# THE INFLUENCE OF SKILL AND VISION
# ON DYNAMIC BALANCE

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# ON DYNAMIC BALANCE

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TO MY MOTHER

FOR HER LOVE AND CONSTANT SUPPORT AND ENCOURAGEMENT

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## Foreword

This thesis has been written in a format suitable for publication. The introduction section was written as a review of the literature to set up the following two papers which are in publication format. The first paper "The Influence of Skill and Intermittent Vision on Dynamic Balance" was accepted by the Journal of Motor Behavior. The second paper was written in the same format with the intention of being submitted for publication.

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# INTRODUCTION

Many studies dealing with the role of afferent feedback show it to be an important variable affecting the performance and learning of motor skills (Bilodeau & Bilodeau, 1961; Fischman & Schneider, 1985; Shick, 1982). Yet considerable controversy arises over the exact nature of the feedback's role in the learning process.

Three prominent theories dealing with the role of sensory information while learning a motor skill have been postulated. First, Pew (1966) suggested that as expertise increases there is a reduction in the need for sensory information. This will be called the closed-loop to open-loop position because subjects switch from a closed-loop mode of control early in practice to an open-loop mode of control later in practice. Secondly, Fleishman and Rich (1963) proposed that as expertise increases there is a decrease in the importance of visual feedback in favour of proprioceptive feedback. This will be referred to as the vision to proprioception position. Finally, Proteau, Marteniuk, Girouard, and Dugas (1987), concluded that learning is specific to the feedback conditions in which the skill was acquired. According to this 'specificity of learning' position, subjects learn to integrate the sources of information available into a representation that guides subsequent performance.

## THE CLOSED-LOOP TO OPEN-LOOP POSITION

Pew (1966) advanced the hypothesis that as learning increases, subjects switch from closed-loop control (a control system employing feedback and subsequent corrections) to open-loop control (a control system with preprogrammed instructions that does not use feedback) (Schmidt, 1975). He demonstrated this in an experiment in which the subject's task was to align a dot with a predetermined target by way of successive key presses. Early in practice (150 trials) the subjects produced discrete presses (waiting for feedback from each response) but later in practice (1700 trials), shorter interresponse delays were observed suggesting the use of a more preprogrammed mode of control. Although, the closed-loop to open-loop interpretation seems straight-forward, a comparison of the interresponse times with a control condition is instructive.

In the control condition, the target dynamics were disconnected so the subjects simply pressed alternating keys as quickly as possible (presumably open-loop). This yielded a mean interresponse time of 125 ms. The mean interresponse times of the last sessions of the experimental group, deemed open-loop, were 292 ms which leaves a difference of 167 ms. Presently, we know that this is likely enough time to permit the utilization of visual feedback (Carlton 1981; Zelaznik, 1983). Thus an open-loop explanation of performance on the final sessions can be disputed.

More recently, Schmidt and McCabe (1976) investigated the role of feedback in learning a motor skill that involved precise timing. Their task was to hit a barrier in a specified movement time. They used an index of preprogramming as a measure of feedback involvement. This index of preprogramming was a within-subject correlation between starting time and algebraic error. For example, if movements were preprogrammed starting time would be highly associated with variation in algebraic error approaching a correlation of 1.0. On the other hand, if feedback is used during the movement then the start time would only weakly correlate with algebraic error, thus the index of preprogramming would be expected to approach zero. Their index increased linearly with practice. Hence their results showed that with practice (1000 trials in 5 days), the mode of control in timing movements shifted from a more closed-loop mode toward a more open-loop mode. Although Schmidt and McCabe (1976) have shown open-loop control to be a feature of skilled performance, their calculation of a preprogramming index lead to some potential artefacts that could limit its interpretation. For example, artificial distributions were used to solve the problem of the bias that the decreasing algebraic error variance with practice had on the calculated preprogramming index (increasing it). In fact, these artificial distributions were not taking into account responses with large errors thus eliminating some viable data. Likewise, the starting time variance also decreased with practice. Starting time is the difference between movement time and algebraic error. It is also one of the variables used to obtain the index of preprogramming which also may have increased the index with increasing practice. Thus it appears that the calculation of a preprogramming index may have introduced complications.

## VISION TO PROPRIOCEPTION LEARNING POSITION

The second theory predicts that proprioceptive feedback becomes dominant with increasing expertise. In a study examining between-subject differences in skill level and the role of vision and proprioception in one-hand catching, unskilled catchers made more positioning errors than skilled catchers (Fischman & Schneider, 1985). Thus, it was concluded that skill level may serve as a mediator in the ability to use proprioception for limb positioning. As a result, for highly skilled baseball athletes, proprioception appears to provide quite reliable information about the position of the catching limb in space. Whereas novices could not use the information specified by the proprioceptors, therefore they relied heavily on vision. Although Fischman and Schneider (1985) adopt this theory, they do not rule out the possibility that central motor programs may differentiate skill level (Schmidt, 1975). In fact, upon further investigation the dependent variable (# of catches) and task itself (barehand catching a tennis ball) are not very representative of "skilled" baseball players. Firstly, skilled baseball players have varying skill levels of catching with respect to their positions. Secondly, they catch a baseball with a baseball glove (Fischman & Mucci, 1989). Thus the results of this study may be confounded by these factors.

Starkes, Grabriele, and Young (1989) conducted another study which suggests that there is an increasing reliance on proprioception with increasing expertise. A body-orienting skill, specifically the "vertical position" in synchronized swimming, confirmed that expert swimmers were more accurate and less variable at reaching the correct position, even after a perturbation off vertical and, with or without vision. The results of this study suggest that through learning swimmers were capable of using either proprioceptive cues, semicircular canals or some combination of sensory feedback. As Starkes and colleagues posit, the feedback gained through extensive practice must allow experts to recognize and use proprioceptive information more effectively, or perhaps experts may be able to more efficiently switch between the use of visual and proprioceptive feedback systems.

Fleishman and Rich (1963) worked with a 2-hand coordination tracking task in which rotation of a left handle moved the target left-to-right and rotation of the right handle moved the target to-and-from. A measure was taken of spatial performance (using the correct number of matched cockpit views of land-sea-sky horizons with positions of airplanes) and kinesthetic performance (in which a difference limen was calculated for judgements of lifted weights). Both of these performance measures were then correlated with the performance of the previously explained 2-hand coordination task. It is assumed that the higher the correlation of the 2-hand coordination task with either the spatial or kinesthetic performance, the more involved that type of performance is in the 2-hand task. The results revealed that as practise increased on the 2-hand coordination task, the correlation with spatial performance decreased while the correlation with kinesthetic performance increased. Thus their results indicate that sensitivity to visual-spatial cues is critical early in learning a motor skill and that kinesthetic cues take on greater importance later in learning.

Conversely, Cox and Walkuski (1988) suggested the opposite. They used a partial replication of Fleishman and Rich (1963) but added two additional kinesthetic sensitivity tasks. These were passive angular and linear positioning tasks plus the weight discrimination task already used. As well, a comparable rotary pursuit task was used plus a ball tossing task. Their results indicate that for a continuous task, angular kinesthetic sensitivity is more important in the early stages of learning (trials 1 - 12). This is consistent with Keele's (1968) program theory in which kinesthetic sensitivity is important in the early stages of learning certain motor tasks. It is important to note that Cox and Walkuski (1988) qualify their conclusions, indicating that they hold true for a continuous task, because the discrete ballistic ball tossing task produced low correlations. Also, only angular kinesthetic sensitivity correlated significantly with pursuit rotor learning. Thus using the weight discrimination task as the sole measure of kinesthetic sensitivity (Fleishman & Rich, 1963) appears to be problematic.

## SPECIFICITY OF LEARNING POSITION

Proteau et al. (1987) and others have recently provided evidence for the latest specificity of learning theory, suggesting that if the type or amount of feedback is changed, performance is negatively affected. Proteau used a transfer of learning paradigm. By comparing the efficiency of an individual performing tasks under a variety of feedback conditions, during both acquisition and transfer, one should be able to determine the sources of information used to control the movement. Further, by comparing performance after differing amounts of practice, one should be able to assess the importance of the available feedback as expertise increases. In Proteau et al.'s (1987) study, the task was to displace a stylus 75 cm sagitally, 35 cm vertically and 5 cm laterally within a specified movement time bandwidth. Two groups practised for 200 trials (novice), one with complete vision of the performing limb and the target and the other with only vision of the target. Similarly, two groups (who were divided into the same visual learning conditions) performed for 2000 (expert) trials. As expected the subjects' aiming and temporal error decreased with practice. More interesting is the result that subjects who trained under complete visual conditions (limb and target) showed greater error after extensive practice than subjects who received moderate practice when transferred to the target only visual condition.

Recently, Proteau, Marteniuk and Lévesque (1992) conducted another study with the same task. The goal of this experiment was to examine the robustness of the specificity of learning hypothesis. This was done by employing a task that was learned in the absence of a significant source of information, specifically vision, and then transferring subjects to a full vision situation. Once again, their hypothesis was that when a movement is learned with one source of information and subjects are transferred to different sensory conditions, there should be a decrement in performance. Their findings supported this hypothesis. For example, the group who practised with only vision of the target showed increased spatial error when transferred to full vision.

Elliott and Jaeger (1988) conducted a similar study. In their experiment subjects were trained in a target-pointing movement with a stylus in a specified movement time (300-400 ms) with either full vision, no vision, or in a 2 second no vision delay condition. In the no vision delay condition, subjects would sit in the dark for 2 seconds prior to moving in the dark. Following training, all subjects were transferred to a delayed vision, a no vision and then a full vision situation. Their results revealed that subjects aimed more accurately in retention when they were performing in the same visual conditions in which they trained. Basically, Elliott and Jaeger's (1988) results paralleled Proteau et al.'s (1987, 1992) findings.

In agreement with Proteau's specificity of learning position Aksamit and Husak (1983) found that the elimination of vision may enhance learning even in the early stages of golf putting (5 trials). They came to this conclusion in view of the fact that, neither looking at the target, nor the ball, nor being blindfolded prior to putting, was a better strategy for decreasing putting errors. Proteau (1992) suggests that a major characteristic of motor learning is the specificity to feedback sources available when learning occurred. Since Aksamit and Husak's (1983) subjects were all novices and all learned with a different strategy (yet the outcomes were equally successful) Proteau's explanation is plausible. It may be premature however, to discuss these results in terms of learning since only 5 putts per condition were performed and there were no transfer conditions.

Graydon and Townsend (1984) conducted another study compatible with the specificity position. In this study a forward somersault on the trampoline was used as a predominantly proprioceptive task (since it relies on the correct orientation of the body in space for success), and a badminton serve was used as an predominantly exteroceptive task (since it relies on correctly assessing the visual parameters of the net and target). The hypothesis was that in a task in which visual assessment was minimal (somersault on the trampoline), learners should be forced early on to rely on proprioceptive information, since that source of information is of critical importance later. Conversely, in a visually-dominated task, maximizing visual information from the beginning, will be of more benefit. Graydon and Townsend's (1984) results confirmed the proposition that forcing dependence on proprioceptive cues of novice subjects may be beneficial in learning skills which depend solely on the movement and shape of the body (body-oriented). Similarly when a skill has to be performed according to some external reference point (target-oriented) visual cues are needed. Thus central representations may develop with practice that include rules for using the sensory information available. In this body-orienting task the role of the semicircular canals may also play a role. Thus, the Graydon and Townsend (1984) findings not only support Proteau's specificity of learning hypothesis, but also suggest that perhaps different types of tasks would benefit more from specific types of feedback.

Although the specificity of learning hypothesis appears to have strong empirical support, it also has its dissidents. Recently Whiting and Savelsbergh (1992) questioned the generality of Proteau's increasing dependence of feedback present while learning, in favour of transference to proprioceptive cues. They reported an experiment in which expert (good) and novice (poor) catchers were compared across five different visual conditions. Their results suggest that preventing sight of the hand, for subjects who trained with sight of their hand, does have an effect on performance. However, this effect is less traumatic for the expert catchers than the novice. These results seem to point to a reduced need for vision, in favour of proprioception. In a second study, novice subjects were trained for a long period with full vision (600 trials over 4 days), for a long period with no vision (600 trials in 4 days), or for a shorter period with no vision (360 trials over 3 days). All subjects were transferred to a full vision condition on the final day. Their results showed no significant training effects in any of the conditions. Therefore transfer to full vision after training with no vision had no detrimental effects, as Proteau would suggest. However, when their pre-test scores were compared with scores on day one and post-test, those with full vision training increased continually until day three while those who trained with varying practice and no vision also showed an increment up to day three, but only after an initial decrement. On transfer to full light the subjects who trained with no vision picked up where they left off after full vision pre-test trials. Their results could be interpreted as evidence against a specificity of learning position, however, they pooled their data since all subjects participated in all vision conditions. This type of procedure introduces carry over effects which may have washed out the specificity effect. Despite the fact that there are certain limitations to this work, their flexibility hypothesis is an interesting idea and needs further investigation.

