Physical Guidance in Motor Learning

James Thomas Howard III, B.A.

School of Human Movement Studies

For: Masters of Applied Science by Research

2003
Keywords:
Physical guidance, visual guidance, motor learning, visual dominance, knowledge of results, knowledge of performance

Abstract:
Previous studies of physical guidance (PG - physically constraining error during practice of a motor task) have found it to be ineffective in enhancing motor learning. However, most studies have used a highly constraining form of physical guidance that may have encouraged undue dependency. In addition, previous research has not fully considered the interaction between visual feedback and PG, and many of the studies have failed to use standard delayed retention tests with knowledge of results unavailable (no-KR). The current experiment examine the effects of varying levels of constraint in PG, as well as the interaction of PG and visual guidance (VG), using no-KR retention tests.

This study involved 99 subjects divided into nine acquisition trial condition groups, forming from a 3 x 3 factorial design with factors of PG x VG, each presented at levels designated as tight, bandwidth, or none. Subjects undertook a two-dimensional pattern drawing task with no KR, PG, or VG as a pre-test, before completing 100 practice trials under one of the nine conditions. The same test was given as a retention test (immediately after practice) and as a delayed retention test (two days later). A transfer test, using a different pattern, was also administered on the second day.

Almost all groups performed better on the immediate transfer test than they had on the pre-test. However, after two days only three groups (PG bandwidth-VG tight, PG none-VG bandwidth, and PG none-VG none) retained this improvement and only two groups (PG bandwidth-VG bandwidth and PG none-VG none) performed significantly better on the transfer task than their pre-test. It is proposed that bandwidth guidance generally promotes learning and that bandwidth physical guidance may enhance proprioceptive cues. Independent of PG and VG effects, KR (an overall error score) also facilitated learning.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures and Tables</td>
<td>ii</td>
</tr>
<tr>
<td>List of Abbreviations</td>
<td>iv</td>
</tr>
<tr>
<td>Statement of Original Authorship</td>
<td>iv</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iv</td>
</tr>
<tr>
<td>Chapter 1 – Literature Review</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2 – Methods</td>
<td>24</td>
</tr>
<tr>
<td>Chapter 3 – Results</td>
<td>32</td>
</tr>
<tr>
<td>Chapter 4 – Discussion</td>
<td>44</td>
</tr>
<tr>
<td>Appendix A – Subject Instructions</td>
<td>58</td>
</tr>
<tr>
<td>Appendix B – Error Calculation</td>
<td>64</td>
</tr>
<tr>
<td>Bibliography</td>
<td>65</td>
</tr>
</tbody>
</table>
List of Figures and Tables

<table>
<thead>
<tr>
<th>Figure/Table Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1 Armstrong’s (1970) position-time pattern</td>
<td>5</td>
</tr>
<tr>
<td>Figure 1.2 Results from Armstrong’s (1970)</td>
<td>6</td>
</tr>
<tr>
<td>Table 1.1 Significance table from Holding and Macrae (1964)</td>
<td>7</td>
</tr>
<tr>
<td>Figure 1.3 Results from Holding and Macrae (1964)</td>
<td>8</td>
</tr>
<tr>
<td>Figure 1.4 Melcher’s (1934) maze</td>
<td>8</td>
</tr>
<tr>
<td>Table 1.2 Results from Melcher (1934)</td>
<td>9</td>
</tr>
<tr>
<td>Table 1.3 Acquisition data from Waters (1930)</td>
<td>10</td>
</tr>
<tr>
<td>Table 1.4 Results from Waters (1930)</td>
<td>11</td>
</tr>
<tr>
<td>Figure 1.5 Results from Winstein, Pohl, and Lewthwaite (1994)</td>
<td>12</td>
</tr>
<tr>
<td>Figure 1.6 Amplitudes from Wulf, Shea, and Whitacre (1998)</td>
<td>13</td>
</tr>
<tr>
<td>Figure 1.7 Force onset from Wulf, Shea, and Whitacre (1998)</td>
<td>13</td>
</tr>
<tr>
<td>Table 1.5 Summary of experiments</td>
<td>21</td>
</tr>
<tr>
<td>Table 2.1 Make-up of groups</td>
<td>24</td>
</tr>
<tr>
<td>Figure 2.1 Image of the apparatus</td>
<td>25</td>
</tr>
<tr>
<td>Figure 2.2 Required pattern for main task</td>
<td>25</td>
</tr>
<tr>
<td>Figure 2.3 Required pattern for transfer task</td>
<td>27</td>
</tr>
<tr>
<td>Figure 2.4 Flowchart of procedure</td>
<td>28</td>
</tr>
<tr>
<td>Table 2.2 Factor and level combinations</td>
<td>29</td>
</tr>
<tr>
<td>Figure 3.1 Results of present study</td>
<td>32</td>
</tr>
<tr>
<td>Table 3.1 Means for present study testing results</td>
<td>33</td>
</tr>
<tr>
<td>Figure 3.2 Diagram of evaluation of hypothesis one</td>
<td>34</td>
</tr>
<tr>
<td>Figure 3.3 Diagram of evaluation of hypothesis two</td>
<td>35</td>
</tr>
<tr>
<td>Figure 3.4 Diagram of evaluation of hypothesis three</td>
<td>35</td>
</tr>
<tr>
<td>Figure 3.5 Diagram of evaluation of hypothesis four</td>
<td>36</td>
</tr>
<tr>
<td>Figure 3.6 Mean durations for A) physical guidance and B) visual guidance</td>
<td>39</td>
</tr>
<tr>
<td>Figure 3.7 Mean peak velocities for A) visual guidance and B) physical guidance</td>
<td>40</td>
</tr>
</tbody>
</table>
Figure 3.8 Mean standard deviations for A) visual guidance and B) physical guidance 42
Figure 3.9 Error scores for acquisition blocks 43
Table 4.1 Summary of performance 44
Figure 4.1 Relative guidance percentages 46
Figure 4.2 Durations over acquisition 49
Figure 4.3 Standard deviations over acquisition 49
Table 4.2 Summary of performance with proposed guidance effects 52
Figure B.1 Diagram of error score calculation 64
List of Abbreviations (LOA)

VG – visual guidance
PG – physical guidance
KR – knowledge of results
RT – reaction time
MT – movement time
KP – knowledge of performance
PTVT – group physical tight visual tight
PBVT – group physical bandwidth visual tight
PNVT – group physical none visual tight
PTVB – group physical tight visual bandwidth
PBVB – group physical bandwidth visual bandwidth
PNVB – group physical none visual bandwidth
PTVN – group physical tight visual none
PBVN – group physical bandwidth visual none
PNVN – group physical none visual none
(|CE|) – absolute constant error
\( \text{mm}^2 \) – square millimeters
SES – scaled error score
sd – standard deviation

Statement of Original Authorship

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signed: ________________________________

Date: ________________________________

Acknowledgement List

My thanks go to: Dr. Charles Worringham for his time, effort, and encouragement; Dr. Graham Kerr for crucial advice at critical moments; Christine Howard for her spiritual, emotional, and monetary support; and to God through whom all things are possible.
Chapter One

Review of Literature

1.1 Introduction

Physical guidance has been used in several forms for many years within the context of motor skill education. Whether it be holding a player's elbow close to the body for a basketball shot or supporting a gymnast during a difficult move, the restriction of error during acquisition has intuitively been thought to restrict error in performance, thus aiding learning. However, the limited research on this subject does not provide clear support for this position at even an empirical level, leaving aside the question as to how physical guidance may affect learning.

Only six previous studies have been found to be directly applicable to this study of physical guidance (PG) in human motor skill tasks. However within these there are four definitions of PG. These range from passive guidance to psychological security. The tasks used in the experiments, too, are highly diverse. Armstrong (1970) examined PG in the learning of a spatio-temporal arm movement sequence task, Holding and Macrae (1964) used a linear positioning experiment, while Melcher (1934) used a maze in her PG study with children. Waters (1930) was concerned with maze learning by adults while physically guiding them in some practice trials. Winstein, Pohl, and Lewthwaite (1994) concerned themselves with PG in learning a radial-positioning task. Finally, Wulf, Shea, and Whitacre (1998) focussed on the PG provided by ski poles when used with a ski simulator. With so many definitions and tasks it is not surprising that a consensus has not been reached regarding the efficacy of PG. To better understand the sources of disparity in these papers, each will be reviewed with three major factors in mind. First, giving the definitions of PG used in each case will help set the terms of reference for each paper (Section 1.2). Second, describing the tasks employed in each study will further enable comparison and thus recognition of any gaps in knowledge about physical guidance (Section 1.3). Finally, reporting the results of each paper will show the inconsistencies regarding conclusions about PG (Section 1.4).

In addition to the main research findings some relevant concepts need to be clarified. It will be argued that each of these directly concern the testing of Physical Guidance.
One of these relevant concepts is *visual dominance*, which will be discussed in section 1.5. This is the tendency to rely upon vision (when available), as opposed to other senses, in many perception tasks. There is the possibility that during experiments that allow vision of the task, or visual feedback, during either the acquisition or testing phases, the effects of PG could be confounded with those of vision. Vision of the task, and thus any visual feedback, may demand attention to the detriment of that given to the mainly proprioceptive feedback of PG.

The difference between performance and learning effects has major implications for experimental design and the validity of conclusions drawn from research. Performance effects are temporary improvements in performance found soon after acquisition. Learning effects are relatively permanent performance improvements. Sufficient time must be allowed to elapse between acquisition and any test which claims to ascertain learning. The level of compliance of each study with this requirement will be noted in Section 1.6.

In section 1.7 the types of feedback used in this and previous studies will be discussed. Knowledge of results (KR) is another factor that may affect results and must be considered in experimental design. A related concept, knowledge of performance (KP), is information about certain aspects of the action itself. Concurrent continuous feedback, such as physical guidance, is considered KP since the subject receives ongoing information about the success of the movement. The use of KR and KP in the study of physical guidance will be of major importance in this research.

Section 1.8 will deal with the form and scheduling of KR, which has been the topic of much research. The Guidance Hypothesis of Salmoni, Schmidt, & Walter (1984) and Schmidt (1991) has greatly clarified the possible effects of the use of KR as a guiding factor. Thus other forms of guidance to be considered in this paper, such as visual and physical, will also be viewed in the light of the guidance hypothesis.
As part of the scheduling of feedback the idea of bandwidth scheduling will be considered. The bandwidth (BW) concept is an innovation in the scheduling of KR in which KR is given to the subject only when their performance is outside set criteria. The related reverse bandwidth scheduling system involves KR being given to subjects only when performance is inside set criteria. The possibility of replacing one form of guidance (KR) with others (visual and physical guidance) will be considered (Section 1.9).

In conclusion (Section 1.10) the gaps which remain in the literature concerning physical guidance (PG) will be identified. This section will also delineate the current study's experimental aims, and show how they address aspects of PG that are not yet clearly understood.

1.2 Definitions of Physical Guidance
The dates of publication of the papers under review range from the 1930s to 1998. The range of definitions is considerable. However, the common thread to these working definitions is the constraint of error. This constraint of error was achieved in several different ways. Earlier papers focused on physical guidance (PG) as a passive manipulation of a subject’s limb. Later studies allowed the participants to produce movement actively, but still under very controlled conditions. The final paper (Wulf, Shea, and Whitacre, 1998) took a very different approach to the PG question by using PG to enable subjects to perform movements more closely resembling the “perfect” model.

The studies by both Waters (1930) and Melcher (1934) also employed a passive guidance definition - passively conducting the limb through the required movement. Melcher’s subjects (children) gripped a knob lightly as it was pulled through a vertical maze by a motor-driven belt. Waters’ subjects grasped a stylus also held by the experimenter, who moved them correctly through the horizontal maze.

In the linear positioning task of Holding and Macrae (1964), two forms of physical guidance were used. Some subjects received passive guidance by placing their hand on a knob attached to a sleeve, which was then moved along a rod for the required distance. Other subjects produced the movement of the sleeve actively, but a
terminal stop was screwed in position at the required distance. Therefore, Holding
and Macrae operationalised two definitions of PG. One was that of passive guidance
– similar to that of the previous studies. The other concerned only the end point of
the action – eliminating error in the final position of the task.

Armstrong (1970) physically guided his subjects through a spatio-temporal wrist
rotation task with the use of a torque motor coupled to a control stick shaft. The
motor had the same effect as a physical spring. When subjects in the physical
guidance (PG) group deviated outside a 8.255 cm. target zone (reduced to 5.715 cm.
during practice) they were subjected to the spring torque in the direction that would
reduce deviation. By use of this device Armstrong defined (PG) as physically
constraining error in both spatial and temporal dimensions.

