight, but nonsignificant decrease in MT from the first to the fourth observation, suggesting that the improvement seen in the original data reflects an adaptive effect from water to land. The differences in the application of force necessary to produce movements underwater may have led to a greater focus of attention on the sensory consequences of each movement. The strengthened recognition schema (Schmidt, 1975) could then have temporarily (for 3-5 min) facilitated performance on land.

Reference Note


References

THE EFFECT OF INVALID TASK PARAMETERS ON SHORT-TERM MOTOR MEMORY

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Two experiments tested the influence of information from an invalid movement parameter on short-term motor memory for a valid task parameter. Experiment 1 showed that invalid task distance information affected location retention. Experiment 2 showed that invalid task location information affected task distance retention. These findings strengthen the evidence that the codes important for short-term motor retention are affected by a variety of factors within the movement context.

Common practice in short-term motor memory location-retention studies involves elimination of reliable distance cues by using different starting points for criterion and reproduction movements. This manipulation, which varies the distance moved, is intended to force subjects to focus on location (endpoint) and to ignore distance (length) information. Likewise, short-term motor memory distance retention studies eliminate reliable location cues by using different starting and ending points for criterion and reproduction movements. Here subjects are thought to attend to length information and to ignore final spatial location. But are subjects really able to ignore the inappropriate task cue? Changing distance does not eliminate distance cues. Changing location does not eliminate location cues. In effect, the criterion movement provides false information that then conflicts with the appropriate information for the reproduction movement. We already have evidence that distance influences location retention: location accuracy scores vary with the distance moved to reach the reproduction movement endpoint. Location affects distance in a similar fashion; distance retention accuracy varies with endpoint sector location for the reproduction movement (e.g., Laabs, 1973). The next step is to determine whether or not the invalid information provided by the nonattended criterion parameter influences reproduction accuracy.

The presence of invalid information often impairs ability to utilize other valid information. Stroop-effect studies provide a number of striking examples (see Dyer, 1973). More directly, studies of the relative salience of information from visual and kinesthetic modalities show that one’s ability to utilize the best or more informative source may suffer from the simultaneous presence of a second inaccurate or less

A preliminary report for the first experiment was presented at the annual meeting of the North American Society for the Psychology of Sport and Physical Activity, Ithaca, New York, May 1977. I would like to thank Sharon Cormier, Leslie Davidson, Janice Kendrick and Linda Lemon for their assistance with data collection in these studies and Ann Olsen for her advice and assistance in pilot work.

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