As is evident from this review, there is still controversy regarding the influence of various feedback sources in motor learning. In this thesis I report four studies designed to take a closer look at this issue. Following an alternative thesis format recently approved by the Senate of McMaster University, the four studies are presented as two separate papers in journal format. Experiments 1 and 2 are packaged together and have been accepted for publication by the Journal of Motor Behavior. Studies 3 and 4 have been prepared for submission elsewhere. Experiment 1 in the first paper was carried out in conjunction with Jane Collins as part of a graduate course in Human Biodynamics under the direction of D. Elliott and J.L. Starkes.

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# The Influence of Skill and Intermittent Vision on Dynamic Balance

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Running Head: DYNAMIC BALANCE

# Abstract

Two experiments are reported in which expert and novice gymnasts were required to walk across a balance beam as quickly as possible in various vision conditions. In Experiment 1, experts walked faster than novices in all vision conditions, showing the greatest superiority when vision was completely eliminated. Novices were more dependent on vision, and were able to maintain their performance as long as a brief visual sample was available every 250 ms (i.e., 4 Hz samples). The results of Experiment 2 indicate that differences in the no vision condition between expert and novice performers were not related to the use of a short-term visual representation of the movement environment. Our movement time findings are problematic for specificity of learning models of skill acquisition. As well, film data collected in Experiment 2 are not consistent with models that propose a transition from closed-loop to open-loop control.

## The Influence of Skill and Intermittent Vision on Dynamic Balance

The traditional wisdom in motor behaviour has been that as an individual becomes more skilled at a motor task, he/she becomes less dependent on sensory sources of information, including visual feedback (e.g., Schmidt & McCabe, 1976). The assumption is that with repeated trials the performer develops a central representation of the movement pattern that replaces afferent information in motor control. This central representation or 'motor program' may be specific to a single variation of the task (Keele, 1968), or more general in nature (Schmidt, 1975). In either case, the development of a central representation makes people less dependent on response-produced feedback as practice progresses.

While the idea of a progression with learning from closed-loop to open-loop motor control is intuitively appealing, recent evidence suggests that part of becoming skilled may involve learning to use the afferent sources of information available more effectively (Elliott & Jaeger, 1988; Proteau, Marteniuk, Girouard & Dugas, 1987; Proteau, Marteniuk & Lévesque, 1992). The central representations that develop with practice may include rules for the utilization of sensory information including for example, visual feedback. Elimination of feedback then might be expected to affect a skilled performer as much or perhaps more than a novice.

Evidence for this second position comes primarily from studies in which subjects are given practice performing a manual aiming task under one set of feedback conditions, and then transferred to an augmented or degraded feedback situation. For example, the elimination of visual feedback has been shown to result in a deterioration in aiming performance after moderate practice (200 trials) with vision, and even greater disruption of aiming accuracy after extended practice (2000 trials) (Proteau et al., 1987). Thus, "the visual information available during acquisition became more important for movement control as the number of practice trials increased" (Proteau, 1992, p. 83; see also Elliott & Jaeger, 1988 and Proteau, Marteniuk & Lévesque, 1992).

The approach taken in the majority of this research has been to train subjects to a particular level of expertise on a laboratory task such as aiming. Another strategy for examining the role of practice in visual feedback utilization is to employ a novice-expert paradigm in which people of different skill levels are tested with and without the benefit of normal visual feedback (Weeks & Proctor, 1992). In the work reported here, we took this latter approach. Specifically, we compared the ability of novice and expert gymnasts to rapidly traverse a balance beam under a number of vision conditions.

While for manual aiming, visual and kinesthetic information about the position of the moving limb are the main sensory inputs, dynamic balance tasks such as beam-walking depend heavily on afferent inputs from neck muscles and vestibular apparatus for postural control (e.g., Lacour, Xerri & Hugon, 1978; Nashner & Wolfson, 1974). The relative importance of vision and these other sensory sources of information early and late in learning is unknown. Thus part of the motivation behind using an expert-novice paradigm with beam-walkers was to examine the generalizability of the results obtained in manual aiming studies to a task involving a richer array of sensory inputs.

Rather than restrict ourselves to a full vision - no vision comparison, we included a number of conditions in which intermittent visual samples of 20 ms were separated by various periods of visual occlusion. Our interest in intermittent vision stems from work on manual aiming (Elliott, Calvert, Jaeger & Jones, 1990; Elliott, Chua & Pollock in press; Elliott & Madalena, 1987) and locomotion (Assaiante, Marchand & Amblard, 1989; Laurent & Thomson, 1988) which suggests that intermittent visual pickup may be sufficient for reasonably precise movement control if the samples are available frequently.[1] In speeded beam-walking for example, stroboscopic visual samples every 80 ms were almost as good as full vision for novice beam-walkers. If some sort of representation of the movement environment provides spatial continuity between consecutive samples, (see Elliott, 1990 for a review) the viability of the representation may depend on the experience of the performer in that particular movement situation.

## Experiment 1

In this experiment, expert and novice gymnasts traversed a balance beam as quickly as possible in various vision conditions. As well as a full vision and a no vision condition, we employed liquid crystal visual occlusion spectacles to provide subjects with 20 ms visual samples of the movement environment every 80, 100, 120, 170, 250 and 500 ms. If, with practice subjects progress from a closed-loop to open-loop mode of control, visual occlusion should have less impact on expert performers than novice performers. In terms of the intermittent visual manipulation, experts would be expected to maintain performance with fewer visual samples. On the other hand, if part of becoming a skilled beam-walker involves learning to effectively use the sensory sources of information available during practice, then degrading vision may affect expert performers as much or more than novice performers.

# Method

## Subjects

Subjects were 10 female varsity gymnasts (experts, years of experience M = 15) and 10 female first year physical education students (novices). The balance beam experience of the novices consisted of successful completion of a physical education basic balance beam skill requirement. All subjects had normal or corrected-to-normal vision and were paid $10 for their participation.

## Apparatus and Procedure

A Federation of International Gymnastics regulation beam (5 m long, 10.5 cm wide) was used. However, the walking surface of the beam was only 21 cm above the ground. Pressure sensitive mats were placed at the beginning and end of the beam, even with the beam's surface. These mats were connected to a digital timer in order to measure the time it took subjects to cross the beam.

Liquid crystal occlusion goggles (Milgram, 1987) were used to manipulate vision. The lenses on these goggles were either transparent, allowing vision, or translucent, occluding vision without greatly affecting the quantity of light reaching the eyes. The lenses take less than 2 ms to change state. The goggles were interfaced with two banks of an interval timer. One bank controlled the open or transparent state and the other bank controlled the closed or translucent state of the lenses. Either bank could be left continually on (i.e., full vision and no vision conditions) or the two banks could be continually recycled providing the subject with intermittent vision at different frequencies. In this study, visual intermittence was manipulated by keeping the open duration constant at 20 ms and varying the closed duration. Thus, eight visual conditions were used: full vision, 12.5 Hz (20 ms open - 60 ms closed), 10 Hz (20 ms open - 80 ms closed), 8.3 Hz (20 ms open - 100 ms closed), 5.9 Hz (20 ms open - 150 ms closed), 4 Hz (20 ms open - 230 ms closed), 2 Hz (20 ms open - 480 ms closed) and no vision. These visual occlusion times were chosen to give us a closer look at the role of intermittent vision within the range of 4 Hz to 12 Hz, since it was in this frequency range that Assaiante et al. (1989) found the greatest changes in walking speed.

Each subject completed 11 blocks of 8 trials (88 trials), each block consisting of the 8 vision conditions. The first two blocks were practice and the two same random orders of the 8 vision conditions were maintained for all subjects. The remaining 9 blocks (72 trials) were test trials. Ten different random orders were used with a subject in each of the groups receiving an equivalent order.

Subjects were tested individually in a gymnastics gymnasium. On each trial subjects were positioned at one end of the beam with one foot on the beam surface and the other on the pressure sensitive pad. Prior to each trial the goggles were on top of the subject's head. When the subject was ready, she pulled the goggles into position and the vision manipulation was initiated. The subject then began walking across the beam as quickly as possible. Stepping off the mat at the beginning of the beam started the timer, which stopped when the subject reached the mat at the end of the beam. If the subject stepped off the beam before reaching the second mat the trial was discontinued and rerun.

One experimenter walked on the floor to the right of the subject holding a cord which attached the goggles to the interval timer and a remote power source. This experimenter was blind with respect to the vision condition on a particular trial. A second experimenter sat at a table midway along the beam, approximately 1.5 m away. This experimenter recorded the walking times and set the interval timer to control vision condition. While subjects were continually encouraged to walk as fast as possible without falling off the beam, they were given no feedback about their performance. Like Assaiante et al. (1989), time to cross the beam was the main dependent variable.

## Results and Discussion

Generally, subjects in both groups were able to perform the task without falling off the beam. The mean number of falls over the nine test trials are presented in Table 1. Subjects in both groups had few or no falls in the full vision and the intermittent vision conditions. While the experts seldom stepped off the beam even when vision was completely eliminated, novice beam walkers had more difficulty. These results parallel the movement time findings.

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**Insert Table 1 about here**

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Mean movement times based on nine trials were analyzed using a 2 Skill Level (expert, novice) by 8 Vision Condition (no vision, 2 Hz, 4 Hz, 5.9 Hz, 8.3 Hz, 10 Hz, 12.5 Hz, full vision) mixed analysis of variance. The analysis yielded a main effect of skill, $F(1,18) = 5.45$, $p<.05$, and vision condition, $F(7,126) = 9.28$, $p<.01$, as well as a skill by vision condition interaction, $F(7,126) = 3.31$, $p<.01$ (see Figure 1). Post hoc analysis of the interaction (Tukey HSD, $p<.05$) revealed that experts were faster than the novices in all conditions. For experts, movement times did not differ with vision condition, while novice subjects required more time to cross the beam when vision was completely eliminated. The only other pairwise comparison for novice subjects to approach significance was the difference between the full vision and the 2 Hz condition (critical difference at .05 = 1.27 s; obtained difference = 1.24 s). It would appear then that both novice and expert gymnasts maintained their beam walking performance reasonably well with only intermittent visual samples of the movement environment. While experts continued to perform well when vision was completely eliminated, novice gymnasts showed marked increase in the time to cross the beam.

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**Insert Figure 1 about here**

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The results of Experiment 1 failed to support the specificity hypothesis for visual information utilization in this motor skill (Elliott & Jaeger, 1988; Proteau et al., 1987). Although subjects in the expert group have practised balance beam walking for years with vision available, removing vision had very little effect on performance. This would suggest either sensory feedback including vision is less important, because over the years gymnasts may develop central representations to control their movements (e.g., Pew, 1966; Schmidt & McCabe, 1976), or that kinesthetic and vestibular information becomes more important than visual information as skill develops (Whiting & Savelsbergh, 1992).

An alternative explanation is that expert gymnasts have visual-spatial information available to them about the environmental layout even after vision is occluded, while novice beam-walkers do not. It is possible that since experts crossed the beam in 2-4 seconds, they were able to maintain a visual image and use it to guide them across the beam. It may be that the use of this visual image is responsible for experts' superior results when vision was eliminated. The purpose of Experiment 2 was to examine this possibility as well as to perform a more detailed analysis of beam-walking.

## Experiment 2

In Experiment 1 both novice and expert gymnasts performed reasonably well during the intermittent vision conditions. A number of investigators have suggested that during intermittent vision, a brief visual-spatial representation of the movement environment may be used to guide locomotion when direct visual contact with the task layout is prevented (Assaiante et al., 1989; Elliott, Jones & Gray, 1990; Laurent & Thomson, 1988). One possibility in Experiment 1 is that expert gymnasts were able to use a visual-spatial representation of the movement environment to guide locomotion when vision was completely eliminated. This was not a possibility for novice beam-walkers who crossed the beam in much greater movement times.