Winstein, Pohl, and Lewthwaite (1994) used the second of Holding and Macrae’s
(1964) definitions. They used a physical block placed at the required target a one-
dimensional radial positioning task. This block acted as the physical guidance only
in constraining end point error.

In a more complex, gross motor skill learning study Wulf, Shea, and Whitacre (1998)
guided subjects in the use of a ski simulator by allowing the use of ski poles. The
purpose of the poles was to allow for greater amplitudes and frequencies in
movement than would be obtained without their assistance. The poles gave a greater
base of support and possibly a reduced fear of falling. They compared this type of
PG with training wheels on a bike. The inferred definition of PG is allowing higher
quality movements, and thus reducing error, through physical support and
psychological security.

All of these definitions of physical guidance (PG) include a component of decreasing
the error allowed in practice. They differ primarily in the degree to which error is
restriction occurs. The error may be completely prevented throughout the
movement, as in passive guidance, or only at the final position, as in constraining
end point error. The error reduction may be in more than one dimension -
constraining error in spatial and temporal dimensions.
1.3 Tasks

1.3.1 - Armstrong (1970) used a spatio-temporal task with one degree of freedom in which the subjects were attempting to recreate a position-time pattern (see Figure. 1.1) by moving a control stick. A motor attached to the control stick could be engaged or disengaged.

Figure 1.1 Required position-time pattern redrawn from Armstrong (1970).

Subjects were divided into four groups. 1) Control group – This group only received knowledge of results after each block of 15 trials. 2) Visual tracking – Subjects saw a target on a computer screen and attempted to keep the cursor on the target by moving the control stick, thus producing the pattern. 3) Target zone group – While within a target-specified distance from the correct pattern these participants felt nothing, but when moving too slowly they would feel the motor engage and push the control stick. Conversely if going too fast, the motor would pull the stick back within the target zone. 4) Derivative target zone group – In which the motor engaged more quickly during the more rapidly changing portions of the task and more slowly during the more constant portions. 5) Guided group – These subjects had their arm guided by the motor throughout the movement by the torque motor being constantly active unless it was perfectly on target.

Armstrong reported mean error scores for blocks of 15 trials. After two days of five blocks of the practice conditions the third day included four practice blocks and then testing for two blocks – 30 trials. These tests were performed with no feedback. However, an absolute error score summarizing each trial and an XY plot of each trial were made available after the first block of testing (block 15).
From figure 1.2 it can be seen that the groups’ scores are almost a mirror image of the practice conditions (blocks 1-14) to the testing period (blocks 16 and 17). From these results it was concluded that while the training methods, including PG, had a great effect upon performance, there was no positive effect of learning relative to the control. In contrast, the visual tracking group and the guided group had mean test scores significantly worse than the control group. It is suggested that a different skill than that which was required to perform the task was being developed during the training time for all the groups except the KR only subjects.

Figure 1.2. Mean error scores of blocks redrawn from Armstrong (1970). Blocks 1-14 were the practice period, blocks 15 and 16 were the test period. The breaks after blocks 5 and 10 represent the breaks between daily sessions.

Although PG, as presented by Armstrong (1970), was deemed to be detrimental to learning there are several concerns with the experimental procedure and design. Visual feedback was not completely controlled and, as will be detailed in section 1.5 (Visual Dominance), may have confounded the results. The immediacy of the testing blocks after practice may bring the results into question, as will be seen in section 1.6 (Performance and Learning Effects). Lastly, the availability of knowledge of results (KR) after the first block of testing may have led to further improvements during testing. The necessity of no-KR delayed testing will be argued in section 1.8 (Guidance Hypothesis).
1.3.2 - In the study by Holding and Macrae (1964) a one-dimensional positioning task was used. This required subject to slide a sleeve four inches (10.16 cm.) along a rod. A knob was attached to the sleeve for the subjects to grasp. Subjects were divided into one of six groups: 1) Control – subjects made all movements without correction or guidance, 2) Continuous Guidance – subjects gripped the knob as it was moved for them to the correct position, 3) Distributed Guidance – alternated trials between continuous and control conditions, 4) Restrictive Guidance – where a terminal stop was screwed into the position at the required target, 5) Right-Wrong Correction – these subjects were told ‘right’ if they were within half an inch of the target or told ‘wrong’ if outside this zone, 6) Full Knowledge of Results – the extent and direction of error was given to these participants after each trial.

Holding and Macrae used pre- and post-acquisition test blocks with no correction or guidance. Figure 1.3 shows the results for the six groups. In their statistical analysis Holding and Macrae combined the Continuous and Distributed Guidance groups. Table 1.1 shows that the Restrictive Guidance, Right-Wrong Correction, and Full KR groups improved the most, while the combined Continuous/Distributed group also showed significant improvement.

While supporting the efficacy of physical guidance toward the improvement on immediate retention tests the question remains whether learning took place. Section 1.6 (Performance and Learning Effects) will demonstrate that the improvements seen in these results may have been temporary in nature.

Table 1.1. Amount and significance of improvements from Holding and Macrae (1964).
1.3.3 - A vertical block maze, for which there was one correct path to move a knob with the hand, was the task chosen by Melcher (1934). (See Figure 1.4) Children from three to five years of age were divided into three groups: 1) Visual guidance – who were only allowed to watch the knob proceed along the correct path, 2) Manual guidance – who were only allowed to have their hand on the knob as it followed the correct path while curtains occluded vision, and 3) Mixed – participants allowed to view the maze and have hand on the knob as it followed the correct path.

Melcher reported on several dependent variables. These were: 1) number of trials to learn the maze, 2) distance covered – in total blocks passed and average number of blocks passed per test, 3) total and average number of turns per test, 4) total and average number of correct turns per test. The most important of these are shown in Table 1.2.

Melcher concludes that, although without reporting statistical tests, there is "little doubt" that the manual guidance without vision was much less effective than the visual methods in producing learning. The point is made that, although of similar age and intelligence, only subjects from the two groups including vision had success in learning the maze.

It would seem prudent to agree with Holding and Macrae (1964) when they deemed Melcher’s results to be “inconclusive”. This is especially true when considering that there was no delayed retention test – all testing occurred immediately after practice. This design will be further discussed in section 1.6 (Performance and Learning Effects).

Table 1.2 Age, success, average number of blocks per test, average number of turns per test, and average number of correct turns per test for Melcher’s (1934) three groups.

This table is not available online. Please consult the hardcopy thesis available from the QUT Library.
1.3.4 - The task used by Waters (1930) was horizontal maze, the correct path of which was to be followed with a stylus as quickly as possible with the goal of mastery of the maze in as few attempts as possible. Subjects were divided into four groups: 1) **Control** – learned the maze with trial and error only, 2) **Guidance 20** – received 20 passively guided trials before being left to master the maze without further guidance, 3) **Guidance 40** – received 40 passively guided trials, 4) **Guidance 80** – received 80 passively guided trials.

Waters’ main measures of maze learning were 1) the number of trials to mastery (four consecutive errorless trials), 2) errors – including retracing and cul-de-sac entry, and 3) average speed of maze completion on the mastery trials. Table 1.3 sets outs these results for the different groups.

**Table 1.3 Mean trials to mastery, mean errors, and average final speed (seconds to complete maze) for day one (acquisition phase) from Waters (1930).**

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean Trials to Mastery</th>
<th>Mean Errors</th>
<th>Average Final Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidance 20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidance 40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidance 80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Waters (1930) points out that trials to mastery were fewer for the G-40 and G-80 groups and all guided groups had fewer errors than the control. The average final speed however was greater for the guided groups than control, except for G-20, which was just under the control time. The groups all returned for a retention test on the same maze seven days later. The control group performed better than the guidance groups on all criteria. In conclusion Waters claims value for guidance and the more the better, but this is based almost solely on the acquisition phase of his experiment.

Seven days after acquisition subjects performed trials until re-mastery was accomplished (four errorless trials in succession). The retention testing seems to show little value for passive guidance. (Table 1.4) It took all of the guidance groups
more trials to re-master the maze. Only the G-40 group had fewer errors during re-
mastery. The Control group also took less time to re-master the maze.

Table 1.4 Mean trials, mean errors, and time to re-master the maze seven days after acquisition. from Waters (1930).

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean Trials</th>
<th>Mean Errors</th>
<th>Time to Re-master</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G-10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G-20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G-40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although Waters (1930) mainly focuses on the positive results of PG upon performance of testing immediately after practice, he spends little time considering the decrement in performance, relative to the control group, after a delay of seven days. The difference between these two tests and the conclusions which can be drawn from them will be discussed in section 1.6 (Performance and Learning Effects).

1.3.5 - Winstein, Pohl, and Lewthwaite (1994) used an angular positioning lever, which was placed in one of eight starting positions. Subjects were to rapidly extend the forearm to a target position at 80 deg. Subjects were divided into four groups: 1) High-Presentation (High PG) – who moved to a physical guidance block at the target on the first five of each six trials, 2) Fade-Presentation (Fade PG) – who moved to the PG block on 50% of the first two sets of six trials, 33% of the next two sets of trials, and 16% of the last set of trials. 3) High-KR – who had no physical block at the target, but were given knowledge of results (KR) in the form of constant error in degrees from the target and a visual display of required and actual final positions, the KR was given for the first five of six trials in each block, 4) Fade-KR – received KR in a fading schedule analogous to the Fade-Presentation group.

The main findings of Winstein, Pohl, and Lewthwaite’s study are represented in Figure 1.5. The acquisition trial blocks have very different scores due to the condition’s requirements. However, the immediate retention tests of blocks seven and eight were performed under the same conditions (no augmented feedback) for all subjects. Over the two blocks it was found that the absolute constant error (|CE|) was
lower for the High-KR group than the Fade-KR group. But, when comparing the PG
groups, the High-PG group had higher $|\text{CE}|$ than the Fade-PG group (although this
was not statistically significant). In the delayed retention test (blocks nine and ten)
the performance of those in the High-PG group was significantly worse than the
three other groups. The transfer test (blocks 11 and 12) used a different target. The
results of this test showed that the subjects in the two Fade groups had lower $|\text{AE}|$
than the High groups.

These experimenters conclude that practice with frequent presentation trials was
detrimental for learning compared to practice under the testing conditions. They also
found that even though frequent on-target experience was detrimental for learning,
the same frequency of KR for the less constraining KR feedback was not. However,
in this study visual feedback was not completely controlled and may have
confounded the results. This possibility will be detailed in section 1.5 (Visual
Dominance).

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library

Figure 1.5 Group mean six-trial absolute constant error ($|\text{CE}|$) scores in degrees for acquisition
(blocks 1-6), immediate retention (blocks 7-8), delayed retention (blocks 9-10), and transfer
(blocks 11-12) redrawn from Winstein, Pohl, and Lewithwaite (1994).

1.3.6 - Wulf, Shea, and Whitacre (1998) used a ski-simulator task in which the
subjects were asked to make oscillatory movements with as large an amplitude and
with as high a frequency as possible. The subjects were either in the group with poles or the group without poles.

Wulf, Shea, and Whitacre (1998) focussed on the amplitude and relative force onset measures as indices of quality of movement in their snow skiing simulation study. Their results are represented in figures 1.6 and 1.7. During the immediate retention tests (trials 7 and 14), performed without poles by both groups, the pole group performed less well than the no pole group as measured by movement amplitude.
The difference was almost significant on day two (trial 14). Relative force onset was not significantly different at the end of day one, but the pole group did have significantly later force onset (more similar to expert skiers) on day two. More importantly with regards to learning are the delayed retention tests of day three (trials 15-21). There was no significant difference found between the two groups’ amplitudes. However, the no pole group had significantly later relative force onset in the delayed retention tests.

Wulf, Shea, and Whitacre (1998) conclude that the later relative force onset advantages produced by the poles during practice were not restricted to performance during practice, but transferred to a delayed no-pole test situation. Thus learning was improved by the use of this form of physical guidance.

1.3.7 - The experiments used for discerning the effects of physical guidance (PG) have been diverse in both the complexity of the tasks and the mode of PG presentation. Not surprisingly, the reviewed literature fails to provide a consensus concerning the effects of PG on learning. Although a few studies show positive improvements in performance immediately after acquisition, only Wulf, Shea, and Whitacre (1998) have found improvements in delayed tests. Differences in testing procedures and PG presentation modes also add to the confusion. The most important of these procedural discrepancies will be discussed in the following sections.