While there is some controversy regarding the duration (Elliott, 1986; Steenhuis & Goodale, 1988; Thomson, 1986), of this representation, the most liberal estimate is 8 seconds. Since the expert gymnasts traversed the beam in far less than 8 seconds even when vision was completely occluded, it is conceivable that they were able to use this indirect visual-spatial information before it had an opportunity to decay. For the novice performers, any representation may have deteriorated before they reached the end of the beam. Alternatively, it is possible that the contextual knowledge that expert beam-walkers bring to the task allows them to maintain information about the task layout for a longer period of time.

In Experiment 2, we examined this "visual representation" hypothesis by introducing a condition in which there was an 8 second no-vision delay prior to beam walking (see Thomson, 1983). Thus novice and expert beam walkers were required to cross the beam as quickly as possible with full vision, with vision eliminated immediately prior to walking, and with vision occluded 8 seconds prior to walking. Once again, the purpose of the 8 second no-vision delay was to allow time for any visual-motor representation of the movement environment to decay, making subjects more dependent on kinesthetic and motor sources of information.

As well, we decided to conduct a more detailed analysis of beam-walking form. Although subjects were once again instructed to cross the beam as quickly as possible, they were also instructed to maintain an upright posture. To assess beam-walking form, subjects were filmed over the duration of the whole experiment to obtain the frequency of various balance errors in each of the three conditions. In order to eliminate the possibility that the group differences in Experiment 1 were due to confidence and/or fear of injury (Wyrick, 1970), mats were placed even with the surface of the beam on all sides.

## Method

### Subjects

Subjects were 9 female varsity gymnasts (experts, years of experience M = 12) and 9 female physical education students (novices). Six of the experts had also participated in the first study. The balance beam experience of the novice walkers was identical to Experiment 1. All subjects had normal or corrected-to-normal vision and were paid $10 for their participation.

### Apparatus and Procedure

As in Experiment 1, a Federation of International Gymnastics regulation beam (5.0 m long and 10.5 cm wide) was used. However, in this study, gymnastics mats were piled even to the top surface making the effective height of the beam zero cm. This adaptation was designed to eliminate any fear of injury. Again, pressure sensitive mats were placed at the beginning and end of the beam to measure the time it took to cross the beam. As in Experiment 1 subjects were tested individually in a standard gymnastics gymnasium. In a full vision condition, the goggle lens remained in a transparent state, while in a second condition vision was occluded when subjects began their first step to cross the beam (no vision). The third condition involved an 8 second no-vision delay prior to walking. In this situation the subject indicated to the experimenter when she was ready for the trial to begin, and the goggle lenses immediately closed. The experimenter timed an eight second interval after which an auditory tone indicated to the subject that she could begin walking, (no vision with delay). In the two no vision conditions, the goggles became transparent again when the subject stepped onto the mat at the end of the beam. The whole experiment was filmed to provide a record of the number of steps and form errors associated with each trial. Form errors were classified as unintentional deviations from a relaxed upright standing position. They included one or both arms being raised above horizontal, a leg being lifted to the side, or the waist or hips being noticeably bent. Once again, if the subject stepped off the beam before reaching the end of the beam the trial was discontinued and rerun.

Consistency between two scorers on one randomly chosen expert and novice subject in scoring form errors within each condition was 89% agreement or above.

Each subject completed 10 trials per condition. Ten different random orders were used with a subject in each of the groups receiving an equivalent order.

## Results

The three dependent measures analyzed in this study were mean movement time, mean number of steps and total number of form errors when crossing the beam. These measures were based on 10 trials and analyzed in three separate 2 skill level (expert,novice) X 3 vision conditions (full vision, no vision, no vision with delay) mixed analyses of variance. The results of these analyses are discussed in turn.

As well, the mean number of falls over 10 trials are presented in Table 2. Subjects in both groups had minimal or no falls with full vision. Both groups showed an increase in number of steps off the beam in the no vision and no vision with delay conditions although experts' values were considerably lower. There were more falls overall in this study than in Experiment 1. This finding may reflect the fact that subjects took more risks because the mats were even with the top of the beam, or the added difficulty of maintaining an upright posture. In any event, the number of falls data paralleled the results of the other dependent measures.

**Insert Table 2 about here**

## Mean Movement Time

Mean movement time analysis yielded a main effect of skill $F(1,16) = 22.88$, $p<.01$ and vision condition, $F(2,32) = 50.65$, $p<.01$ as well as a skill by vision condition interaction, $F(2,32) = 16.50$, $p<.01$ (see Figure 2). Overall, experts were faster than novices and performance was best with full vision. A post hoc analysis (Tukey HSD, $p<.05$) of the skill by vision condition interaction revealed that experts performed equally in all conditions, while the novices were inferior in the two no vision conditions. In contrast to Experiment 1, experts were not reliably faster than novice performers when vision was available.[2] There were no differences between the no vision and no vision with delay conditions in either group. These results parallel Experiment 1, and indicate that group differences in performance are not the result of experts differentially utilizing a short-lived representation of the movement environment.

**Insert Figure 2 about here**

## Mean Number of Steps

Analysis of the total number of steps to cross the beam yielded a main effect of skill, $F(1,16) = 15.11$, $p<.01$, and vision condition, $F(2,32) = 64.94$, $p<.01$, as well as a skill by vision condition interaction, $F(2,32) = 16.83$, $p<.01$.

As is evident in Figure 3, experts took fewer steps to cross the beam and the number of steps increased when vision was eliminated. Although this increase was significant for both groups, the impact of eliminating vision was greater for the novices.

**Insert Figure 3 about here**

Total Form Errors

The analysis of total form errors yielded a main effect for skill level, *F*(1,16) = 9.56, *p*<.01, and vision condition, *F*(2,32) = 78.32, *p*<.01, as well as a skill by vision interaction, *F*(2,32) = 5.26, *p*<.01. As can be seen from Figure 4, these results are similar to the number steps findings. Tukey *HSD* (*p*<.05) post-hoc analysis of the interaction indicated that experts and novices increased their form errors from full vision to no vision and the no vision with delay conditions, although there were no differences between the two no vision situations. Once again it would appear that experts did not benefit differentially from visual-spatial information maintained over the duration of the walk.

**Insert Figure 4 about here**

## Discussion

The primary purpose of this experiment was to determine if the absence of a vision - no vision difference in movement time for expert performers was the result of experts using a brief visual-spatial representation of the movement environment to guide their performance. As well, we wished to determine if a more detailed analysis of beam-walking might isolate specificity effects related to the types of errors expert beam-walkers are trained to avoid. Specifically, we examined form errors by recording how often subjects deviated from an upright posture. In terms of our primary purpose, we found that for all three dependent variables there were no reliable differences between the no vision and no vision with delay conditions for either group. The absence of a delay effect is consistent with other work examining locomotion (e.g., Elliott, 1986, 1987; Steenhuis & Goodale, 1988; cf. Thomson, 1983), and eliminates the possibility that no vision performance differences between experts and novices are due to the use of a short-lived visual representation of the movement environment by the former.[3] Moreover, the movement time results were consistent with Experiment 1, since experts were less affected by the elimination of vision than novice beam-walkers. Once again, this type of finding is difficult to reconcile with a strong specificity position which predicts greater deterioration in expert performance with the elimination of vision.

Of potentially greater importance were the findings derived from the film data. In contrast to the movement time data, experts took more steps and committed a greater number of form errors in the two no vision conditions than they did when full vision was available. Although this change/ deterioration in performance was not as pronounced as in novice performers, it still indicates that experts performed the beam-walking task quite differently to produce similar movement time performance. These results are problematic for models proposing a progression from closed-loop to open-loop control, since experts are apparently not depending on a stereotyped movement that has developed over years of practice.[4]

The sensitivity of the film data to detect vision - no vision differences in experts is probably related to one of the primary goals of beam-walking; that is, through training gymnasts attempt to eliminate any unintentional deviations from upright in their routine. Seldom would they be concerned with crossing the beam as quickly as possible. Thus specificity effects appear to be limited to the precise task that was trained (see Fischman & Schneider, 1985 and Fischman & Mucci, 1989 for similar results with ball catching).

## General Discussion

Taken together, the results of Experiments 1 and 2 create problems for both a specificity of learning model, (Elliott & Jaeger, 1988; Proteau, 1992) and motor learning models proposing a gradual progression from closed-loop to open-loop control. In terms of movement time, expert performers showed no deterioration in performance in either experiment when vision was eliminated. This is in spite of the fact that our experienced beam-walkers have spent hundreds of hours performing routines with full vision available.

When a more sensitive measure of performance was employed in Experiment 2, the expert beam-walkers did exhibit some decrement in performance when vision was occluded; that is, they committed more form errors. Although the form error results are not as damaging to the specificity position, the degree of deterioration was more pronounced in novice performers. This result is different from Proteau et al.'s (1987) findings with manual aiming, and could reflect either task differences or the type of experimental paradigm employed (i.e., a training vs. an expert-novice paradigm).

While initially the movement time results appear to support the closed-loop to open-loop transition model, the form error and number of steps results in Experiment 2 are even more damaging for this position. Specifically, expert subjects in Experiment 2 were able to maintain their movement times when vision was eliminated, by performing the beam-walking task quite differently (i.e., with more steps and more errors). The greater number of steps and errors in the no vision situations indicated that experts performed in anything but a preprogrammed, stereotyped mode. The fact that movement times were maintained in spite of the increase in errors suggests that part of becoming skilled involves developing the ability for rapidly and efficiently correcting movement errors. In the no vision situation, these corrections may be based on kinesthetic, vestibular or feedforward information (see Whiting & Savelsbergh, 1992). The idea that motor skill entails the development of efficient error correction procedures is compatible with kinematic manual aiming data from our laboratory (Chua & Elliott, in press; Elliott, Chua, Pollock & Lyons, 1993) which suggest that feedback-based adjustments become more continuous and less discrete with practice.

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# Author Notes

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# Footnotes

1 These vision-based performance commonalities between manual aiming and locomotion were a further motivation for extending the specificity of learning work to dynamic balance task.

2 Once again, this could be due to the change in the effective height of the beam, or added postural constraints.

3 Both groups of subjects could however, be using a relatively stable representation of the beam dimensions to guide performance.

4 These results also indicate that expert-novice differences are not due to stereotyped closed-loop control associated with neck and labyrinthine reflexes (see Brooks, 1986 for review).

Table 1

Mean Number of Steps Off the Beam During the Nine Test Trials

| Group | Vision Condition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No Vision | 2 Hz | 4 Hz | 5.9 Hz | 8.3 Hz | 10 Hz | 12.5 Hz | Full Vision |
| **Expert** | 0.3 | 0.1 | 0.5 | 0.2 | 0 | 0 | 0 | 0 |
| **Novice** | 2.4 | 0.5 | 0.4 | 0.4 | 0.4 | 0.2 | 0 | 0 |

## Table 2

Mean Number of Steps Off The Beam
During 10 Trials in Experiment 2

| Group | Vision Full | No Vision | 8s Delay |
|---|---|---|---|
| Expert | 0 | 1.7 | 1.5 |
| Novice | 0.3 | 5.6 | 3.7 |