1.4 Visual Dominance
Visual dominance is the tendency to rely on visual information to a greater extent than the other senses for perception and memory tasks. In the classic experiment by Gibson (1933), subjects wore prisms, which made straight edges appear curved, and moved their hands along these straight edges. Even though the kinesthetic information correctly attested to the straightness of the edge, the subjects "believed" the visual information and judged the edges as curved. Several authors have confirmed the phenomenon of visual dominance. Bacon and Shaw (1982) found visual dominance even when cues were given that there was a conflict between visual and tactile information. Reeve, Mackey, and Fober (1986) showed visual dominance created error in previously learned movements. Batic and Gabassi (1987)
found visual dominance over the sense of smell. Tloczynski (1992) found that it took a concerted effort to disregard visual in favour of kinaesthetic information. Tloczynski (1993) found visual dominance to occur when presenting feedback information through templates and through vision in a line drawing task. The bias toward vision was also shown in a study by Jordan (1972) in which subjects chose to rely upon slower visual information when having their fencing foil hit by a mechanical foil even though the kinaesthetic cue of contact produced faster reactions.

Posner, Nissen, and Klein (1997) have proposed four reasons for visual dominance. One, visual signals are less alerting. That is, changes in the visual field are less likely to be brought to our conscious attention than changes of input to other senses. The threshold for a visual stimulus to be consciously considered is high. For example, touching someone on the shoulder gains attention more readily than merely being seen. Two, lowering the alerting threshold for visual stimulation requires effort. Since the tendency is for vision to be less alerting, use of vision to alert oneself must be a conscious decision requiring effort. Three, there are costs and benefits of sensory set. Due to requiring effort to alter the naturally high visual alert-threshold other sensory inputs receive less effort and, therefore, higher thresholds for alerting. Four, there is a bias towards vision. There is a tendency to rely upon vision when one is trying to ascertain changes in their environment.

The reasons for visual dominance therefore, stem from the bias toward using the visual sense to determine alterations in surroundings. This bias, however, must overcome the high threshold for bringing visual information to one's attention. To do this - mental effort must be used and this attentional effort to analyse visual sensory information directly decreases the that remaining for information coming from other senses.

Visual dominance in motor learning can been seen in the example of a young basketball player trying to dribble. Attention is directed toward vision as a player looks at the ball and hand during the action. During acquisition this allows for better dribbling, but not better game play since attention is needed elsewhere – teammates, opposition, goal. The highest level of skill, exemplified by Fitts’ (1964)
“autonomous stage” of learning, is characterised by decreased attentional demands of the primary task. Therefore, high levels of performance in the absence of visual feedback would denote such a level.

When studying the effects of physical guidance (PG) the visual dominance phenomenon has often been neglected. If visual feedback is allowed during the presentation of PG, the visual dominance concept would support the probability that the tactile PG sensory input would be neglected in favour of the visual. In this case an experiment might not test the effects of PG at all, but merely the individual responses to visual feedback. Thus, the lack of control over visual feedback during PG could lead to erroneous results and conclusions. Visual feedback is not only restricted to computer monitors and other augmented forms, but vision of the hand/limb used in the action and the apparatus could also be sources of visual cues. These cues could serve as well as augmented visual feedback in many circumstances. This may be the case with several of the reviewed papers.

Among the PG experiments being considered the visual dominance effects have only been allowed for by Holding and Macrae (1964) and Melcher (1934). Holding and Macrae (1964) controlled for visual dominance by having all subjects wear darkened glasses. Melcher (1934) had one group practice with PG and not vision, but even here the final testing was done with vision of the maze and of the limb. Even though Armstrong (1970) had a group with visual tracking and the other groups received no such visual information on screen, there is the difficulty that all groups could see their limbs and the control stick. The subjects may have attended to this "natural" visual feedback to the neglect of the physical guidance (PG). Waters (1930), Weinstein, Pohl, and Lewthwaite (1994) and Wulf, Shea, and Whitacre (1998) allowed vision during acquisition for all groups including those with PG. The final testing was done with vision of the apparatus and limb(s). Since there is the tendency toward visual dominance the visual information from watching the apparatus, limbs, etc. may have contributed to the subjects’ learning of the task. If so, information from the kinaesthetic feedback of PG would have been, to a great extent, disregarded.
1.5 Performance and Learning Effects

When attempting to determine the effects of a practice regimen the difference between performance and learning effects must be considered. Performance effects are temporary. Temporary effects of feedback may include motivation and guidance (error constraint). Learning effects are those which create a relatively permanent change in the capability of responding. (Salmoni, Schmidt, & Walter, 1984) These writers argue that sufficient rest must be allowed before testing for learning, thus allowing any performance effects to have dissipated.

Armstrong (1970) failed to allow sufficient rest between practice and testing. On the fifth day of the experiment four blocks of practice were followed by two blocks of testing. Having only immediate test results for the Holding and Macrae (1964) study makes their findings questionable. There is proof of a performance effect from the different groups, but without a delayed retention test it can not be discerned whether learning occurred. Melcher's (1934) experiment included only testing immediately after practice trials, thus no learning can be deduced from her data. Waters (1930) allowed seven days to elapse between immediate testing and the delayed test, however almost all of his conclusions come from the immediate test findings while the real learning data from the delayed test are almost disregarded. Winstein, Pohl, and Lewthwaite (1994) and Wulf, Shea, and Whitacre (1998) waited an acceptable full day before delayed testing for learning.

1.6 Knowledge of Results and Knowledge of Performance

In sport, whether the ball went into the goal or if a throw was caught by a teammate is response-produced feedback. It comes naturally as a result of a movement. Knowledge of results (KR) is augmented information on the outcome of a movement. In the laboratory situation response-produced feedback is often withheld or not reproducible. In its place KR, in a manipulable form, is given. KR is often a score reflecting the "success" of the movement relative to the requested outcome. Knowledge of performance (KP) is often confused with KR. KP is feedback concerned with aspects of the movement itself regardless of outcome. A golf coach might give KP by the comment, "Your head came up too early." KR regarding the shot could be, "That was a 200 metre drive ten degrees to the right." The response-produced feedback might be, "That landed in the rough." KR has long been
considered to have a profound impact upon motor skill learning as a guide toward the
correct movement. (Salmoni, Schmidt, & Walter 1984)

In the present experiments KR has been presented as a score, distance, time, or other
final outcome information. This KR gives the subject the knowledge about the "need
for change." If the KR did not signify a perfect movement then the subject knew
some change was necessary to better their result. What exactly had to be done to
improve is rarely part of KR. Even when highly specific KR is given, it comes after
the fact of error. In contrast KP is specific, by definition, to "what change is
needed" for improvement and in some cases it can be presented continuously and
concurrently.

Physical guidance (PG) is a way of presenting continuous and concurrent feedback
through the kinesthetic pathways. The present studies have used PG to guide the
subject toward less error in movement. Most of these experiments have done so by
reducing error to near zero. However, Armstrong's (1970) motor allowed for a
"target zone" in which no PG was received and Wulf, Shea, and Whitacre's (1998)
ski poles only provided support and security - aiding attempts of better movements.
These restrictions of error by use of KP in the form of PG during acquisition may not
lead to learning, however, if the guidance hypothesis applies to this form of
feedback.

1.7 Guidance Hypothesis

In the laboratory setting, knowledge of results (KR) works as a guide - pointing the
way to a better outcome. The guidance hypothesis of Salmoni, Schmidt, & Walter
(1984) and Schmidt (1991) states that one difficulty with guidance (KR) is that of
dependency. Although the guidance leads the subject to the correct response they
can become dependent on it. Thus learning is hindered when tested with guidance
withdrawn. This becomes especially important when considering the implications
for appraising techniques to be used in the real world. While a coach may be able to
give KR frequently during practice it is rarely available during a performance
situation.
Salmoni, Schmidt, & Walter (1984) conclude that to truly test learning of a task the testing must be completed under 'no-KR' conditions. In other words there should be no KR given during any tests for learning. A concern with the testing procedure of Armstrong (1970) is that KR in two forms was given after the first block of test trials. Holding and Macrae (1964), Melcher (1934), Waters (1930), Weinstein, Pohl, and Lewthwaite (1994), and Wulf, Shea, and Whitacre (1998) all had subjects perform testing under no-KR conditions.

As has been seen physical guidance (PG) is knowledge of performance (KP) and not KR. But does the same dependency problem affect both forms of information? Since both KR and KP can be considered forms of guidance it would follow that subjects could become dependent upon either to the decrement of learning. However, some feedback would seem to be necessary to get participants started in the right direction. How much KR can be given in practice without creating dependency and thus impaired learning? Can the same schedule be applied to forms of KP?

1.8 The Bandwidth Concept
In an attempt to find an optimal schedule for giving knowledge of results (KR) Sherwood (1988) was the first to look at the effects of bandwidth (BW) knowledge of results (KR). That is, KR is given only if the subject’s previous movement is outside certain specified limits. In his study subjects were allocated to either the 5% BW, 10% BW, or control group. Subjects were to move a horizontal lever through 60 degrees in 200 msec. Those in the 5% BW group received KR only when their previous performance was outside the 190 msec to 210 msec (5%) bandwidth. Those in the 10% BW group received KR only when their previous performance was outside the 180 msec to 220 msec (10%) bandwidth. Those in the control group received KR after every trial. His results showed that even though the 10% BW group was given KR less frequently, their within-subject variability was less than that of either the 5% BW or the control group. Although there was no significant difference between the groups’ absolute constant error, “the results suggest that giving KR about a large BW enhances movement consistency.” (Sherwood, 1988, p.535)
A slightly different interpretation was put on the bandwidth (BW) concept by Cauraugh, Chen, & Radlo (1993). In their study of forty-eight subjects traditional BW KR was compared with reversed BW KR and two yoked control groups. Subjects were to press three keys in a certain order in exactly 500 msec. Those in the traditional BW group received visual and verbal KR when outside a 10% BW, 450 – 550 msec. Those in the reversed BW group received KR when their movement was inside a 10% BW. The trials upon which KR was given were recorded and this pattern used for the two yoked groups. The yoked traditional group received KR on the same trials as their traditional BW counterparts. The yoked reverse group received KR on the same trials as their reverse BW counterparts. On the immediate no KR retention test both BW groups showed significantly less error than the corresponding yoked group and there was no significant difference between the traditional and reversed BW groups.

Since BW presentation of KR seems to overcome the difficulties of dependence, thus allowing learning, perhaps forms of knowledge of performance (KP) can be similarly scheduled. Most of the papers reviewed here have presented KP in the form of physical guidance (PG) with an absolute schedule. Whether the end point of a trajectory is blocked at the correct distance each time (Holding and Macrae, 1964; Weinstein, Pohl, and Lewthwaite, 1994) or the full trajectory has been perfectly guided (Melcher, 1934; Waters, 1930) complete PG has been the effect - allowing near zero error in the movement. Although Wulf, Shea, and Whitacre's (1998) use of the ski poles would not fit into the 'absolute physical guidance' definition, there is still the use of the ski simulator itself. The simulator was a platform which slid side-to-side over an arch of two metal runners. In this way the trajectory of movement was totally guided regardless of the use of poles. An exception to the absolute PG paradigm is found in Armstrong (1970). In this study a 'target zone' in which no PG was given was created around the correct spatio-temporal trajectory. Through this procedure, relative to both time and position, PG was applied in a bandwidth presentation.

1.9 Conclusion
Table 1.5 is a summary of the experiments dealing with physical guidance (PG). It can be seen that at the most basic level, there is no definitive conclusion about the
effects of physical guidance (PG). It is also apparent that most of the studies have used absolute forms of PG. If this tends to create dependence perhaps another form of PG would be better. Finally, the interaction between visual feedback and PG has not been investigated while controlling all forms of feedback.

Table 1.5 A summary of the reviewed experiments with PG definition, task, results, and procedural concerns.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Definition</th>
<th>Task</th>
<th>Results</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armstrong (1970)</td>
<td>Constraining error in the spatial and temporal dimensions</td>
<td>One degree of freedom, spatio-temporal, control stick</td>
<td>PG has <strong>no positive</strong> performance effect</td>
<td>Visual dominance not considered, no delay for learning test, KR part of test</td>
</tr>
<tr>
<td>Holding and Macrae (1964)</td>
<td>Passive guidance &amp; Constraining end point error</td>
<td>One-dimensional, positioning, sleeve on rod</td>
<td>PG has <strong>positive</strong> performance effect</td>
<td>No delayed learning test, absolute PG only</td>
</tr>
<tr>
<td>Melcher (1934)</td>
<td>Passive guidance</td>
<td>Two-dimensional, maze learning</td>
<td>PG has <strong>positive</strong> performance effect</td>
<td>No delayed learning test, absolute PG only</td>
</tr>
<tr>
<td>Waters (1930)</td>
<td>Passive guidance</td>
<td>Two-dimensional, maze learning</td>
<td>PG has <strong>positive</strong> performance effect</td>
<td>Visual dominance not considered, absolute PG only</td>
</tr>
<tr>
<td>Weinstein, Pohl, and Lewthwaite (1994)</td>
<td>Constraining end point error</td>
<td>One-dimensional, angular positioning, lever</td>
<td>PG has <strong>positive</strong> performance effect</td>
<td>Visual dominance not considered, absolute PG only</td>
</tr>
<tr>
<td>Wulf, Shea, and Whitacre (1998)</td>
<td>Physical support &amp; Psychological security</td>
<td>Whole-body, oscillatory ski simulation</td>
<td>PG has <strong>positive</strong> performance and learning effect</td>
<td>Visual dominance not considered</td>
</tr>
</tbody>
</table>

First, the learning as well as the performance effects of physical guidance (PG) need to be determined using delayed retention testing without knowledge of results. Since many experiments have not included no-KR delayed retention tests (and those in which it was included failed to consider visual dominance) this most basic question still begs an answer. In order to answer this question an experiment must be devised in which there is: a) a no-KR immediate retention test, b) a no-KR delayed retention test, c) consideration of visual dominance by controlling all visual feedback.
Second, the bandwidth concept needs to be adapted to presenting PG in a spatial task and the effects of this type of PG determined. Although Armstrong (1970) applied a BW presentation to his control stick task, the BW was based on both the temporal and spatial dimensions. As has already been discussed, the resultant push-pull of the PG enacting motor may have lead subjects to learn a movement which was not representative of the actual task. Due to the inclusion of both dimensions, subjects who may have been spatially accurate could nonetheless have been subjected to PG, thus identifying error in their movements. The converse could also have been true for subjects with good timing, but incorrect pattern production. Thus the question remains unanswered as to what learning effects BWPG would have upon a spatial task. To this end a presentation of spatial PG must be devised where error is allowed within set criteria, but outside of which PG comes into play.

Third, the interaction between visual and physical feedback must be resolved When controlling the mode and level of both visual and physical guidance, does visual dominance cause the PG to be disregarded in favour of the visual? Due to the possible confounding of visual and physical guidance in many of the studies on PG this question still needs to be addressed. Designing an experiment in which vision of the limb and apparatus are occluded will allow for all visual feedback to be in a controlled, augmented form. To allow for study of the interaction between PG and visual feedback a bandwidth (BW) presentation for visual guidance is also needed. This would therefore allow visually unguided action until BW criteria were exceeded.

The present paper will evaluate the following hypotheses:
Hypothesis 1: Bandwidth physical guidance will lead to better performance than absolute or no physical guidance.
Hypothesis 2: Physical guidance will lead to better performance than visual guidance of comparable level.
Hypothesis 3: When visual and physical guidance are combined, the effects of visual guidance will dominate the effects of physical guidance.
Hypothesis 4: Bandwidth physical guidance will lead to better performance than other levels of physical guidance and better than the comparable level of visual guidance on a new version of the task.
A two-dimensional pattern drawing task with no KR, PG, or VG will be used as a pre-test, immediate post-test, delayed post-test and (with a different pattern) as a transfer test. There will be nine practice condition groups. The nine groups are formed by a 3 x 3 factorial design where the two factors, physical guidance (P) and visual guidance (V) are each presented in three ways; tight (T), bandwidth (B), and none (N).
Chapter 2
Methods

2.1 Subjects
The results of 99 subjects with a mean age of 21.6 (4.5) were used after the replacement restriction described in c), below. There were 54 females (54%) and 45 males (45%). (See Table 2.1) The subjects were randomly allocated to one of the nine groups with the following conditions: a) no group had more than seven of the 11 members of one sex, b) no group had less than one and no more than two left handed subjects, c) no group’s pre-test error score would significantly differ from another group. Compliance with these restrictions required the replacement of six individuals. All participants were volunteers able to discontinue participation at anytime without penalty of any kind. All subjects provided written informed consent following procedures approved by the Queensland University of Technology Research Ethics Committee.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Females / Males</th>
<th>Right / Left</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ct. (%) / Ct. (%)</td>
<td>Ct. (%) / Ct. (%)</td>
<td>mean (sd)</td>
</tr>
<tr>
<td>PTVT</td>
<td>6 (55) / 5 (45)</td>
<td>10 (91) / 1 (9)</td>
<td>21.9 (6.4)</td>
</tr>
<tr>
<td>PBVT</td>
<td>6 (55) / 5 (45)</td>
<td>10 (91) / 1 (9)</td>
<td>21.2 (4.6)</td>
</tr>
<tr>
<td>PNVT</td>
<td>6 (55) / 5 (45)</td>
<td>10 (91) / 1 (9)</td>
<td>22.3 (5.7)</td>
</tr>
<tr>
<td>PTVB</td>
<td>6 (55) / 5 (45)</td>
<td>10 (91) / 1 (9)</td>
<td>22.6 (5.5)</td>
</tr>
<tr>
<td>PBVB</td>
<td>5 (45) / 6 (55)</td>
<td>10 (91) / 1 (9)</td>
<td>21.2 (4.7)</td>
</tr>
<tr>
<td>PNVB</td>
<td>7 (64) / 4 (36)</td>
<td>10 (91) / 1 (9)</td>
<td>22.8 (4.2)</td>
</tr>
<tr>
<td>PTVN</td>
<td>6 (55) / 5 (45)</td>
<td>9 (82) / 2 (18)</td>
<td>21.8 (3.8)</td>
</tr>
<tr>
<td>PBVN</td>
<td>5 (45) / 6 (55)</td>
<td>9 (82) / 2 (18)</td>
<td>20.5 (3.3)</td>
</tr>
<tr>
<td>PNVN</td>
<td>7 (64) / 4 (36)</td>
<td>9 (82) / 2 (18)</td>
<td>19.6 (1.7)</td>
</tr>
<tr>
<td>ALL GROUPS</td>
<td>54 (54) / 45 (45)</td>
<td>87 (88) / 12 (12)</td>
<td>21.6 (4.5)</td>
</tr>
</tbody>
</table>

2.2 Apparatus
A diagram of the apparatus set up is shown in figure 3. The 2-D planar movement device was constructed with a 100mm vertical handle (diameter 19mm) for subjects to grip. This handle was mounted by ball-bushings to both an X and Y hardened steel travel bar. These travel bars were in turn attached, via bushings, to sets of
support bars (one bar on either end, and perpendicular to, the travel bars). This arrangement permitted movements of the handle in an area extending 640 mm. along the X axis and 480 mm. along the Y axis. Ten turn Spectrol potentiometers (100R ± 5%, linearity ± 5%) were attached to the handle base perpendicularly. Each potentiometer had a 20mm diameter gear running on a drive chain secured parallel to the travel bar and thus perpendicularly to the potentiometer. This allowed detection of movement with an accuracy of 1 mm at the rate of 136 Hz. The potentiometers were connected to a BioCommunications amplifier, and a CB 16/1600 16 bit analog to digital computer board. A 320 x 240 mm. SyncMaster 750s computer monitor displayed all visual guidance and knowledge of results (eye level at a distance of 1.2m). A cloth occluded vision of the hand and X-Y table used for the task. The experiment was controlled by custom software on a 133 mHz PC. A template could be placed over the X-Y table so that the handle would extend through the pattern in the template. The pattern in the template was 72mm wide. Two collars were used at the level of contact between the handle support and the template, one with an external diameter of 12mm and the other of 70mm. (See Figure 2.1)

Figure 2.1 An image of the apparatus used for the study.
2.3 Procedure

After allocation to one of nine acquisition trial condition groups, all subjects began with a familiarisation period and a scaling task unrelated to the learning task. (See appendix A for a transcript of subject instructions.) Familiarisation consisted of moving the handle and thus the corresponding cursor on the screen around the workspace. Subjects were encouraged to move to the four corners and hit a boundary to experience the auditory warning sound was used during testing. The scaling task required moving from a lower right starting point to within a target zone while receiving no feedback. After each attempt feedback was given by showing the actual trajectory on the screen and a statement about success. Subjects were required to successfully hit the target three times consecutively for each of the three targets.

A pre-test block of five trials followed the scaling familiarisation. These were performed under no visual feedback, no physical feedback, and no knowledge of results conditions. For this and all following trials the procedure was that the required pattern was drawn on the screen, where it remained for two seconds. (See Figure 2.2) The word 'Ready' appeared on the screen for 500 msec in addition to one of nine randomly selected fore-period times. (between 1 and 2666 msec incremented by 1/3 sec.) A beep and the change of the screen from blue to black signalled the subject to begin the movement. The trial was deemed to be complete when the subject came to a stop (defined under 'measures' below), hit a boundary, or was still moving after seven seconds.

Figure 2.2 The required pattern for the pre-test, acquisition blocks, immediate retention, and delayed retention tests with approximate scale.
During the acquisition phase of testing subjects were asked to perform five blocks of 20 trials under their specific practice conditions. Five seconds after the end of each trial an error score was presented on the screen. This was to be used by the subjects as a judge of the success of the last trial. There was a one-minute break between blocks.

An immediate retention test block on the no physical guidance, no visual guidance, no knowledge of results task was given for all groups after their final acquisition trial. This was a ten trial block.

A delayed retention test block of ten trials on the no physical guidance, no visual guidance, no knowledge of results task was given for all groups two days after the acquisition phase.

A transfer test of ten trials was given one minute following the delayed transfer test block. All conditions and procedures were held constant, but the required pattern was one which the subjects had not seen previously (See Figure 2.3).

Figure 2.3 The pattern to be replicated for the transfer task with approximate scale.
2.4 Design

There were nine practice condition groups in the study. The nine groups were formed by a 3 x 3 factorial design where the two factors, physical guidance (P) and visual guidance (V) are each presented in three ways; *tight* (T), *bandwidth* (B), and *none* (N). (See Table 2.2)

The characteristics of each condition were such that subjects -
(1 - PTVT) saw a yellow trace of the path being made. If this was more than one millimetre off the correct pattern the entire pattern appeared on the screen in white. If the produced pattern was more than two millimetres off the correct pattern, the sides of the template were encountered, thus restricting movement.

(2 - PBVT) saw a yellow trace of the path being made. If this was more than one millimetre off the correct pattern the entire pattern appeared on the screen in white. If the produced pattern was more than 29 millimetres off the correct pattern, the sides of the template were encountered, thus restricting movement.

(3 - PNVT) saw a yellow trace of the path being made. If this was more than one millimetre off the correct pattern the entire pattern appeared on the screen in white. No template was used, so subjects were free to move anywhere in the available workspace.
(4 - PTVB) saw a yellow trace of the path being made. If this was more than two millimetres off the correct pattern the sides of the template were encountered, thus restricting movement.

(5 - PBVB) saw a yellow trace of the path being made. If this was more than 28 millimetres off the correct pattern the entire pattern appeared on the screen in white. If the produced pattern was more than 29 millimetres off the correct pattern the sides of the template were encountered, thus restricting movement.

(6 - PNVB) saw a yellow trace of the path being made. If this was more than 28 millimetres off the correct pattern the entire pattern appeared on the screen in white. No template was used, so subjects were free to move anywhere in the available workspace.

(7 - PTVN) saw nothing on the screen. If the produced pattern was more than two millimetres off the correct pattern the sides of the template were encountered, thus restricting movement.

(8 - PBVN) saw nothing on the screen. If the produced pattern was more than 29 millimetres off the correct pattern the sides of the template were encountered, thus restricting movement.

(9 - PNVN) saw nothing on the screen. No template was used, so subjects were free to move anywhere in the available workspace.

Table 2.2 Three levels of the two factors combined to create nine groups and their resultant visual and tactile presentations.

<table>
<thead>
<tr>
<th></th>
<th>Physical Guidance</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tight</td>
<td>Bandwidth</td>
<td>None</td>
</tr>
<tr>
<td>Tight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 See: trace, and</td>
<td>See: trace, and</td>
<td>See: trace, and</td>
</tr>
<tr>
<td></td>
<td>pattern if off by</td>
<td>pattern if off by 29 mm</td>
<td>pattern if off by 1mm</td>
</tr>
<tr>
<td></td>
<td>1 mm Feel: template if</td>
<td>Feel: template if</td>
<td>Feel: nothing</td>
</tr>
<tr>
<td></td>
<td>off by 2 mm</td>
<td>off by 29 mm</td>
<td></td>
</tr>
<tr>
<td>Visual Guidance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Guidance</td>
<td>4 See: trace</td>
<td>See: trace, and</td>
<td>See: trace, and</td>
</tr>
<tr>
<td></td>
<td>Feel: template if</td>
<td>pattern if off by 28 mm</td>
<td>pattern if off by 1mm</td>
</tr>
<tr>
<td></td>
<td>off by 2 mm</td>
<td>Feel: template if</td>
<td>Feel: nothing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>off by 29 mm</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>7 See: nothing</td>
<td>See: nothing</td>
<td>See: nothing</td>
</tr>
<tr>
<td></td>
<td>Feel: template if</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>off by 2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 See: nothing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feel: template if</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>off by 29 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9 See: nothing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feel: nothing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5 Measures

Error was the main dependent variable for the study. Error was defined as the area (mm$^2$) between the required trajectory and the actual trajectory. Both lines had the same start position and the end point of the actual trajectory was connected to the end of the required trajectory by a straight line. A further explanation of this process can be found in Appendix B.