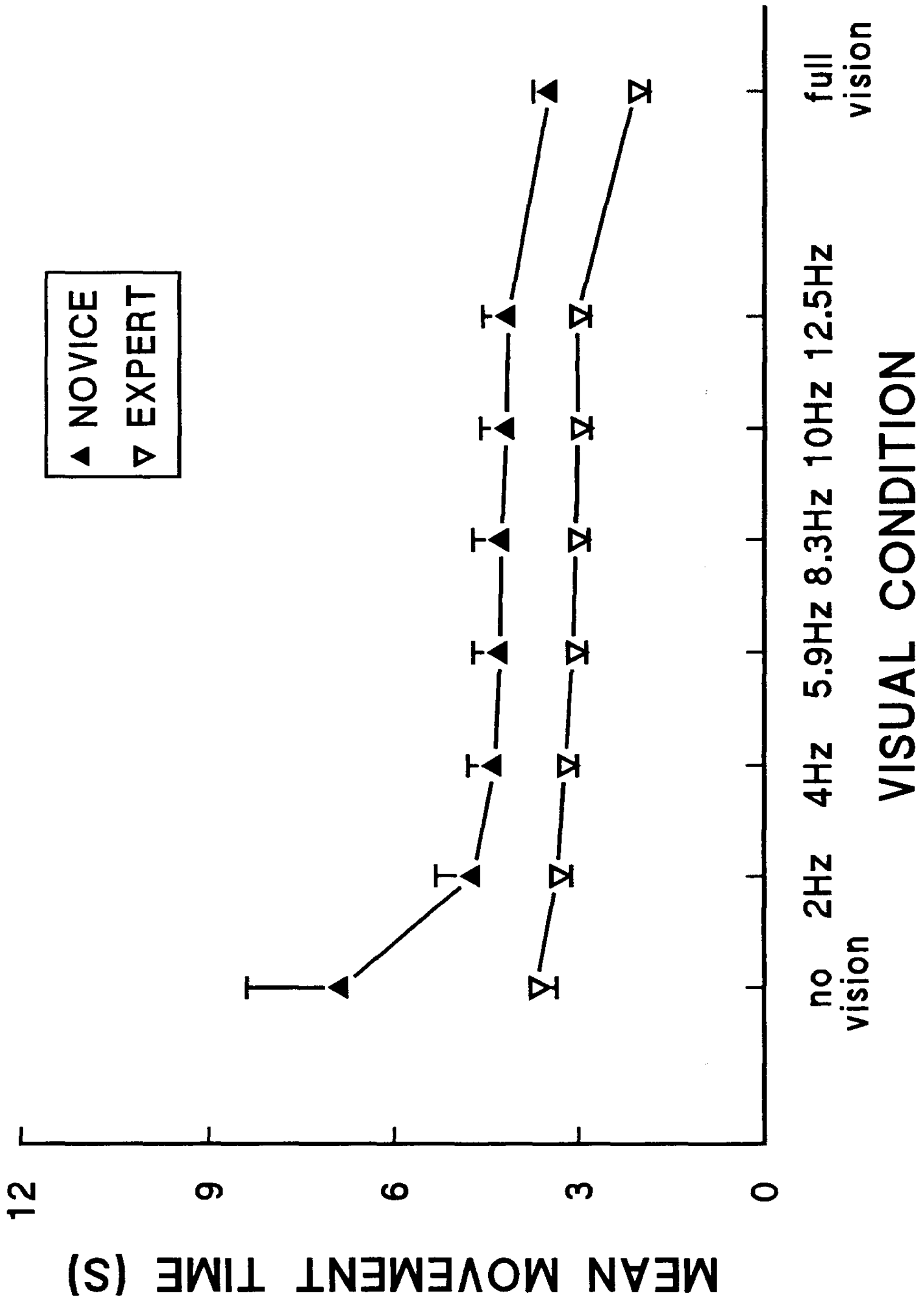
# Figure Captions

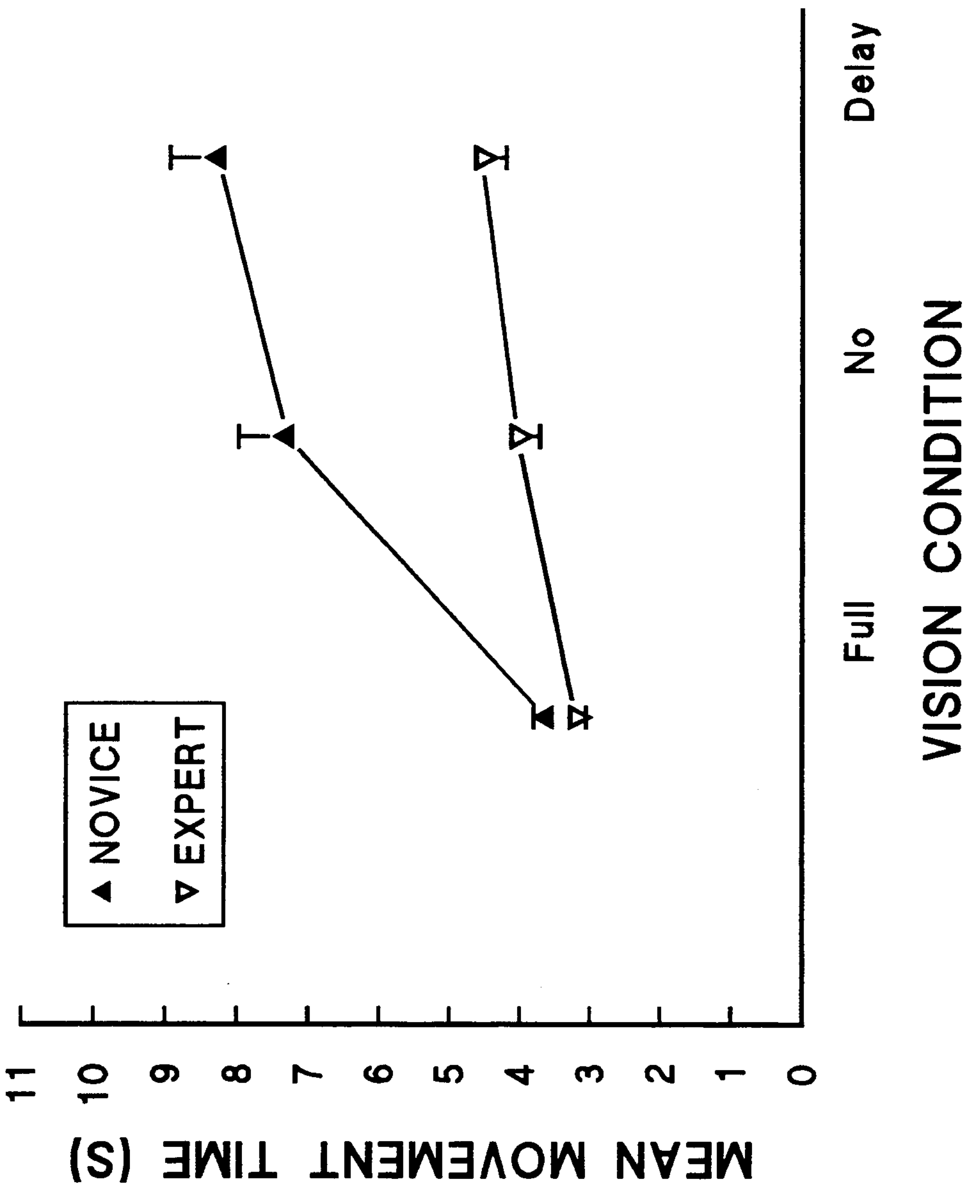
_Figure 1_. Mean movement time and standard error as a function of skill group and vision condition in Experiment 1.

_Figure 2_. Mean movement time and standard error as a function of skill group and vision condition in Experiment 2.

_Figure 3_. Mean number of steps and standard error as a function of skill group and vision condition in Experiment 2.

_Figure 4_. Total number of form errors and standard error as a function of skill group and vision condition in Experiment 2.


MEAN MOVEMENT TIME (S)
0
3
6
9
12
VISUAL CONDITION
no vision
2Hz
4Hz
5.9Hz
8.3Hz
10Hz
12.5Hz
full vision
▲ NOVICE
▽ EXPERT


MEAN MOVEMENT TIME (S)
0
1
2
3
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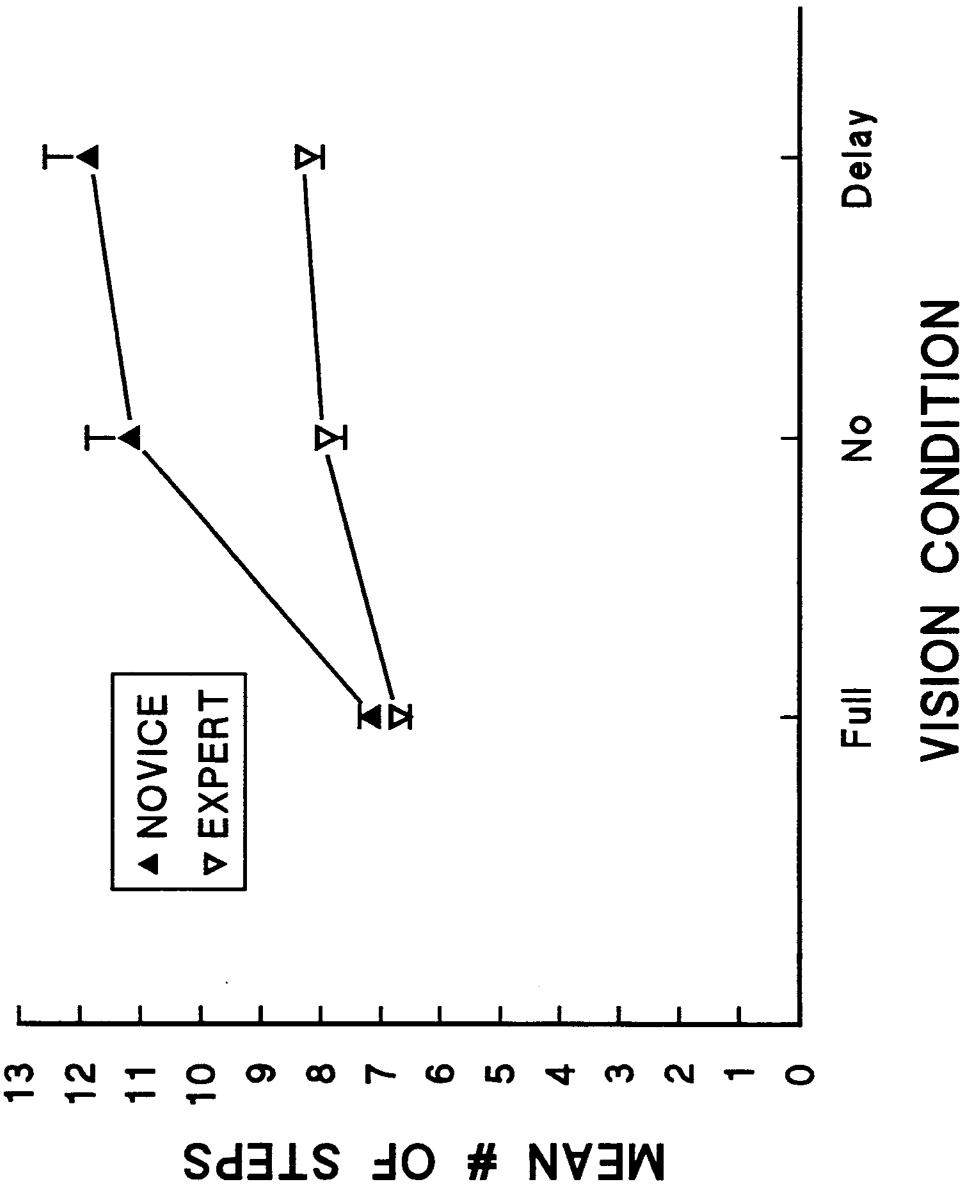
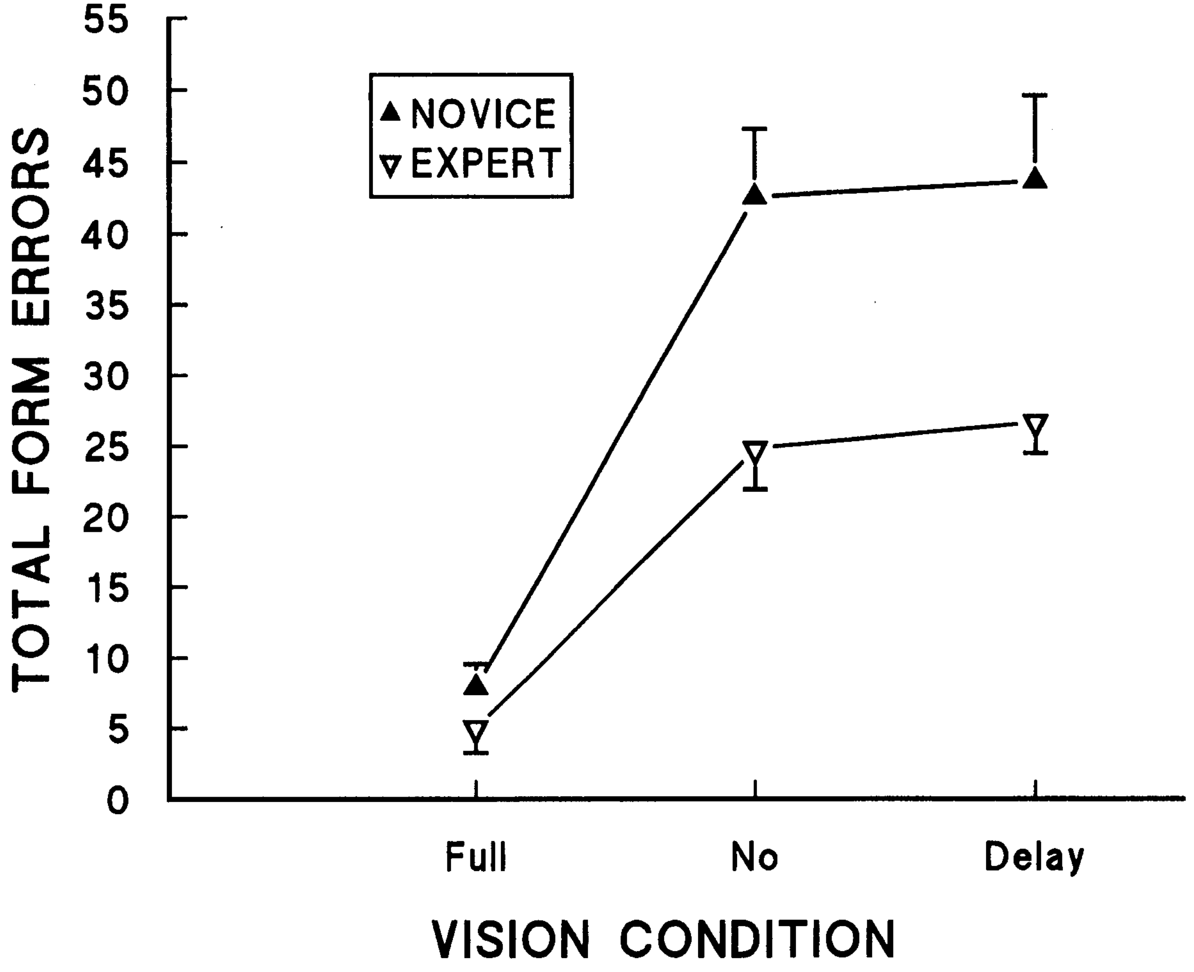
6
7
8
9
10
11
▲ NOVICE
▽ EXPERT
Full
No
Delay
VISION CONDITION