X-scaling factor was determined by taking the distance of the subject’s farthest point along the x-axis from the start position and dividing this into the required trajectory’s width. This measure could then be used to determine if subjects compressed or stretched their representation of the pattern in the X dimension, which would increase error, but otherwise maintained the pattern.

Y-scaling factor was determined by taking the distance of the subject’s farthest point along the y-axis from the start position and dividing this into the required trajectory’s height. This measure could then be used to determine if subjects compressed or stretched their representation of the pattern vertically, which would increase error, but otherwise maintained the pattern.

Scaled Error Score (SES) was obtained by using the X and Y-scaling factors to "stretch" or "shrink" the subject’s pattern to the correct dimensions. After this the error score was again computed, as explained above, to return the SES. Therefore, subjects who maintained the correct pattern, but with incorrect proportions, could be differentiated from those with incorrect pattern production.

Cross points was a measure of the number of times the required trajectory was crossed by the actual trajectory. This enabled the calculation of error as well as a measure of pattern accuracy.

Final distance was the straight-line distance (mm) from the end point of the required trajectory to the end point of the actual trajectory. This was used in scaling procedures.

Final angle was the direction of the end point of the actual trajectory from the end point of the required trajectory measured in degrees with 90° being to the right.

Scale was the ratio of the straight-line distance (mm) from the start position to the end point of the actual trajectory to the distance from the start to the end of the required trajectory. Scale was another way to determine if some subjects maintained pattern accuracy, but incorrectly scaled the image.
Line length indicated the length of the actual trajectory in millimetres. This measure allowed the experimenter to look for possible pattern production differences in the different practice groups.

Reaction time (RT) was time interval between the auditory and visual signal to start and the subject moving the handle two millimetres from the start position. RT's under 100 msec. and over 1000 msec. triggered a restart of that trial. If RT differences were found between the practice groups it could be a sign of differing pre-movement cognitive processes.

Movement time (MT) was the time, in milliseconds, from the initiation of movement by the subject (previously defined under RT) to the end of the movement. The end of the movement was taken as the point at which the velocity went under 25mm/second. Alternatively, the end of the movement was the point at which a boundary was hit or seven seconds after the initiation of movement, as a “time-out”.

Peak velocity was the greatest velocity reached within each trial in cm/sec. This measure allowed for checks between groups for pattern production differences. Visual Guidance % was the percentage of the movement time during which the subject’s error was great enough to cause the pattern to appear on the screen. This allowed for analysis of practice session use of the visual guidance between groups. Physical Guidance % was the percentage of the movement time during which the subject’s error was great enough to cause them to come into contact with the edge of the template. This allowed for analysis of practice session use of the physical guidance between groups.

Standard deviation was the standard deviation of the error scores within each of a subject’s nine blocks of trials.
Chapter Three

Results

3.1 Data Analysis

The dependent measure of error score was treated with a $3 \times 3 \times 4$ (Visual Guidance x Physical Guidance x Test) ANOVA with repeated measures on the last factor. This analysis included only testing trials performed under common conditions for all groups (i.e. no knowledge of results, no physical guidance, and no visual guidance) and excluded the five blocks of 20 practice trials. There was a main effect of Test with retention and transfer error lower than pre-test values ($F(3, 270) = 22.35, p < 0.0001$), and a significant three-way interaction ($F(12, 270) = 2.19, p \leq 0.012$).

Although the main effect of Visual Guidance approached significance with tight groups having more error than bandwidth or none groups ($F(2, 90) = 2.97, p < 0.0562$), there were no other significant main or interaction effects ($p > 0.05$). (See figure 3.1) The means and standard deviations for Figure 3.1 are presented in Table 3.1.

![Figure 3.1 Mean error scores for the nine groups over the four testing blocks. Visual Tight - (VT), Visual Bandwidth - (VB), Visual None - (VN), Physical Tight - (PT), Physical Bandwidth - (PB), Physical None - (PN).]
Table 3.1 Means and standard deviations of the error scores for the nine groups over the four testing blocks.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Pre-Test mean (sd)</th>
<th>Immediate Retention mean (sd)</th>
<th>Delayed Retention mean (sd)</th>
<th>Transfer Test mean (sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTVT</td>
<td>50,083 (10,430)</td>
<td>45,459 (11,942)</td>
<td>44,028 (7,682)</td>
<td>44,562 (10,794)</td>
</tr>
<tr>
<td>PBVT</td>
<td>51,849 (11,069)</td>
<td>39,019 (9,057)</td>
<td>40,923 (9,090)</td>
<td>43,118 (6,138)</td>
</tr>
<tr>
<td>PNVT</td>
<td>52,811 (14,106)</td>
<td>44,898 (12,210)</td>
<td>50,320 (12,198)</td>
<td>48,335 (11,150)</td>
</tr>
<tr>
<td>PTVB</td>
<td>47,695 (4,185)</td>
<td>38,142 (7,163)</td>
<td>41,719 (4,587)</td>
<td>45,090 (12,410)</td>
</tr>
<tr>
<td>PBVB</td>
<td>48,964 (7,634)</td>
<td>36,799 (8,162)</td>
<td>44,443 (7,867)</td>
<td>37,259 (8,699)</td>
</tr>
<tr>
<td>PNVB</td>
<td>48,810 (7,944)</td>
<td>36,425 (6,729)</td>
<td>38,564 (6,037)</td>
<td>47,810 (11,124)</td>
</tr>
<tr>
<td>PTVN</td>
<td>46,897 (14,083)</td>
<td>35,115 (9,735)</td>
<td>41,860 (7,960)</td>
<td>45,816 (12,537)</td>
</tr>
<tr>
<td>PBVN</td>
<td>46,751 (7,768)</td>
<td>38,229 (13,056)</td>
<td>40,545 (7,976)</td>
<td>47,976 (14,305)</td>
</tr>
<tr>
<td>PNVN</td>
<td>50,555 (11,538)</td>
<td>43,243 (11,354)</td>
<td>40,473 (6,420)</td>
<td>39,419 (9,888)</td>
</tr>
</tbody>
</table>

The data was also analysed using a change score (the difference between post-acquisition tests and the pre-test) as the dependent variable. No significant main or interaction effects were found ($p > 0.05$). Neither were significant effects found when a percentage change score (percentage difference between pre-test and post-acquisition test) was used as the dependent variable ($p > 0.05$).

Group PTVB, it is realised, is only nominally a visual bandwidth group. As shown in Table 2.2, due to the tight physical condition subjects in this group could not err enough to trigger the pattern presentation, as is the case for the visual bandwidth condition. Functionally, this group's visual feedback was also dissimilar to none groups in that the yellow trace was almost perfectly drawn on the screen by the end of the movement. Neither was it like visual tight feedback in that the pattern was not presented in advance so as to be available for use in movement planning. Thus, the conclusions about this condition, outlined later, will be qualified accordingly, as this group does not truly represent the visual bandwidth practice condition.

### 3.2 Evaluation of Hypotheses

Having no similar data upon which to base an a-priori power analysis, a post-hoc analysis of power was performed using GPOWER (Faul and Erdfelder, 1992). A 20% difference in scores was considered to have clinical significance. Alpha was set at 0.05. Sigma was 8846 - the average inter-subject standard deviation on testing blocks. Therefore, the power for hypothesis I was 99% since groups of three
conditions were combined for the comparisons (group \( n = 33 \)). For the remaining hypotheses a power of 71% was calculated (group \( n = 11 \)).

3.2.1 **Hypothesis 1:** Bandwidth physical guidance will lead to better performance than absolute or no physical guidance. This hypothesis was tested by a planned comparison of the three groups which practiced with *bandwidth* physical guidance (PB) to the three groups which practiced with *tight* physical guidance (PT). Separately, the PB groups were also compared with the three groups which practiced with no physical guidance (PN). (See Figure 3.2) Both of the comparisons included scores from the immediate and the delayed retention tests. The group means over both tests were PT= 41,054, PB= 39,993, and PN= 42,320. Neither of these comparisons was significant, \( F(1, 90) = 0.28, p > 0.05 \) and \( F(1, 90) = 1.35, p > 0.05 \) thus leading to acceptance of the null hypothesis.

![Physical Guidance Diagram](image)

**Physical Guidance**

<table>
<thead>
<tr>
<th>Visual Guidance</th>
<th>Tight</th>
<th>Bandwidth</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTVT</td>
<td>PBVT</td>
<td>PNVB</td>
<td></td>
</tr>
<tr>
<td>PTVB</td>
<td>PBVB</td>
<td>PNVN</td>
<td></td>
</tr>
<tr>
<td>PTVN</td>
<td>PBVN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.2 Physical bandwidth groups compared first (dark arrow) with physical tight groups and then with physical none groups (gray arrow).

3.2.2 **Hypothesis 2:** Physical guidance will lead to better performance than visual guidance of comparable level. As with the previous hypothesis, planned comparisons of the physical and visual guidance data for the immediate and delayed tests were performed. However, in this instance the groups contrasted were those with similar levels of physical or visual guidance and combined with the *none* level of the other factor. (See figure 3.3) First, the PBVN group and the PNVB group were contrasted. Their means over the two tests were PBVN=39,387 and PNVB=37,495. There was no significant difference found between these two groups \( F(1, 90) = 0.3, p > 0.05 \). Second, the two groups with *tight* guidance were compared (PTVN (mean=38,488) and PNV (mean=47,609)). This contrast showed that the PTVN group had a significantly lower error score than the PNVT group \( F(1, 90) = 6.92, p < 0.02 \). This provides partial support for the alternate hypothesis.
3.2.3 Hypothesis 3: When visual and physical guidance are combined, the effects of visual guidance will dominate the effects of physical guidance. For this hypothesis the contrasts of concern were between groups where comparable levels of physical and visual guidance were combined, with the groups for which the same levels were present for only one factor. (See figure 3.4) Thus, a planned comparison was made between the PTVT group and the PTVN group over the immediate and delayed test results \( F (1, 90) = 0.68, p > 0.05 \) and a similar comparison of the PTVT group with the PNVT group was performed \( F (1, 90) = 3.25, p > 0.05 \). Their means were PTVT=44,743, PTVN=38,488, and PNVT=47,609. Neither of these contrasts was found to be significant, thus neither factor, at the tight level, can be deemed to dominate the other. The same contrasts were performed for the PBVB group. That is, PBVB (mean=40,621) contrasted to PBVN (mean=39,387) and then with PNVB (mean=37,495). Again, no significant differences were found, \( F (1, 90) = 0.81, p > 0.05 \), \( F (1, 90) = 0.13, p > 0.05 \), and so the null hypothesis was accepted.

3.2.4 Hypothesis 4: Bandwidth physical guidance will lead to better performance than other levels of physical guidance and better than the comparable level of visual guidance on a new version of the task. In order to test this hypothesis the three PB groups were contrasted in a planned comparison with the six PT and PN groups combined on the transfer test. (See figure 3.5) Their means were PB=42,784 and
PT-PN=45,172 \( (F (1, 90) = 1.03, p > 0.05) \). Separately, the PBVN (mean=47,976) group was contrasted with the PNVB group (mean=47,810) on the transfer test \( (F (1, 90) = 0.001, p > 0.05) \). Neither of the comparisons showed significant differences between the groups and thus the null hypothesis was accepted.

![Physical Guidance](image)

**Figure 3.5** Bandwidth compared to the tight and none levels of physical guidance (dark arrows) and physical and visual bandwidth compared (gray arrows).

### 3.3 Immediate Retention Test

In an attempt to better understand the significant 3-way interaction between PG, VG, and Test, specific comparisons were made between the pre-test and immediate retention test data within groups. (See Table 3.1) The reason for these comparisons was to confirm whether performance improved as a result of practice for each individual group. As well, contrasts were made between groups within the immediate retention test in order to ascertain if any group performed significantly better or worse than another. It was found that only one group (PTVT) did not significantly improve from the pre-test to the immediate retention test. On the immediate retention test contrasts between groups found that the PTVT group performed significantly worse than groups – PTVN \( (F (1, 90) = 5.68, p < 0.02) \), PNVB \( (F (1, 90) = 4.34, p < 0.04) \), and PBVB \( (F (1, 90) = 3.99, p < 0.05) \). It was also found that group PNVT was worse than PTVN \( (F (1, 90) = 5.09, p < 0.03) \).