MEAN # OF STEPS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
▲ NOVICE
▽ EXPERT
Full
No
Delay
VISION CONDITION



TOTAL FORM ERRORS
55
50
45
40
35
30
25
20
15
10
5
0
▲ NOVICE
▽ EXPERT
Full
No
Delay
VISION CONDITION

# The Influence of Skill and Perturbed Visual Feedback on Dynamic Balance

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Running Head: DYNAMIC BALANCE

# Abstract

Previously, we showed that balance beam performance of expert gymnasts was less affected by the withdrawal of vision than the performance of novice gymnasts (Robertson, Collins, Elliott & Starkes, in press). Two experiments are reported in which expert and novice gymnasts were required to walk across a balance beam as quickly as possible. In Experiment 1, an expert-novice paradigm was employed and prism goggles were worn to introduce a visual perturbation. The results indicated that the perturbed vision degraded performance in both novice and expert subjects. In Experiment 2, a training paradigm was used in which novice subjects were trained either with vision or without vision. As well, a small group of experts were trained without vision. The results of this study indicate that subjects who trained with vision improved slightly more with vision, and subjects who trained without vision improved more without vision. No negative transfer effects were present. The findings in both Experiments are problematic for models proposing a progression with learning from closed-loop to open-loop control. At least to some extent, learning appears to be specific to the visual conditions in which the movement task was acquired.

# The Influence of Skill and Perturbed Visual Feedback on Dynamic Balance

Recently Robertson, Collins, Elliott and Starkes (in press) employed the task of balance beam walking to examine the importance of vision at different levels of expertise. In an initial experiment, expert and novice gymnasts performed the dynamic balance task of beam-walking under eight vision conditions. They performed with and without vision and in 6 situations involving intermittent vision. In these vision conditions 20 ms visual samples were provided either 2,4,6,8,10, or 12 times a second. The results revealed that experts' movement times were shorter than novices' in all vision conditions, with the greatest superiority when vision was completely eliminated. Novices were more dependent on vision and were able to maintain their performance as long as vision was available every 250 ms (i.e., 4 Hz).

The results of this study support two major theoretical positions concerning the role of feedback at different stages of skill development. One position introduced by Pew (1966) and extended by Schmidt and McCabe (1976) proposed that as skill level increases, sensory information becomes less important. This theory is based on the premise that during early practice, learners use feedback (closed-loop control) to develop a central representation of the movement which allows the movement to be carried out without using feedback (open-loop control) later in learning. The findings of Robertson et al. (in press), are in agreement with this position since the novice subjects needed the visual information to complete the task optimally, whereas the expert subjects were performing just as well with vision as without vision. This finding may be attributed to the fact that experts use a central representation that was developed early in learning to complete the task.

The results of Robertson et al. (in press) are also in agreement with another position which evolved from research by Fleishman and Rich (1963; see also Starkes, Gabriele & Young, 1989). This position proposes that visual information is very important in the early stages of learning but during the later stages, proprioceptive information becomes dominant. In the Robertson et al. (in press) study, novice subjects benefitted from the visual information and experts performed just as well without visual information. Thus if experts are at a later stage of learning, they may rely on proprioceptive information to complete the task.

Robertson et al. (in press) conducted a follow-up experiment which indicates that the findings may not fit quite as nicely into the two positions as originally thought. The goal of this second experiment was to conduct a more detailed analysis of beam-walking form and to examine the possibility that experts use a visual representation of the movement environment to cross the beam in the absence of vision.[1] In this experiment, two dependent measures (mean number of steps and total form errors) were added to mean movement time. The results revealed that even though experts were crossing the beam in the same amount of time with or without vision, they displayed an increase in number of steps and total form errors when vision was occluded. These results indicated that experts' performance was degraded or at least changed without vision even though their movement times were unaltered. Thus, experts were not performing in a stereotypical manner. This finding is in contrast to Schmidt and McCabe's (1976) position that well-learned movements are preprogrammed. As well, these findings contradict the position suggesting the dominant role of proprioception with increased learning, because proprioceptive and vestibular information alone were not enough to produce a performance similar to the full vision condition.

A third position was forwarded by Proteau, Marteniuk, Girouard and Dugas (1987) and supported by Elliott and Jaeger

(1988) to explain the role of sensory information as learning progresses. This specificity of learning theory predicts that the sensory information used early in learning will also be the most valuable information as learning continues. The results of Robertson et al. (in press) provided some support for this position since experts' performance (measured by # of steps and form errors) was degraded when they were transferred to a condition with which they had little experience (no vision). However, this finding does not support a strong specificity position, which would predict that the more practice at a task, the greater the dependence on the sources of information available during practice. Thus a moderate practice group would have less deterioration in performance, when switched to sensory conditions to which they were not exposed, than a high practice group (e.g., Proteau et al., 1987). In Robertson et al. (in press), both novice and expert groups' prior experience was with vision yet the novices' performance was slightly poorer without vision than the experts'. A strong specificity position (see Weeks & Proctor, 1992), would predict that the experts' performance with no vision would be poorer than the novices' performance with no vision because the experts have spent more time learning with vision, and hence should have developed a greater dependence on vision.

As Proteau (1992) points out, this strong specificity position may only hold for certain types of tasks. Thus, the findings of Robertson et al.'s (in press) Experiment 2 provides partial support for the specificity of learning position. A strong test of Proteau's (1992) theory would be to learn with degraded sensory information (no vision) and transfer to augmented sensory information (vision) to determine if performance is still negatively affected.

One of the differences between the studies investigating this issue has been the type of paradigm employed. In our initial work (Robertson et al., in press) and the work of others (Starkes et al.,1989), a novice-expert paradigm was used in which experts had a history of specific training. The disadvantage of this type of paradigm is that the manner in which the experts achieved their level of expertise in balance beam walking was not monitored or controlled. In the case of the Robertson et al. (in press) study, the experts' performance was similar with vision and without vision. Perhaps, during the experts' training, they also learned some strategies that could be used in a no vision situation. This possibility may be eliminated if the learning phase is more controlled such as in a training experiment in which all subjects in a particular condition are trained in the same way (e.g., Elliott & Jaeger, 1988; Proteau et al., 1987, 1992).

The two experiments reported here were designed to further explore the changing role of vision during skill acquisition. In Experiment 1, an expert-novice paradigm was employed in order to determine how expert beam walkers would use vision when it was distorted. In this study prism goggles were employed to introduce a visual perturbation that would be expected to disrupt beam walking performance only if visual information is being used to perform the beam walking task.

In Experiment 2, the subjects were trained to walk the beam with or without vision then transferred to the condition which they did not practice. This approach allows tighter experimental control over the learning history of the subjects.

## Experiment 1

Alternative theories dealing with this issue of feedback and skill suggest a switch from closed-loop to open-loop control with practice (Pew,1966) or a greater reliance on kinesthetic as opposed to visual information as training progresses (Fleishman & Rich, 1963). Robertson et al.'s (in press) work initially appears to support these theories. A closer investigation through a more in depth analysis of the skill suggests this might not be the case. Now a specificity of learning position is supported because experts performed the task differently when vision was eliminated as evidenced by a deterioration in form.

In the following experiment vision was perturbed through the use of prism goggles. The goggles displaced the visual field 15 degrees to the right or to the left, depending on which way the base of the 25 dioptre prism was turned. The assumption of the first two theories is that if vision is no longer important to experts, then displaced visual information should not hinder the expert gymnasts. The reason is because they would not be depending on visual information. If this is the case, perturbed vision should have little or no effect on experts and a drastic negative effect on novices.

## Method

### Subjects

Subjects were 9 female varsity gymnasts (experts, and 9 female physical education students (novices). The balance beam experience of the novice subjects was successful completion of a physical education basic balance beam skill requirement. Expert gymnasts had competed for 7 - 12 years and participated in an earlier study. Subjects ranged in height from 155 cm to 175 cm and had normal or corrected-to-normal vision. Subjects were paid $10 for their participation.

## Apparatus and Procedure

The apparatus was a Federation of International Gymnastics regulation beam (5.0 m long, 10.5 cm wide). An effective height of 0 cm was created by arranging mats around the beam so they came even with the top surface. Pressure sensitive mats were placed at the beginning and end of the beam even with the beam's top surface. These mats were connected to a digital timer in order to measure the time it took subjects to traverse the entire beam length.

Subjects were required to walk across the beam as quickly as possible in four visual conditions: full vision, no vision, vision displaced 15 degrees to the left and 15 degrees to the right. A 25 dioptre prism secured to welder's goggles was positioned over the left eye The right side of the goggles was covered. The prism displaced the view of the beam approximately 15 degrees to the right or left depending on which way the experimenter rotated the prism. To achieve the no vision condition a circular piece of felt was placed in the goggles on the side with the prism. The full vision condition was binocular in the previous experiments (Robertson et al., in press), but was monocular in this experiment (by removing the prism from the left eye) so as to be comparable with the perturbed condition which involved only use of the left eye. Two directions of displacement were used so that the subjects would not be able to predict the direction of the displacement and adapt to the prismatic displacement ( e.g., Held & Freedman, 1963). Prior to a trial, the subjects were instructed to lift the goggles up until they felt comfortable then put them down and begin walking.

The subjects' task was to walk as quickly as possible without stepping off the beam, while maintaining an upright posture. Stepping off the mat at the beginning of the beam started the timer which stopped when the subject reached the mat at the end of the beam. If the subject stepped off the beam before reaching the second mat, the trial was discounted but recorded as an error then rerun.

Each subject completed ten trials per condition. Nine different random orders were used with a subject in each of the two groups receiving an equivalent order.

Subjects were tested individually in a standard gymnastics gymnasium. One experimenter stayed near the subject to ensure safety, to count the number of steps to cross the beam and to manipulate vision. A second experimenter sat at a table midway along the beam, approximately 1.5 m away. This experimenter recorded the walking times and number of steps as well as informed the other experimenter of the upcoming visual conditions. Subjects were filmed with a Sony V8 camera that was placed approximately 3.0 m away from the end of the beam facing the subject. While subjects were continually encouraged to walk as fast as possible without stepping off the beam, they were not given feedback about their performance.

## Results

The dependent measures were mean movement time, mean number of steps, and total number of form errors while crossing the beam. These measures were analyzed in separate, 2 skill level (expert,novice) X 4 vision conditions (full vision, no vision, displaced left and displaced right vision) mixed analyses of variance.

The mean number of incomplete trials per condition due to stepping off the beam are presented in Table 1. Both groups had few or no falls in the full vision condition. Generally, the task was performed well, but the number of missed trials increased as vision was removed and distorted. In the no vision and displaced vision conditions, novices stepped off the beam twice as many times as experts. It is also important to note that displacement to the right and left had a similar affect. These data parallel the results of the other dependent measures.

**Insert Table 1 about here**

## Mean Movement Time

The movement time analysis revealed main effects for skill level, _F_(1,16) = 6.72, _p_<.02, and vision, _F_(3,48) = 39.42, _p_<.01, as well as a skill by vision interaction, _F_(3,48) = 4.27, _p_<.01. Once again, experts performed faster and performance for both groups was best with full vision. Intuitively, no difference between left and right displacement was anticipated. Thus, a weighted means analysis for which the two perturbed conditions were pooled was employed to post hoc the interaction. Experts showed similar performance with full vision and no vision, _p_>.10, but performance with full vision was better than the displaced conditions, _F_(1,48) = 25.21, _p_<.001. Similarly, movement times were shorter with no vision than in the displaced conditions, _F_(1,48) = 11.49, _p_<.005. As well, the novices showed better performance with full vision than with no vision, _F_(1,48) = 7.64, _p_<.01, full vision than with displaced vision _F_(1,48) =100.62, _p_<.001, as well as better performance with no vision than in the displaced vision conditions, _F_(1,48) = 20.29, _p_<.01 (see Figure 1).

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**Insert Figure 1 about here**

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Mean Number of Steps

The total number of steps analysis yielded main effects for skill level, F(1,16) = 12.25, p<.01, and vision, F(3,48) = 80.79 p<.01, as well as the skill by vision interaction, F(3,48) = 11.23, p<.01. As is obvious from Figure 2, experts took fewer steps than novices and the number of steps increased from the full vision to the no vision situation. Results revealed that experts did show a slight, but significant decrease in steps with full vision as compared to the no vision condition, F(1,48) = 4.14, p<.025 , and a large increase in steps from full vision to displaced vision conditions, F(1,48) = 52.90, p<.001. As well the number of steps increased from no vision to the displaced vision conditions, F(1,48) = 10.28, p<.001. Similarly, novices took fewer steps with no vision than displaced vision, F(1,48) = 5.36, p<.025, and with full vision than with displaced vision, F(1,48) = 214.92, p<.001 . As well, they took fewer steps in full vision as compared to the no vision condition, F(1,48) = 38.10, p<.001 (see Figure 2).

**Insert Figure 2 about here**

Total Form Errors

The total form errors analysis yielded a main effect for skill level, F(1,16) = 19.41, p<.01, and vision, F(3,48)

= 136.98, *p*<.01, as well as a skill by vision interaction, *F*(3,48) = 6.08, *p*<.01. As in previous work (Robertson et al., in press), experts committed fewer form errors than novices and form errors increased when vision was eliminated and displaced. In contrast to the movement time analysis, a post hoc analysis revealed that experts showed an unexpected large increase in form errors from full vision to no vision, *F*(1,48) = 11.19, *p*<.005, as well as fewer form errors with no vision than displaced vision, *F*(1,48) = 28.13, *p*<.001. Likewise, fewer form errors were evident with full vision than with displaced vision, *F*(1,48) = 144.02 ,*p*<.001. Similarly, novices showed typically large increase in form errors when vision was eliminated, *F*(1,48) = 36.53, *p*<.001, as well as fewer form errors with full vision than with displaced vision, *F*(1,48) = 277.88, *p*<.001. Also, novices committed fewer form errors with no vision as compared to the displaced vision conditions, *F*(1,48) = 20.99, *p*<.001 (refer to Figure 3).

**Insert Figure 3 about here**

## Discussion

The primary purpose of this study was to examine the indication of earlier studies that visual information is not necessary for experts to perform the task successfully. To examine this position, we perturbed visual information from the movement environment with a prism spectacle. If experts no longer use visual information (since their movement time performance is similar with or without vision) then displaced visual information should not disrupt their performance. However, the results revealed that experts showed a deterioration in performance across all dependent measures when vision was displaced. Specifically, movement time was shorter with full vision and no vision as compared to displaced vision. As well, fewer steps were taken to cross the beam with full vision and no vision than with displaced vision and more form errors were committed with displaced vision than with full or no vision. Thus when vision was available in any form subjects could not ignore it.

The finding that subjects favour vision over kinesthetic and vestibular information, even when it is misleading, is compatible with other work examining postural control (Lee & Aronson, 1974; see also Lee & Lishman, 1975). This visual dominance may reflect an attentional bias toward vision related to its relatively weak alerting properties (Posner, Nissen, & Klein, 1976).

While even misleading vision demanded attention when it was available, the form error data provide important information on control processes when it was occluded. As Robertson et al. (in press) have suggested, total form errors may be a more sensitive dependent measure than movement time since form errors provide information about how the beam-walking is being performed. With this in mind, the most striking finding of this experiment was the large increase in form errors from full vision to no vision in experts. This finding indicates that the quality of performance deteriorates once vision is removed. If it can be assumed that experts train primarily with their eyes open, this decrement in performance provides support for the specificity of learning hypothesis. One would think that since experts had much more practice with full vision they would have a larger dependency, hence greater deterioration with the elimination of vision than novices (Proteau et al.,1987). This was not the case. Perhaps this occurred because the learning environment of the expert subjects was not controlled. It may be that while vision is important throughout learning, so is the detection of balance errors through the vestibular system, neck and labyrinthine reflexes, proprioception and feedforward information. Thus the increased dependence on vision in experts may be absent because, in this task, alternative strategies were simultaneously learned and were used in the absence of vision to maintain a similar performance. It seems as though some combination of specificity of learning and a change in the ability to use specific sensory information with increasing expertise is probable.

When comparing the different dependent measures it is intriguing to realize that although experts are crossing the beam in the same movement time in the no vision and full vision conditions, they are taking more steps and making many more form errors and subsequent corrections. Perhaps experts are faster or more efficient at correcting errors.

## Experiment 2

Movement time results in Experiment 1 and the Robertson et al. (in press) studies provided little support for Proteau et al.'s (1987) specificity of learning position. However, when more sensitive measures of performance were examined such as form errors and number of steps to cross the beam the situation changed. It became apparent that expert gymnasts were not expert at walking across the beam as quickly as possible, but were expert at crossing the beam with few form errors or unintentional deviations from upright.

Specifically, the results of Robertson et al.'s (in press) form error analysis revealed vision condition effects that are somewhat compatible with the specificity hypothesis; that is, experts who presumably train with full vision did show an increase in form errors when transferred to no vision conditions. One of the main differences between Proteau et al.'s work and this study is the differences in tasks (aiming vs. dynamic balance) which lead to the use of different dependent measures. Perhaps, the form error measures of this study are the best comparison to the variable and constant error measures used by Proteau et al.

In Experiment 1, both experts and novices showed deterioration in performance in the displaced vision condition. This finding is incompatible with the position that, with training, proprioception becomes the dominant source of sensory feedback. If proprioception becomes dominant it would override the perturbed visual information and performance would not be negatively affected.

As well, the switch from closed-loop to open-loop theory would predict that experts become less dependent on response-produced feedback as practices progresses. Therefore they should be able to perform the task regardless of the visual circumstance since a central representation may provide the basis for performance. Although motor programs have been used to explain this closed-loop to open-loop phenomenon in short (< 1 sec) aiming tasks, they may not apply to the dynamic balance task used in this study which took place over 2-8 seconds.

At this point, the number of steps and form error data as well as the perturbed vision experiment provide evidence against the Pew (1966) and Fleishman and Rich (1963) positions. Robertson et al.'s (in press) Experiment 2 and Experiment 1 of this paper, provided partial support for the specificity of learning position. Thus further investigation into this position is warranted.

Besides the type of task under consideration, the major difference between Proteau et al.'s (1987) experiments and Robertson et al.'s work (in press) was the training paradigm employed. The one disadvantage of the expert-novice approach used by Robertson et al. is the fact that the training experience of the experts was not controlled. In the training paradigm used by Proteau et al. (1987), all subjects begin at the same level and progress and learn in the same manner. Thus, the only factors affecting learning are those that are experimentally manipulated. Experiment 2 employed Proteau et al.'s (1987) approach. Novice subjects were trained either with or without vision for 30 trials (moderate practice) and later, 330 trials (high practice) to examine the effect of training on performance after different amounts of practice. All subjects' performance was recorded with and without vision initially, after 30 trials and after 330 trials. According to the specificity position the subjects who trained with no vision were expected to perform better with no vision than with vision, and the group that trained with full vision was expected to perform better with full vision than with no vision. Poorer performance was expected after extensive practice than after moderate practice when subjects were tested in the condition in which they did not train. For example, the group that trained with no vision were expected to perform poorer with vision after moderate practice and even poorer with vision after extensive practice. As in previous studies, the subjects were trained either with vision or without vision.

## Method

### Subjects

The subjects were 20 female physical education students (novice) with little prior experience on the balance beam and 5 female competitive gymnasts (experts, years experience M = 6). Only 4 competitive gymnasts were used in the analysis since after the study was complete, one of the subjects volunteered that she had inner ear problems which affected her balance without vision. Subjects had normal or corrected-to-normal vision and were paid $20.

### Apparatus and Procedure

The experimental set up and data collection procedures were identical to Experiment 1.

However, in this experiment two vision conditions were involved. The full vision condition consisted of walking across the length of the beam with the eyes open. The no vision condition consisted of walking across the beam with blackened ski goggles. Twenty novice female subjects were randomly assigned to one of two training conditions:

1) 10 subjects who practised with full vision and transferred to no vision.

2) 10 subjects who practised with no vision and transferred to full vision.

The study was conducted over five days. On day one, 10 full vision trials and 10 no vision trials were recorded initially for each subject to represent a baseline. Thirty trials were then performed to represent a moderate practice schedule. On day two, 10 full vision trials and 10 no vision trials were recorded again to examine the effect of moderate practice from day one. Then 100 trials, in their respective training conditions, were performed. On day three and four subjects practised 100 trials (each day) in their appropriate training condition. Finally, on day five, 10 trials with full vision and 10 trials with no vision were recorded. On the trials that were recorded, the order of the vision conditions was counterbalanced within each group.

Four experts followed the same training protocol as the subjects who trained with no vision. Three subjects performed the 10 no vision trials first, followed by 10 full vision trials and 1 subject completed the recorded trials in the opposite order.

Subjects were tested individually in a standard gymnastics gymnasium. The recorded trials were filmed on days 1, 2, and 5 with a Sony V8 camera that was placed approximately 3 m from the end of the beam. One experimenter sat at a table midway along the beam approximately 1.5 m away and recorded the number of training trials and movement times. Subjects were also given feedback about their movement times after every trial during acquisition, but were not given feedback on any of the transfer trials.

## Results

the four dependent measures analyzed in this study were mean movement time, mean number of steps, total number of form errors and percent improvement in mean movement time. These measures were based on 10 trials and the first three dependent measures were analyzed in three separate 2 groups (trained with full vision, trained with no vision) X 2 vision conditions (vision, no vision) X 3 times (pre, day 2, day 5) mixed analyses of variance. The percent improvement in mean movement time was analyzed in a 2 group (trained with full vision, trained with no vision) X 2 vision conditions (full vision, no vision) X 2 times (day 2, day 5) analysis of variance. Also, a 2 group (novice trained with no vision, expert trained with no vision) X 2 vision conditions (vision, no vision) X 3 times (pre, day 2, day 5) mixed analysis of variance was performed for each of the first the three dependent measures. The percent improvement in mean movement time was analyzed using a 2 group (novice trained with no vision, experts trained with no vision) X 2 vision conditions (vision, no vision) X 2 times (day 2, day 5) mixed analysis of variance.

## Vision-No vision Training Analyses

### Mean Movement Time

Mean movement time analysis yielded a main effect of day, $F(2,36) = 58.22$, $p<.001$, and vision condition, $F(1,18) = 115.36$, $p<.001$. This indicates that, overall, both groups improved their movement times over the days and both groups performed faster with vision than without vision. As well, there was a group by day, $F(2,36) = 3.48$, $p<.05$, a day by condition, $F(2,36) = 37.47$, $p<.001$ and a group by day by condition interaction, $F(2,36) = 5.33$, $p<.01$. A Tukey HSD ($p<.05$) post hoc analysis of the group by day by condition interaction indicated that in the vision condition, there were no differences between groups or with increasing practice. In the no vision condition, there were no differences between training groups in the beginning, and both groups improved with practice. The group which trained without vision decreased their movement times with moderate practice and even more with high practice while the group which trained with vision, only decreased their movement times after high practice. It appears that only the no vision group conformed to the specificity position by improving more with the sensory information they trained with (no vision) than the sensory information they did not train with (vision) (see Figure 4).