### 3.4 Delayed Retention Test

Similar comparisons were performed on the delayed retention test data. (See Table 3.1) Only three groups significantly improved from the pre-test to the delayed retention test. These were – PBVT \( (F (1, 90) = 9.52, p < 0.01) \), PNVB \( (F (1, 90) = 8.37, p < 0.01) \), and PNVN \( (F (1, 90) = 8.11, p < 0.01) \). The only differences between groups on the delayed retention test involved group PNVT, which had significantly higher error scores than all groups other than PTVT and PBVB.
3.5 Transfer Test

Only groups PBVB \( (F(1, 90) = 7.08, p < 0.01) \) and PNVN \( (F(1, 90) = 6.41, p < 0.02) \) had significantly better scores on the transfer test than on the pre-test, although group PBVT approached significance \( (F(1, 90) = 3.94, p < 0.05014) \). (See Table 3.1) The only differences between groups on the transfer test were involving group PBVB, which had smaller error scores than groups – PNVT \( (F(1, 90) = 5.56, p < 0.03) \), PNVB \( (F(1, 90) = 5.04, p < 0.03) \), and PBVN \( (F(1, 90) = 5.21, p < 0.03) \).

3.6 Scaling and Pattern Representation

The two components to be learned for correct completion of the task were scaling and pattern representation. Scaling refers to the general size of the trajectory made, whereas pattern representation is concerned more with the correctness of the design made regardless of its size. In order to separate these two parts of the task a scaled error score (SES) was produced for each of the testing blocks, as explained in Methods 2.5. This scoring process eliminates any error in scaling and thus reflects the pattern representation qualities of the movement. The SES was treated with a 3 x 3 x 4 (Visual Guidance x Physical Guidance x Test) ANOVA with repeated measures on the last factor. There was only a main effect of Test \( (F(3, 270) = 64.81, p < 0.00001) \). There were no other significant main or interaction effects \( (p < 0.05) \).

The change over testing blocks was also the only significant factor when analyzing the scaling portion of the test movements. First, the x-scaling factor and then the y-scaling factor (see Methods 2.5) were treated with 3 x 3 x 4 (Visual Guidance x Physical Guidance x Test) ANOVAs with repeated measures on the last factor. There was only a main effect of Test for the x scaling \( (F(3, 270) = 26.28, p < 0.00001) \) and the y scaling \( (F(3, 270) = 5.81, p < 0.0007) \). There were no other significant main or interaction effects \( (p < 0.05) \). Interestingly, however, the direction of change for the x and y scaling factors were opposite. That is, subjects scaled in the x dimension better after practice than in the Pre-Test, but they scaled worse in the y dimension on post-practice tests.
3.7 Acquisition Phase Differences

Although many of the differences between groups during the acquisition phase are obviously due to the constraint of error, either physically or via visual guidance, there are several secondary variables which suggest that error scores were not the only difference in the way subjects practiced. Duration of movement, peak velocity, and the variability (as indicated by the standard deviation of error scores within practice blocks), though not directly constrained by the feedback conditions, showed significant differences between groups.

The subjects, although constrained to less than seven seconds, systematically varied the duration of the movement. However, there were significant differences in the duration of practice trials depending upon the feedback conditions. When considering the physical and visual factors separately, as can be seen in figures 3.6A and B, there were no significant differences in the duration of the pre-test block. But during the acquisition blocks the differences become obvious. The three physical tight (PT) groups practiced with significantly shorter durations than the bandwidth (PB) and none (PN) levels of physical guidance. When returning to test conditions there are no significant differences between groups. A very different story emerges in the visual factor analysis. This time the tight level (VT) groups practiced with significantly longer durations than the bandwidth (VB) and none (VN) levels. Once again, during testing conditions there were no significant differences between levels.
Figure 3.6 Mean durations over blocks grouped by level of A) physical guidance and B) visual guidance. (Acq.=Acquisition blocks, Imm. Ret.=Immediate Retention Test, Del. Ret=Delayed Retention Test)
Figure 3.7 Mean peak velocities over blocks grouped by level of A) visual guidance and B) physical guidance. (Acq.=Acquisition blocks, Imm. Ret.=Immediate Retention Test, Del. Ret.=Delayed Retention Test)
Peak velocity data reveals a different aspect of the movement performance. The 2-way interaction between visual guidance and block was not significant, however that between physical guidance and block was highly significant \((F (16, 720) = 9.92, p < 0.00001)\). (See Figures 3.7A and B) The groups were initially similar, showed clear differences during the acquisition phase, and then converged on the retention and transfer tests. Within this interaction the levels of physical guidance have pre-test peak velocities which are not significantly different. However, during the practice blocks the $tight$ groups (PT) have significantly higher peak velocities than the $bandwidth$ groups (PB) which are significantly faster than the $none$ groups (PN). When returning to testing conditions there are no significant differences between levels.

The standard deviation of the error scores within blocks was another area of interest. As can be seen in figures 3.8A and B there were significant 2-way interactions between both physical guidance and block \((F (16, 720) = 8.76, p < 0.00001)\) and visual guidance and block \((F (16, 720) = 2.31, p < 0.003)\). In neither of these were there significant differences in levels within any of the testing blocks. However, during practice the visual level of $none$ (VN) had significantly higher standard deviations than either of the other two levels (VB, VT) in practice blocks two and three. (See figure 3.8A) VN groups' standard deviations were also significantly greater than VT for practice blocks four and five. Even more significant differences were found between the physical guidance levels. (See figure 3.8B) Here the $bandwidth$ level (PB) had significantly greater standard deviations than the $none$ groups (PN) which were significantly higher than the $tight$ groups (PT) on all but the last of the practice blocks.
Figure 3.8 Mean standard deviations over blocks grouped by level of A) visual guidance and B) physical guidance. (Acq.=Acquisition blocks, Imm. Ret.=Immediate Retention Test, Del. Ret.=Delayed Retention Test)
While analyzing the practice blocks’ data it was noted that the groups with physical
*bandwidth* (PB) did not appear to have reached asymptote, as did the other groups.
(See figure 3.9) It was found that when contrasting the final practice block mean
error score with the next lowest block for the different levels of both factors that only
the PB level was significantly different ($F(1, 90) = 21.72, p < 0.000011$).

![Figure 3.9 Mean error scores for the nine groups over the five practice blocks. Visual Tight - (VT), Visual Bandwidth - (VB), Visual None - (VN), Physical Tight - (PT), Physical Bandwidth - (PB), Physical None - (PN).]
4.1 General Findings

The previous literature regarding physical guidance has presented varied results and conclusions. In the current study much of this variability has been attributed to three factors: 1) lack of control over visual feedback, 2) lack of delayed, no-KR retention testing, and 3) use of absolute physical guidance (PG) as the only PG presentation. Through the inclusion of visual feedback, this experiment has shown that there is a significant interaction between the two forms of guidance. That is, the effects of PG in this study were not independent of visual feedback and thus any general statements concerning whether PG is or is not beneficial would not be valid for situations in which visual feedback may be available. However, the relationship is complex and cannot be simply explained by visual dominance. By use of delayed no-KR retention testing the group results can be more assuredly classified as either showing learning effects or not. In the creation of levels for both visual and physical guidance more light has been shed on the relationships between these two factors and learning, as well as their interactions.

Table 4.1 A summary table of the groups and their performances relative to pre-test scores, as taken from Results 3.3, 3.4, and 3.5.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Immediate Retention</th>
<th>Delayed Retention</th>
<th>Transfer Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTVT</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PBVT</td>
<td>Yes</td>
<td>Yes</td>
<td>No*</td>
</tr>
<tr>
<td>PNVT</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PTVB</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PBVB</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>PNVB</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PTVN</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PBVN</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PNVN</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Note group PBVT’s pre-test / transfer comparison approached significance ($F(1, 90) = 3.94$, $p < 0.05014$).
The null hypotheses have almost all been accepted. Only in the case of Hypothesis 2 (that tight physical guidance would lead to better performance than tight visual guidance), was there support for an alternate hypothesis. As can be seen in table 4.1 there is no simple pattern to the group performance data. However, after considering the interactions between the effects of the levels and the guidance factors upon practice variables a more coherent picture can be obtained.

4.2 Effects of Levels of Guidance

The effects of the different levels of guidance appear to have been large, regardless of the guidance type involved (physical or visual). The groups who practiced with tight levels of guidance seem to have suffered from the effects of dependency, in that only one group with a tight level of guidance managed to have significantly better scores on the delayed retention or transfer tests than their pre-test. This one exception was PBVT which will be discussed below. In general these five groups practiced very differently from the other four groups in the study. They had much lower practice error scores (See Figure 3.9). They had significantly different durations of movement during practice (PT - short duration (Figure 3.6A) and VT - long duration (Figure 3.6B)). As would be expected, the tight groups also had their guidance form presented to them a greater percentage of the time. For the visual tight groups this was around 95 percent and for the physical tight groups it was near 60 percent of the movement time. (See Figure 4.1) It is proposed that this greater availability of guidance caused dependency, which has been linked to poor performance on learning tests (Salmoni, Schmidt, & Walter, 1984 and Schmidt, 1991). It is also noted that when combined with other levels of guidance (bandwidth or none) the tight level may have created a dependency on feedback. This can be seen in the lower scores for tight groups (See Figure 3.9) and lack of significant improvement on the delayed and transfer tests regardless of the other level in the combination (See Table 4.1). The exception to this is again group PBVT, which will be considered below.
Figure 4.1 Percentage of movement time for which the guidance mode (Visual and Physical) was presented to the nine groups.

The bandwidth groups, as a whole, seem to not have had a problem with dependency, which agrees with the work of Sherwood (1988) and Cauraugh, Chen, & Radlo (1993). For both visual and physical bandwidth the guidance forms were presented around 10 percent of the movement time. (This was not the case for group PTVB since the visual bandwidth could never be triggered due to the tight physical level of guidance.) (See Figure 4.1) This amount of guidance seems to have been superior to the near constant, tight level where it is seen that almost every group with a bandwidth level component achieved significantly better scores on the delayed retention or transfer tests compared to the pre-test scores (See Table 4.1). The exception to this is the PBVN group, which will be discussed below.

Although not leading to dependency the bandwidth level of physical guidance (PB) seemed to create some practice effects not seen in the visual bandwidth or any of the other groups. First, while other groups’ ‘learning curves’ flattened out from practice block three or four on, PB groups’ curves may not have reached asymptote. See Figure 3.9 where the middle panel shows continued improvement for all physical guidance bandwidth groups, while the six other groups appear to have reached asymptote. That is, these groups may have still been learning to use the PB
guidance, and may have continued to improve. Improving under PB conditions would mean not using the guidance as often. There could have been lower scores obtained without creating dependency upon the guidance had the acquisition phase been extended. Second, the PB groups had significantly higher standard deviations than other groups during the first four of the practice blocks. (See Figures 3.8A and B) Looking further into the PB groups and standard deviations it is found that groups PBVB and PBVN had significantly higher error score standard deviations for the practice blocks than the other PB group – PBVT ($F (1, 90) = 5.22, p < 0.025$) and ($F (1, 90) = 11.58, p < 0.001$).

The *none* levels of guidance obviously had little effect upon practice or the testing results. However, it must be considered that when the *none* level was part of the guidance combination the other level (of physical or visual feedback) may have received the subjects’ attention. This is especially important to remember in the case of PNVN. The subjects in this group had only knowledge of results (KR) in the form of an error score and yet this was the only group to show significant improvement from the pre-test on the immediate retention, delayed retention, and the transfer test. It must be pointed out that although KR was given after every practice trial, which might raise a concern about dependency, the KR was very general. While the visual and physical guidance provided quite specific feedback about where in the trajectory an error had been made and given at the time of movement (knowledge of performance), the error score (KR) only reported the overall deviation from the correct pattern after the completion of the trial. Obviously subjects were able to use some information to produce improvement. There seem to be two sources of helpful information for this group. First, there is the error score, as described. Second, the display of the pattern before each trial could have been used more effectively by those in PNVN. Regardless of which source, or how the two were combined, it may well have taken more attention and effort to use them than was required from the other groups who had other forms of more specific guidance. This may have produced stronger learning effects through a requirement for "deeper processing."

### 4.3 Physical vs. Visual Guidance

There are several obvious differences between physical and visual guidance as used in this study. The mechanisms by which error is reported to the subject were quite
dissimilar. Physical guidance forced subjects to alter their movement due to contact with the template edge. This mechanism delivers error information through the proprioceptive pathways. Visual guidance did not force subjects to alter their movement. Error information was provided visually, but the subject did not necessarily have to react to it.

The hypothesised "visual dominance" was not found. However, during the practice blocks there were two variables on which the visual and physical forms resulted in very different data - mean duration of movement and standard deviations of error scores. In figures 3.6A and B the mean durations for the factors are presented. It was noted that the physical tight groups had significantly shorter durations than the other physical groups. It was also shown that the visual tight groups had significantly longer durations than the other visual groups. When these two opposing factors of the tight level of guidance were combined in group PTVT these subjects practiced with shorter durations, as did the physical guidance groups, not with longer duration like the visual tight groups. The PTVT mean duration over acquisition was 4586 msec. This was significantly different from the other VT group mean (5671 msec.) \( (F(1, 90) = 14.64, p < 0.001) \). It was not significantly different from the other PT groups (4353 msec.) \( (F(1, 90) = 0.67, p < 0.41) \). (See Figure 4.2)

A similar tendency for PG practice characteristics to dominate was found with the PBVB group and their standard deviations. As shown in figures 3.8A and B standard deviations were higher among none groups for visual guidance, but for physical guidance it was the bandwidth groups who had significantly higher standard deviations. Further analysis shows that bandwidth physical guidance groups (PBVT and PBVN) had significantly higher error score standard deviations (mean=9838) during practice than the bandwidth visual guidance groups (PNVB and PTVB (mean=3120)) \( (F(1, 90) = 35.28, p < 0.00001) \). Where these two contrasting practice characteristics are combined, group PBVB, the subjects practiced with similar standard deviations (mean=10,773) to the PG bandwidth groups, but significantly higher than the visual guidance bandwidth groups \( (F(1, 90) = 30.52, p < 0.00001) \). (See Figure 4.3) It appears that the influence of the physical guidance mechanism may have been dominant in the way the practice was performed, at least for groups PTVT and PBVB.
Figure 4.2 Mean durations over all practice blocks for all groups. Visual Tight - (VT), Visual Bandwidth - (VB), Visual None - (VN), Physical Tight - (PT), Physical Bandwidth - (PB), Physical None - (PN).

Figure 4.3 Mean standard deviations over all practice blocks for all groups. Visual Tight - (VT), Visual Bandwidth - (VB), Visual None - (VN), Physical Tight - (PT), Physical Bandwidth - (PB), Physical None - (PN).
4.4 Theoretical Explanations of Results

Five general rules are proposed to account for the pattern of results seen in this experiment. First, a high frequency of guidance given to subjects during acquisition is not conducive to learning or to transfer to similar tasks. This is in agreement with the literature (Salmoni, Schmidt, & Walter, 1984 and Schmidt, 1991) and explains why groups PTVT, PNVT, PTVB, and PTVN did not significantly improve from the pre-test to the delayed retention or transfer test.

Second, the frequency with which guidance was encountered as determined by bandwidth presentation is conducive to learning and/or transfer testing. This is in agreement with the literature (Sherwood, 1988 and Cauraugh, Chen, and Radlo, 1993) and partially explains why groups PBVT, PBVB, and PNVB significantly improved from the pre-test to either the delayed guidance or the transfer test. The characteristic of guiding without causing dependency, is a strength of bandwidth applications.

Third, a level of none for either guidance form forced the attention upon any other available form of guidance. This was not only the case for PNVT and PTVN, where reliance was shifted to the ‘crutch’ of tight guidance, but also explains why PTVB did not show learning or transfer effects. Although this group was nominally VB (and did have a yellow trace presented while practicing), there were no opportunities for the pattern to be shown in the true VB manner since errors sufficient to cross the VB threshold were impossible in the PT guidance. This rule is even more important in understanding the success of group PNVN. This group, by having no other form of feedback, had to rely upon the KR of the error score alone. It seems evident that this group had a superior ability to produce the pattern from their mental representation. This may have been due to the attention during practice being place upon proprioceptive feedback since no other was on offer.

Fourth, physical guidance enhances the conscious processing of proprioceptive information. As pointed out in the first rule, when presented too often (tight) this enhancement can become a crutch. But, when presented at lower frequencies (bandwidth) this proprioceptive enhancement can aid learning and the ability to transfer the learning to a similar task. This rule helps to explain why group PBVT
scored significantly better on the delayed retention test than the pre-test and almost significantly better on the transfer test, while group PNVT not only did not show significant differences between pre-test and delayed or transfer tests, but also was significantly worse than all but two other groups on the delayed retention test. The only obvious difference between the practice of these two groups was that PBVT received physical guidance around seven percent of the time. (See Figure 4.1) The two groups practiced with similar durations (long), peak velocities (low), and error scores and yet performed disparately on testing.

The fifth rule is somewhat more speculative. It states that although perhaps enhancing the conscious processing of proprioceptive information without creating dependency, physical bandwidth (as presented in this experiment) is difficult to use. PB groups had significantly higher standard deviations of error score than other groups during practice (See Figures 3.8A and B). This unstable practice could be a manifestation of the difficulty in using the physical template as per PB conditions. PB groups also may have still been learning when the practice blocks were completed. (See Figure 3.9) These barriers to acquisition could be a partial explanation for the differences in groups PNVB and PBVB. PNVB achieved significantly lower scores on the delayed retention, but not on the transfer test compared to the pre-test, while PBVB did not score significantly better on the delayed test, but did do so on the transfer test. These practice difficulties may go some way in explaining the failure of group PBVN to obtain delayed retention or transfer test scores significantly lower than their pre-test.

To summarize the way these rules relate to the groups and their performance on the post-acquisition testing Table 4.1 is reproduced here (See Table 4.2) with the addition of two columns describing the proposed effects of the visual and physical guidance components of the practice conditions during acquisition.
Table 4.2 A summary of the groups and their performances relative to pre-test scores and the proposed effects of visual guidance (VG) and physical guidance (PG) levels.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PTVT</td>
<td>created dependency</td>
<td>created dependency</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>PBVT</td>
<td>proprioceptive aid, difficult to use</td>
<td>created dependency</td>
<td>Yes</td>
<td>Yes</td>
<td>No*</td>
</tr>
<tr>
<td>PNVN</td>
<td>relied on VG</td>
<td>created dependency</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PTVB</td>
<td>created dependency</td>
<td>relied on PG ^</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PBVB</td>
<td>proprioceptive aid, difficult to use</td>
<td>conducive to learning</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>PNVN</td>
<td>relied on VG</td>
<td>conducive to learning</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PTBN</td>
<td>created dependency</td>
<td>relied on PG</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PTVN</td>
<td>proprioceptive aid, difficult to use</td>
<td>relied on PG</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PNBN</td>
<td>relied on display / KR</td>
<td>relied on display / KR</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Note group PBVT’s pre-test / transfer comparison approached significance ($F (1, 90) = 3.94, p < 0.05014$).

* Note this group could not err enough to encounter VG bandwidth since they were constrained by PG tight.

4.5 Conclusion

There are many points to be made after considering the results of the present experiment. Foremost, it is now apparent that the effects of physical guidance (PG) are not to be simply stated as either beneficial or detrimental for learning of motor skill tasks, as has been the case in the PG literature thus far. Second, one of the reasons for this is the complex interaction between PG and vision. Although not simply “visual dominance” as was hypothesized for this experiment, vision obviously does interact with PG in this form of motor learning. The third point concerns the use of a bandwidth (BW) level of presentation. While generally supporting the conclusions of the bandwidth literature, there are some exceptions when the BW procedure is applied to PG. Fourth, some of these exceptions may be due to the task-specific nature of learning. The idiosyncrasies of this task as compared to those used in previous experiments have had definite effects upon the outcomes and interactions observed. Fifth, one of these peculiarities has lead to findings about the use of knowledge of results (KR) alone as a guiding factor in learning. Finally, this study has raised several additional questions about physical guidance which warrant investigation.
A simple “not beneficial” tag has been placed on PG by Melcher (1934), Waters (1930), and Winstein, Pohl, and Lewthwaite (1994) who all concluded that physical guidance (PG) is detrimental for learning. The Armstrong (1970) study did not even show beneficial results immediately after acquisition. In opposition to these, Holding and Macrae (1964) reported positive results from PG, although not tested with delayed retention trials. As well, Wulf, Shae, and Whitacre (1998), claim beneficial effects of PG for learning in their unusual, whole body movement, ski simulator study. The present study has clarified some of the reasons for these seemingly contradictory conclusions concerning PG. Two of these are considered below. First, there is a complex interaction between PG and vision, which has rarely been controlled. Second, almost all of the studies have only considered absolute PG.

The complex interaction with vision can be readily ascertained from the results of this study. Only Melcher (1934) and Holding and Macrae (1964) controlled all the visual input concerning their experiments. Even so, Melcher (1934) allowed vision of the task during testing and Holding and Macrae (1964) did not use a delayed retention test. Thus, the present experiment is the first to systematically examine the interplay between visual and physical guidance. Although hypothesized to be merely visual dominance, where the visual form of guidance would demand the greater part of the attention of subjects, the results give a more complicated picture. While no evidence of dominance was found in the retention or transfer tests, analysis of the practice data gave some possible clues. A case for physical rather than visual being the dominant form of guidance could be made on the mean durations of group PTVT which were similar to other PT groups (short) and not like those of other VT groups (long). In addition, the error score standard deviations of group PBVB were similar to other PB groups (high) and not like other VB groups (lower). (See section 4.3 for more detail.)

The bandwidth (BW) concept, as conceived by Sherwood (1988) and developed by Cauraugh, Chen, and Radlo (1993), had to do with the frequency of presentation of knowledge of results (KR). This study has expanded BW into the presentation of knowledge of performance (KP), specifically in the forms of visual and physical guidance. The original investigators found BW KR to provide guidance without leading to dependency. The results of this experiment have supported the claims of...
positive effects from BW presentation in general. When comparing the lack of learning of group PNVT to the significant learning effects for group PBVT it seems the PG BW is the key factor in improved learning. Almost every group with a bandwidth level component achieved significantly better scores on the delayed retention or transfer tests compared to the pre-test scores. The main exception to this was the group PBVN. The results of this group have brought out the possibility that PG BW is difficult to use.

Task specific features, especially with the form of presentation of physical guidance (PG), may account for some of the results running counter to the literature. This has been the first study to use two-dimensional spatial bandwidth (BW) PG. Waters (1930), Melcher (1934), Holding and Macrae (1964), and Weinstein, Pohl, and Lewthwaite (1994) all used some form of absolute PG. Although Armstrong’s (1970) experiment had a condition incorporating BW, his was a single dimension task and more importantly involved timing control. As noted earlier, controlling the time component of the action could create a push-pull effect during practice. All groups in the current experiment had to produce their own, active, movement. The benefits of active versus passive practice have been reported by Paillard and Brouchon (1968). Additionally the control of all visual feedback and the introduction of BW visual guidance (VG) set this experiment apart from the previous literature. These differences have allowed for the discovery of the greater complexity of the workings and relationships between PG, VG, BW presentation, and absolute presentation of feedback.

Another component of this study was the use of a very general knowledge of results (KR) format. The error score used gave only an overall picture of error to the subjects. No specific spatial or magnitude errors could be derived from the KR. This characteristic of the KR seems to have been able to overcome the expected difficulties of dependency, as suggested by Salmoni, Schmidt, & Walter (1984) and Schmidt (1991). These writers’ Guidance Hypothesis would indicate that any group receiving KR for every trial of acquisition would suffer from dependency and thus when the KR was removed for testing scores would degenerate. However, this was not the case for group PNVN. Although receiving KR after every trial, they not only performed significantly better on all three post-acquisition tests as compared to the
pre-test, but did not score significantly worse on any of these tests compared to their practice block scores.

The findings of the present experiment lead to a practical application as well as a few areas for further study. One applicable result is that of the superiority of group PBVT over PNVT as explained in rule four. Many practice situations make full use of visual feedback (allowing participants to see what they are doing), however having once left the acquisition phase of learning they are expected to attend to other stimuli and therefore be unable to use the visual information upon which they may have come to rely. In such situations the use of a bandwidth physical guidance mechanism may improve learning. Teaching ball-pitching technique is an example. While students are given full visual feedback both during practice and testing, they are expected to attend to other visual stimuli during game play to the exclusion of watching their pitching technique. A bandwidth physical guidance similar to the one used in the present experiment could be employed toward reducing sidearm throwing by practicing parallel to a wall. When using correct technique students would have no contact, but when straying beyond a set criterion they would come into contact with the wall, cuing them to correct their error.