**Insert Figure 4 about here**

Mean Number of Steps

Analysis of the mean number of steps to cross the beam yielded a main effect of day, $F(2,36) = 58.36$, $p<.001$, and condition, $F(1,18) = 243.23$, $p<.001$. Again both groups took fewer steps with increasing practice and both groups took fewer steps with vision. In addition, there was a day by condition interaction, $F(2,36) = 25.58$, $p<.001$, and a group by day by condition interaction, $F(2,36) = 15.28$, $p<.001$. A post hoc (Tukey HSD, $p<.05$) analysis of the group by day by condition interaction revealed that, in the vision condition the groups differed on every day but this difference increased since the group that trained with vision reduced their number of steps with moderate practice and high practice from their baseline. The group that trained with no vision did not reduce their number of steps to cross the beam. In the no vision condition, the groups were slightly different initially but were not different with moderate practice and were most different with high practice. This was because the group that trained with no vision improved from baseline to day 2 and took even fewer steps from day 2 to day 5. The no vision trained group's improvement was larger than the group who trained with vision since the vision trained group only improved from their baseline after five days. Again these findings are in agreement with the specificity position (see to Figure 5).

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**Insert Figure 5 about here**

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Total Form Errors

The analysis of total form errors yielded a main effect for day, $F(2,36) = 14.64$, $p<.001$, and condition, $F(1,18) = 124.67$, $p<.001$. Similar to all other dependent measures both groups decreased their form errors with practice and performed better with no vision. Again there was a day by condition interaction, $F(2,36) = 14.35$, $p<.001$ and a group by day by condition interaction, $F(2,36) = 5.11$, $p<.01$. Tukey HSD ($p<.05$) post hoc analysis of the group by day by condition interaction demonstrated that in the vision condition there were no differences between groups on any day. In the no vision condition, there were no differences between groups initially but they became different with moderate practice and this difference increased with high practice. Again the group that trained without vision decreased their form errors within each practice level but the group that trained with vision only decreased their form errors after high practice. Once again, only the group that trained with no vision conformed to the specificity position, because they improved more with no vision than they did with full vision (see Figure 6).

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**Insert Figure 6 about here**

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Percent Improvement in Mean Movement Time

It is evident that there is somewhat of a ceiling effect in the vision condition since the subjects were performing well at baseline. In an attempt to determine if this artefact eliminated specificity effects in the vision group, the percent improvement was calculated and analyzed. To calculate percent improvement in mean movement time, the mean movement time on day 2 was subtracted from the mean movement time on day 1, then this value was divided into the mean movement time on day 1 to get a percentage increase of day 2 over day 1. The same procedure was performed using the day 5 mean movement times. The analysis of these data yielded a main effect for day, $F(1,18) = 74.40$, $p<.001$, and condition, $F(1,18) = 20.70$, $p<.001$. Again both groups showed improvement with increasing practice and greater improvement was evident in the no vision condition. There was also a group by condition interaction, $F(1,18) = 13.32$, $p<.01$, and a group by day by condition interaction, $F(1,18) = 4.12$,$p<.055$. A post hoc (Tukey HSD, $p<.05$) analysis of the 3-way interaction revealed an increase in percent improvement in mean movement time from day 2 to day 5 was evident in the vision condition but only by the group that trained with vision. In the no vision condition, the no vision group improved more initially and both groups' improvement increased from day 2 to day 5. Using % improvement values, a specificity position is now supported in the vision condition (see Figure 7). Although when using only mean movement time values, the vision group's overall performance was so good that no changes were evident.

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**Insert Figure 7 about here**

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## Expert-Novice Training Analyses

### Mean Movement Time

The analysis of mean movement time yielded a main effect for group, F(1,12) = 28.54, $p<.001$, day, F(2,24) = 23.32, $p<.001$, and condition, F(1,12) = 49.55, $p<.001$. Experts performed faster, both groups improved with practice and both groups performed more quickly with vision. There were also a number of interactions including group by day, F(2,24) = 5.41, $p<.01$, group by condition, F(1,12) = 15.12, $p<.01$, day by condition, F(2,24) = 20.69, $p<.001$ and lastly, group by day by condition, F(2,24) = 6.23, $p<.01$. A Tukey HSD ($p<.05$) post hoc analysis of the group by day by condition interaction revealed that in the vision condition there were no differences between groups on any of the days. In the no vision condition, experts' movement times were always shorter than novices' but novices improved with each level of practice whereas the experts only improved from their baseline level with high practice. Thus experts showed similar results to the novices although they had less room for improvement (Figure 8).

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**Insert Figure 8 about here**

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### Mean Number of Steps

The analysis of the number of steps data yielded a main effect for group, $F(1,12) = 51.80$, $p<.001$, day, $F(2,24) = 27.78$, $p<.001$, and condition, $F(1,12) = 83.87$, $p<.001$. Thus, experts took fewer steps to cross the beam, both groups decreased their number of steps with practice and more steps were taken in the no vision condition. There was also a group by condition interaction, $F(1,12) = 22.52$, $p<.001$ and a day by condition interaction, $F(2,24) = 26.18$, $p<.001$. A post hoc (Tukey HSD, $p<.05$) analysis of the group by condition interaction showed that novices and experts took the same number of steps with vision but experts took fewer steps than novices when vision was eliminated. Analysis of the day by condition interaction revealed that fewer steps were taken with full vision and performance with full vision did not improve with practice. Both groups decreased their number of steps with each level of practice with no vision. Again, the ceiling effect in the full vision condition may be responsible for this pattern of results (see Figure 9).

**Insert Figure 9 about here**

## Total Form Errors

The analysis of total form errors yielded a main effect for day, *F*(2,24) = 6.74, *p*<.005, and condition, *F*(1,12) = 42.28, *p*<.001. Both groups decreased their form errors with practice and more form errors were committed with no vision than with full vision. As well, there was a group by day interaction, *F*(2,24) = 4.35, *p*<.025, a day by condition interaction, *F*(2,24) = 7.03, *p*<.005, and a group by day by condition interaction *F*(2,24) = 4.81, *p*<.02. As is evident in Figure 10, group differences were most pronounced in the no vision condition. A post hoc (Tukey *HSD*, *p*<.05) analysis of the group by day by condition interaction revealed that, in the vision condition, experts and novices produced the same number of form errors over all practice levels and neither group reduced their form errors with practice. However, in the no vision condition, initially experts exhibited fewer form errors than novices but after moderate and high practice experts and novices displayed similar numbers of form errors. Experts did not decrease their form errors with practice while the novices did so after each practice session. Again, since both groups trained with no vision and are showing more improvements in the no vision condition, a basic specificity position is supported.

**Insert Figure 10 about here**

Percent Improvement in Mean Movement

Again percent improvement in mean movement time was analyzed in an attempt to examine differences that might be concealed due to a ceiling effect when the task was performed with vision. This analysis yielded a main effect for day, *F*(1,12) = 41.76, *p*<.001 and a main effect for condition, *F*(1,12) = 39.77, *p*<.001. Thus movement times improved with practice and improvement was greatest in the no vision condition. There was also an interaction between day and condition, *F*(1,12) = 14.57, *p*<.01. A Tukey *HSD* (p<.05) post hoc analysis of this interaction revealed that there was greater improvement in movement time with no vision and that percent improvement in movement times increased with practice (see Figure 11). This time both groups responded identically, supporting the specificity position.

**Insert Figure 11 about here**

## Discussion

The purpose of this experiment was to employ a training paradigm in order to eliminate the possibility of unaccounted for variables affecting experts' performance in the previous studies. As well, a strong test of the specificity position was introduced by comparing performance after moderate and extensive practice. In this experiment, novices were trained to the level of expert gymnasts, with either full vision or no vision. Some constraints were encountered in the full vision condition because a very high level of beam walking performance was reached at the beginning. Therefore, there was limited room for improvement. This ceiling effect may have concealed some of the relative changes in performance although analysis of percent improvement did prove to be more sensitive. It does appear, with all dependent measures, that more improvements were evident with no vision in the group that trained with no vision and vice versa. These results conform to the specificity of learning position although no negative transfer was evident. Specifically, the group that trained with no vision improved with no vision but was not adversely affected when vision was available. The full vision conditions were never degraded by no vision training.

When considering the effect of differing amounts of practice, the high practice group did not show more deterioration in the condition not practised than the moderate practice group. In fact either no change or an improvement in performance was evident with increasing practice. Thus the results of this study provide only partial support for Proteau et al.'s (1987, 1992) specificity of learning position. This study did not support a strong specificity position. However, this may be due to the differences in tasks (cf. Proteau et al., 1987). In the present study, the task of beam-walking is a whole body movement that involves postural control and maintaining balance as well as speed and accuracy normally measured in the typical pointing tasks. It may be that other control mechanics such as reflexes (neck and labyrinthine) required in this balancing-type task are responsible for differences between our studies.

The expert - novice analysis revealed that novices and experts did demonstrate a specificity effect, improving mean movement time more in the no vision condition, which is the condition in which they trained, than in the vision condition. The improvement of experts was slight and only occurred after 5 days of practice, while novices improved drastically. The specificity effect present in the experts may be due to the fact that the experts in this group were less experienced (M=6 yrs) than participants in previous experiments conducted in our laboratory (i.e., M=12 yrs in the Robertson et al., in press study). On the other hand, it may be that the training paradigm itself produced the specificity effect. For example, a potential drawback of the expert-novice paradigm is that there is a lack of control over training conditions. It appears that the training paradigm has the potential to manipulate the training conditions to the extent that it produces results in the direction of the specificity position.

The mean number of steps data revealed experts again demonstrated a specificity effect although not as distinct as novices. Conversely, the total form errors data revealed that experts produced fewer form errors initially than novices but after practice novices' form errors equalled those of experts'. Thus experts' performance, who trained with no vision, did not improve their form errors with no vision while novices did; that is, a specificity effect was only present in novice performers. Perhaps, in this type of task, quantitative changes (mean movement time, # of steps) occur more rapidly than qualitative changes (form errors).

## General Discussion

The results of Experiment 1 and 2 provide moderate support for the specificity of learning position (Elliott & Jaeger, 1988; Proteau et al., 1987, 1992). In Experiment 1, displaced visual information did degrade experts' performance. This finding creates problems for motor learning models proposing a transition from closed-loop to open-loop control with practice, since a manipulation of sensory feedback should have little or no impact on expert performance. More damaging for this position is the vision - no vision comparison for expert beam walkers. Specifically, experts crossed the beam just as quickly when vision was occluded, but took more steps and committed more form errors. This suggests that at least part of their expertise involves the ability to rapidly detect and correct errors; that is, engage in more efficient closed-loop control.

In Experiment 2, the training paradigm was used for the first time (cf. Robertson et al., in press). This study revealed a number of specificity effects since larger improvements were present in the sensory conditions that were trained. The results, however, were at odds with a strong specificity position, since no negative transfer was present. In this respect, the data are more comparable to Proteau et al. (1992), than earlier findings (e.g., Elliott & Jaeger, 1988; Proteau et al., 1987). Specifically, Proteau et al.'s (1992) data "do not support the hypothesis that greater amounts of practice have greater deteriorating effects on transfer performance due to the increasing specificity of the movement representation" (Proteau et al., 1992, p.572). Proteau et al. (1992) suggest that a ceiling effect may be responsible for these results. Similarly, the results of the present study also indicate a ceiling effect for the beam-walking task when vision was available. Once again, this may be responsible for the lack of consistency between studies.

When experts were trained to cross the balance beam quickly, some specificity effects were evident in the movement time and # of steps dependent measures. This may indicate that the training paradigm promotes specificity of learning. This may be the case since experts performed similarly to novices after being trained in a similar manner. Without specific training experts showed different results. Further investigation into this predisposition of a specificity effect when a training paradigm is used would be interesting. Although it is evident that in any study it is necessary to choose a task in which a ceiling effect is not possible. As well, one must ensure that experts are indeed experts at the task under consideration. Further studies to determine the generalizability of the pointing studies to balance and postural control tasks are warranted. As Knapp (1963) suggests, much of motor learning findings, which are based mainly on fine motor skills, may not be applicable to activities involving the big muscle groups of the body. This is important because the goal of motor learning research is inevitably to apply the findings to practical situations.

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# Author Notes

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# Footnotes

1 To examine this, an 8 second no vision delay condition was added to full vision and no vision conditions. In the delay condition, expert and novice subjects waited in the dark for 8 seconds (ample time for a visual representation of the environment to decay) and then continued across the beam without vision. The results revealed that the 8 second no vision delay condition did not affect the experts' or novices' performance any differently than the immediate no vision condition. Thus, the use of a visual representation of the environment as a strategy used by the experts to explain their performance without vision was discarded.