One question suggested by the present study is whether use of the spatial physical bandwidth mechanism can be improved. As stated in rule two bandwidth knowledge of performance (KP) can be beneficial for learning. As stated in rule four, physical bandwidth may enhance the conscious processing of proprioceptive information. However, as stated in rule five, bandwidth physical guidance seems to be difficult to use. This difference may be attributable to the specific pattern used for the task. Anecdotally, subjects seemed to “get stuck” on the upper right corner turn and the chicane in the middle of the pattern – often this terminated the trial when it was only one third or one half completed. The problem would appear to be that during the use of bandwidth PG, subjects could contact the edge of the template at an angle near perpendicular. This contact often brings the movement to a stop with subjects unsure of the direction to go in order to return to the required trajectory. This contrasts to those subjects in the tight PG groups who, since they were in near constant contact with the edge, rarely came to a stop due to being “stuck.” Obviously, the none level of PG gave no such difficulties. An experiment, similar to the present one, but using
an alternative pattern designed to have less likelihood of perpendicular contact would help confirm or refute the concerns over the task characteristics creating bandwidth PG difficulties. Another explanation could be the dichotomous nature of the physical bandwidth in the experiment in which once beyond the allowed error distance subjects were “hard” against the template edge. Perhaps gradually increasing resistance to spatial error would enable a smoother transition back to the correct pattern and fewer trials abandoned due to “getting stuck”. An experiment in which the results from bandwidth spatial PG presented in a dichotomous manner were compared to those from a gradual presentation, would reveal more about both the efficacy of bandwidth PG and the possibility of increased proprioceptive enhancement without the drawbacks of “getting stuck.”

The second question arising from this study concerns the factor(s) which enabled group PNVN to perform better on all post-acquisition tests. Was it by more intense scrutiny of the pre-trial pattern presentation? Or was it by comparing internal error detection with that of the KR given after each trial? A similar experiment to the present one, but with a component of pattern recognition (can subjects pick the correct pattern from several choices) and error prediction (how well can they predict their error) could help to settle the matter. As well, the use of auditory probe reaction time (RT) tests during presentation of the pattern and then after error score presentation could determine which of these two gain subjects' attention. If subjects in PNVN were better at pattern recognition and/or had longer RT's during pattern presentation than other groups it could be concluded that their use of that presentation was leading to better test results. If the PNVN subjects predicted their error better and/or had longer RT's post-error presentation it could be concluded that their use of the error score was leading to better test results.

Finally, although the hypothesised visual dominance was not borne out in the comparisons of results, there was obviously a complex interaction between the VG and PG in this experiment. To help extract attentional information a similar experiment could include probe reaction time (RT) tests during acquisition. One test could use visual stimuli (perhaps a light flash) and another tactile stimuli (such as a skin tap). Although there would be differences between RT tests of different modalities, the comparison of groups where visual and physical guidance was
combined with those where one or both guidance forms was absent (none) could show if the guidance forms were attention demanding. If groups had longer RT’s for one modality or the other, when compared to none groups, this would show increased attentional demands for that modality, and thus whether visual or physical guidance was dominant.
Appendix A:
Physical Guidance in Motor Learning Subject Instructions

Hi, thanks for coming. The first thing I'll have you do is a handedness inventory to see how right or left-handed you are. (Wait) If you've had a look at the "informed consent information" you'll know that this is a motor learning study. And toward that end data will be collected on your performance on a motor skill task where you will be asked to replicate a visually presented pattern using this apparatus while vision of the pattern, arm, hand, and apparatus are occluded.

There is a chance of your becoming fatigued during testing, however, you will be given rest breaks of one minute between each block of 20 trials and can request additional breaks at any time. First there will be familiarisation and scaling work. Second, there will be a pre-test of five trials. Third, there will be five blocks of twenty practice trials and then last, for today, one block of ten immediate retention test trials. I'll explain more about these as we go along. Two days from now you’ll need to come back for a fifteen-minute session with two more blocks of tests. Participation in this study is entirely voluntary. You are free to withdraw consent before or during the experiment without comment or penalty. Your results will only be revealed to the investigators and yourself. When the results of the study are published we will ensure that you will remain anonymous. Do you have any general questions?

Ok, now let’s look at the informed consent page. If you consent - please sign here.

All right. We can get started. Let’s slide you over to the apparatus to check out the height of this chair. Do your legs hit under the apparatus? Are you comfortable with that height? Try to centre your body on the black line. If you would rest your left hand on this left edge. Your right hand will be doing the work. When it's not you can rest it on the front edge or to your side - what ever is comfortable. I need you to be as close as comfortably possible to the edge. Would you like me to position this footrest for you? Now, I’m going to lock the wheels in place to keep you from rolling around. Anytime you need to push back from the apparatus just tell me and
I’ll move the bar out of the way. Does that feel pretty good? You may rest your right arm on the front edge. The left should be on the left edge of the apparatus, but not in the way of movement.

If you will gently take hold of the handle we’ll begin with the boundaries of your workspace. (start scaling) Move around the area by lightly gripping and moving the handle. Especially explore all four corners and you’ll find that when you approach a boundary that a beep comes on. This will also come on during the testing. You may use all the space, but I don’t want you to hit the boundaries. Have you got a feel for the way the apparatus moves?

Then we’ll go to a scaling practice session. Let me set up the start position for you. The idea of these tests is to let you understand that when you move the handle so much it means this much on the screen. What I’m asking you to do is in one motion to move from the yellow square, your present position, to within the green bands. Now, as you move there will be no change on the screen. So, you won’t be able to use corrective movements. Once you come to a stop it will show where you moved as well as confirmation about success (or not). Please allow me to return the handle to the start position. You will have to get on target three times in a row before going to a second target. After hitting that one three in a row you’ll have the last target, which you have to get three in a row on too. Any questions? Go ahead and start on the first target.

Good, now you’re ready for the pre-test trials. The procedure for these trials is that the required pattern will be displayed on the screen. It will be drawn fairly quickly from right to left, stay up for about a second and will then disappear. This is the pattern I want you to reproduce with your handle. This same pattern will be required for every trial today. Once the pattern disappears, "Ready" will come on to the screen. There will be a random period of time before a beep. The beep is your signal to move the handle to start your trial. If you move too early, or take more than one second to move the start will be disallowed and I’ll reposition the handle to be ready for the next beep. The pattern will not be shown again, however. The trial ends when you come to a stop, you hit a boundary, or at the end of seven seconds. We don’t want the boundary or the overtime to occur and you’ll be warned if one of
them should happen. Speed of movement is not of a concern. Going faster is not better, but you must finish before 7 seconds. When the trial is completed release the handle and I will return it to the start position. There will be five trials in this block. There will be no feedback of any kind. So, once you hear the beep the screen will be blank while you do your thing and no scores will be given to you.

Now we're ready for the practice trials. I’ll get you to roll back while I place this board. Now we’ll move you back into position, close as possible, centred on the black line, left hand left edge. The main thing is to be in the same position each time you come up to the apparatus. The procedure for these practice trials will be just like the pre-test, as far as the required pattern being shown, then the "Ready", then a random time, and then the beep for you to move. About five seconds after the trial is over an error score will be shown on the screen. This is an error score, so lower is better. In general scores will range from 100 (worst) to 1 (best). Use this score to judge the success of your trial. While I may encourage you on your procedure I will not comment on your performance. After the error score is cleared from the screen the process is repeated for the next trial. Any questions about that?

Now, for some instructions specific to your condition. In your condition, during the performance of the practice trials you will -

(1 - PTVT) see a yellow trace of the path you are making. If you get more than one millimetre off the correct pattern you will see the pattern appear on the screen in white. If you get more than two millimetres off the correct pattern you will also feel the sides of a physical template restricting your movement. You are requested to attempt to stay on the correct pattern thus seeing and feeling the guides as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, no template, neither will there be an error score.

(2 - PBVT) see a yellow trace of the path you are making. If you get more than one millimetre off the correct pattern you will see the pattern appear on the screen in white. If you get more than 29 millimetres off the correct pattern you will also feel the sides of a physical template restricting your movement. You are requested to attempt to stay on the correct pattern thus seeing and feeling the guides
as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, no template, neither will there be an error score.

(3 - PNVT) see a yellow trace of the path you are making. If you get more than one millimetre off the correct pattern you will see the pattern appear on the screen in white. You are requested to attempt to stay on the correct pattern thus seeing the guide as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, neither will there be an error score.

(4 - PTVB) see a yellow trace of the path you are making. If you get more than two millimetres off the correct pattern you will feel the sides of a physical template restricting your movement. You are requested to attempt to stay on the correct pattern thus feeling the guide as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, no template, neither will there be an error score.

(5 - PBVB) see a yellow trace of the path you are making. If you get more than 28 millimetres off the correct pattern you will see the pattern appear on the screen in white. If you get more than 29 millimetres off the correct pattern you will also feel the sides of a physical template restricting your movement. You are requested to attempt to stay on the correct pattern thus seeing and feeling the guides as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, no template, neither will there be an error score.

(6 - PNVB) see a yellow trace of the path you are making. If you get more than 28 millimetres off the correct pattern you will see the pattern appear on the screen in white. You are requested to attempt to stay on the correct pattern thus seeing the guide as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, neither will there be an error score.

(7 - PTVN) see nothing on the screen. If you get more than two millimetres off the correct pattern you will feel the sides of a physical template restricting your movement. You are requested to attempt to stay on the correct pattern thus feeling the guide as little as possible. It is important to remember that during the testing
blocks there will be nothing on the screen, no template, neither will there be an error score.

(8 - PBVN) see nothing on the screen. If you get more than 29 millimetres off the correct pattern you will feel the sides of a physical template restricting your movement. You are requested to attempt to stay on the correct pattern thus feeling the guide as little as possible. It is important to remember that during the testing blocks there will be nothing on the screen, no template, neither will there be an error score.

(9 - PNVN) see nothing on the screen. It is important to remember that during the testing blocks there will be nothing on the screen, neither will there be an error score.

Any questions? If you’re ready we’ll have a look at that pattern, then have a go on the beep.

Before blocks each practice block repeat - “It is important to remember that during the testing blocks there will be nothing on the screen, (no template), neither will there be an error score.

That was the last of the practice trials. I’ll get you to roll back while I remove this board. Now we’ll move you back into position, close as possible, centred on the black line, left hand left edge. These will be the immediate retention test. Remember that for this block of ten trials there will be nothing on the screen, (no template), neither will there be an error score. If you’re ready here is the same required pattern.

Thank you very much for your participation. Remember the fifteen-minute session on (day) at (time). It is important that you not discuss the testing procedures or results with any classmates who may also be participating as this could effect their performance. Thank You.
Day2:

Hi, thanks for coming back today. Go ahead and move into position, close as possible to the apparatus and centred on the black line, left hand left edge. This will be a ten trial block with nothing on the screen, (no template), neither will there be an error score. It's just like the last test you had two days ago. The procedure for these trials is the same in that the required pattern will be displayed on the screen, stays up for about a second and will then disappear. Once the pattern disappears, "Ready" will come on to the screen. There will be a random period of time before a beep. The beep is your signal to move the handle to start your trial. Any questions? If you’re ready here is the same required pattern which you practiced two days ago.

Now we're ready for the transfer test. All the procedures are the same as they have been, but the pattern is one that you have not seen before. Even though there will be nothing on the screen, (no template), nor will there be an error score, please try your best to accurately replicate the new pattern. If you’re ready here is the new required pattern.

Thank you very much for your time. Again please don't discuss this experiment with others that may participate. I'll attempt to send you the results of the study once it is completed.
Appendix B:
Error Score Calculation

Error score was equivalent to the area between the required and the actual trajectories. Since one pixel on the screen was equivalent to one square millimetre on the apparatus, the calculations using pixels could be directly converted to area of error. The process to calculate this area used a set of computer algorithms. These began with connecting the two trajectories at both ends by having the same start position and connecting the two end points with a straight line. Next, the places where the two trajectories crossed were found (cross points). Then for each loop, between two cross points, an inner loop line was drawn one pixel inside the loop. The nearest pixel of the same Y value was found of either the inner loop line or either of the two trajectories. These two pixels and any between them were counted and checks were made to ensure the area was inside the loop and that the line of pixels was not recounted. This was repeated for each pixel of the inner loop line.

(See Figure B.1) After each loop was processed the actual trajectory, minus the cross points, was added to the error score. For display to the subjects during acquisition the score was then divided by 1000 and rounded, so that a score of 14,597 mm$^2$ would have been given as an error score of 15.

![Diagram of error score calculation](image)

Figure B.1 Diagram of error score calculation. A) finding of cross points between required and actual trajectories, B) addition of inner loop line, C) filling and counting of pixels between inner loop line points.
Bibliography