Table 1

Mean Number of Steps Off The Beam

During 10 Trials in Experiment 1

| Group | Full Vision | No Vision | Distorted Left Vision | Distorted Right Vision |
|---|---|---|---|---|
| Expert | 0.2 | 2.5 | 8.4 | 8.3 |
| Novice | 0.4 | 5.0 | 13.4 | 14.5 |

# Figure Captions

Figure 1. Mean movement time and standard error as a function of skill group and vision condition in Experiment 1.

Figure 2. Mean number of steps and standard error as a function of skill, group and vision condition in Experiment 1.

Figure 3. Total form errors and standard error as a function of skill group and vision condition in Experiment 1.

Figure 4. Mean movement time and standard error as a function of training group, amount of practice and vision condition in Experiment 2.

Figure 5. Mean number of steps and standard error as a function of training group, amount of practice and vision condition in Experiment 2.

Figure 6. Total form errors and standard error as a function of training group, amount of practice and vision condition in Experiment 2.

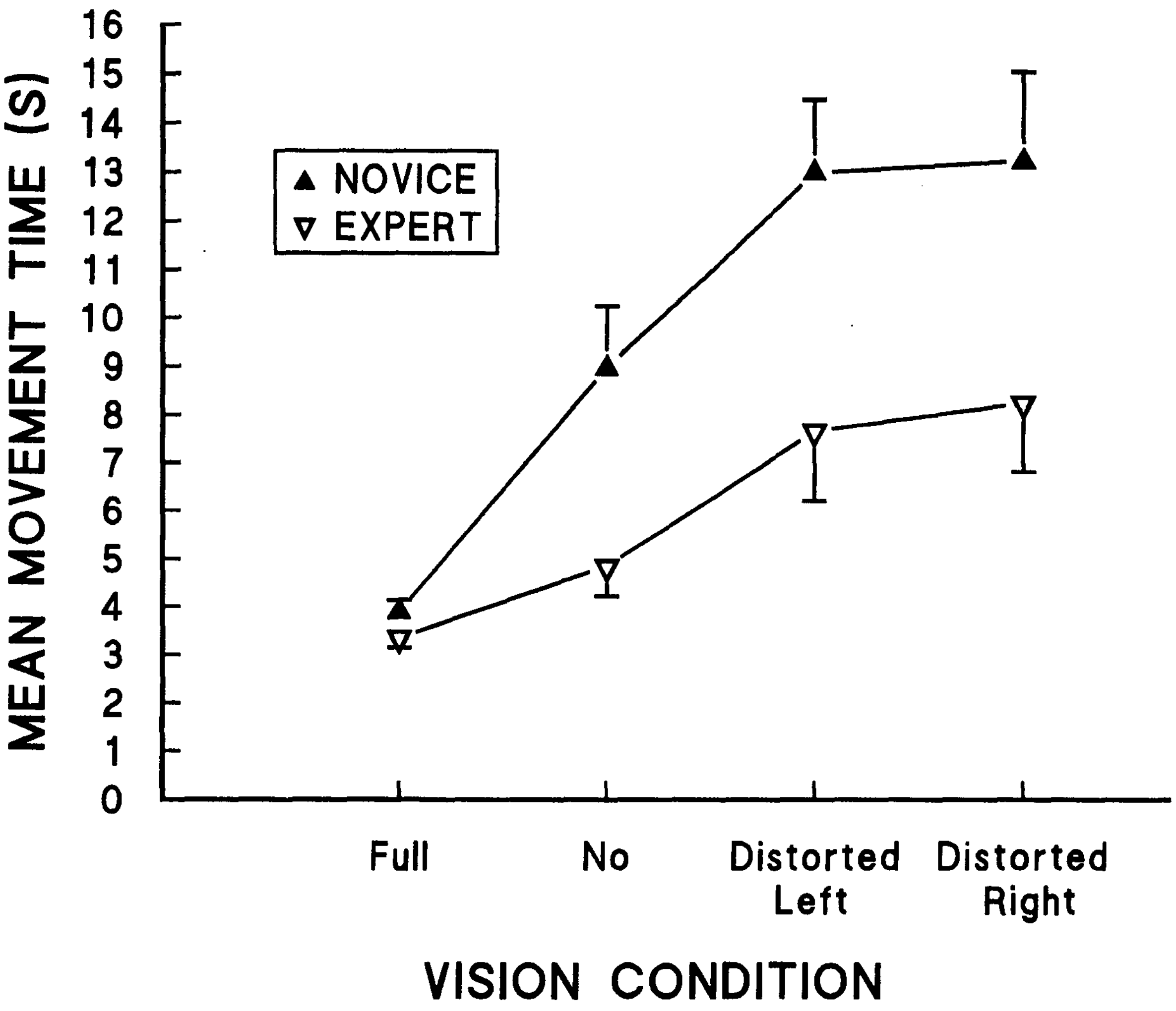
Figure 7. Percent improvement in mean movement time and standard error as a function of training group, amount of practice and vision condition in Experiment 2.

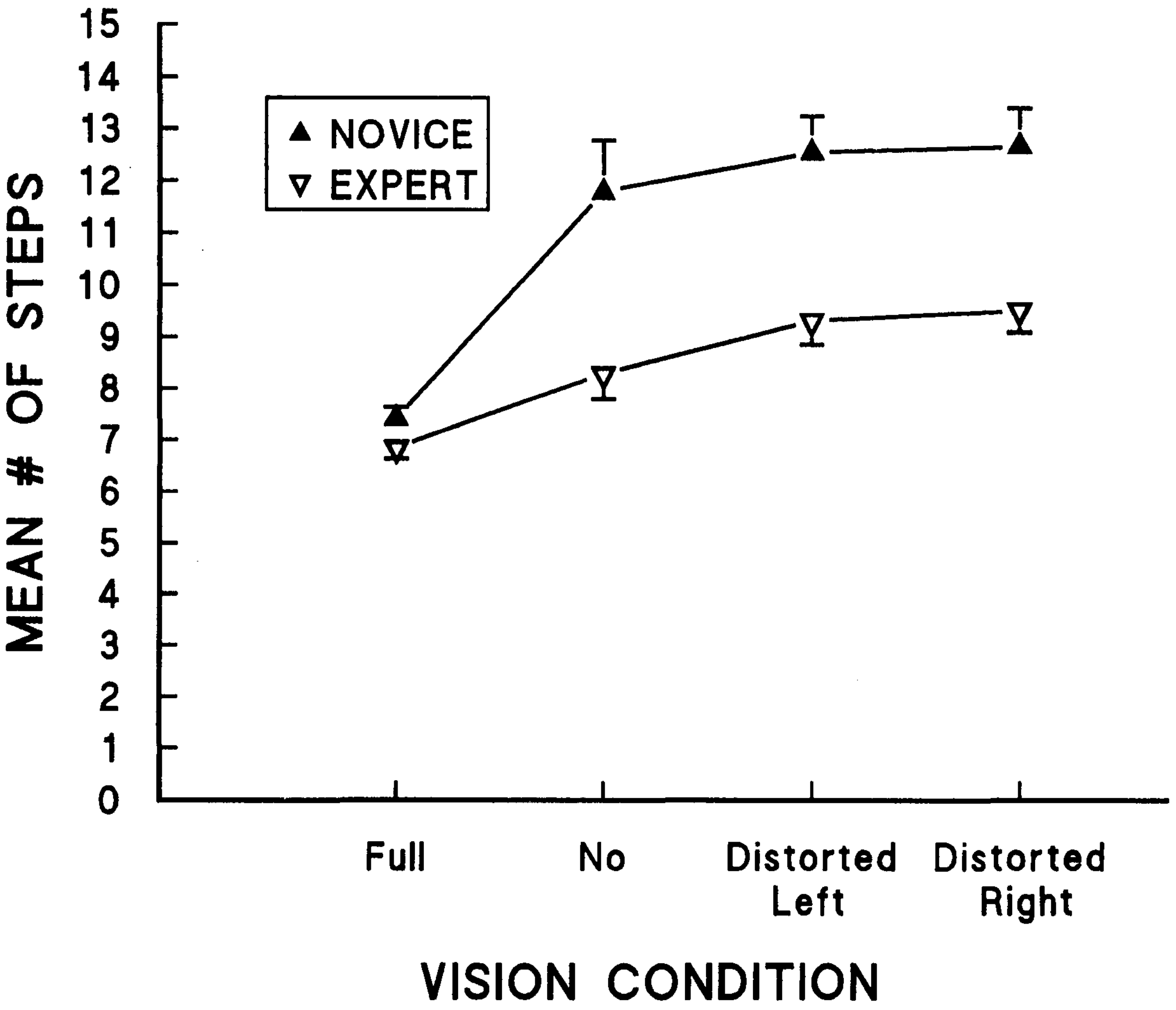
Figure 8. Mean movement time as a function of skill, amount of practice and vision condition in Experiment 2.

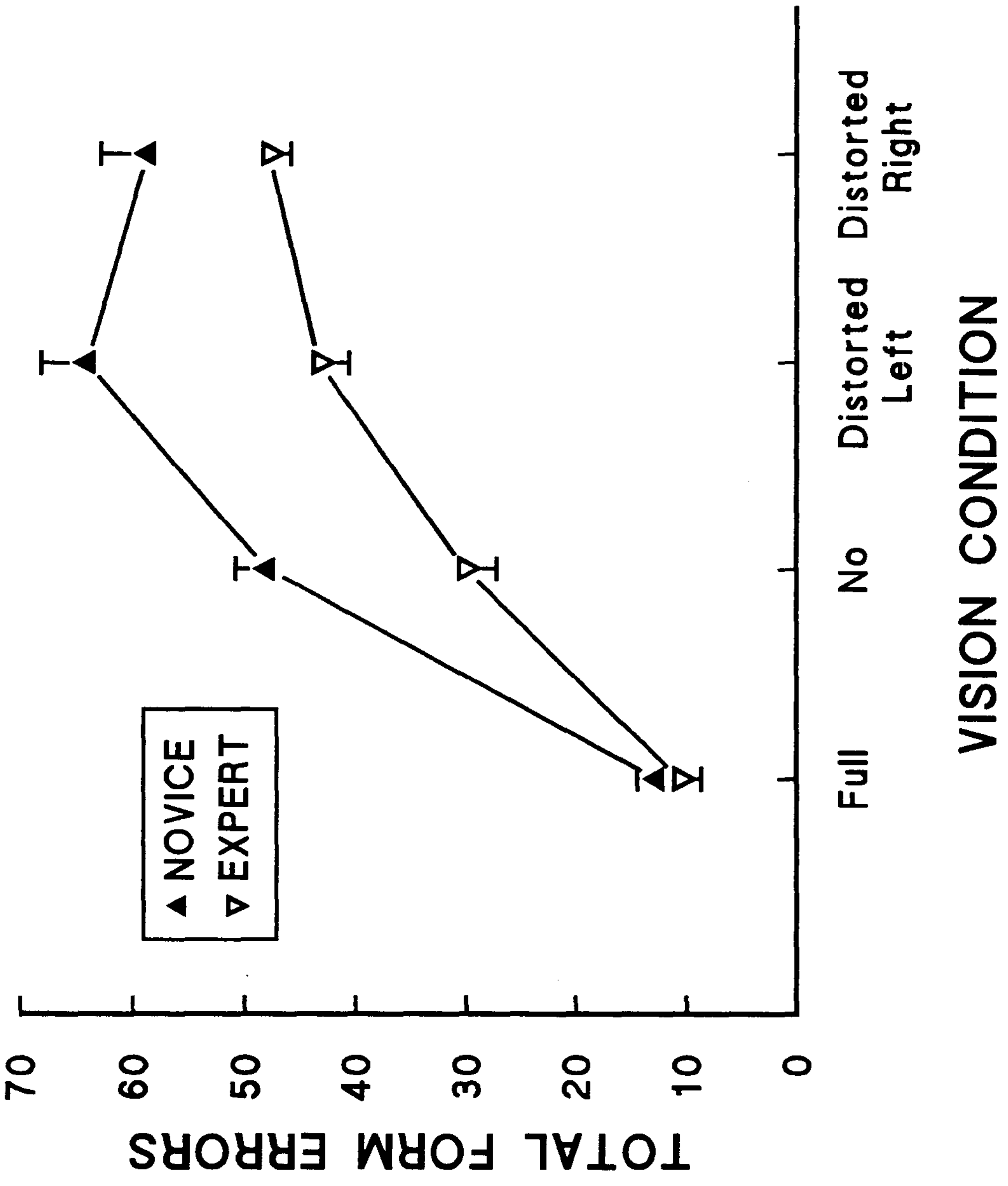
Figure 9. Mean number of steps as a function of amount of practice and vision condition in Experiment 2.

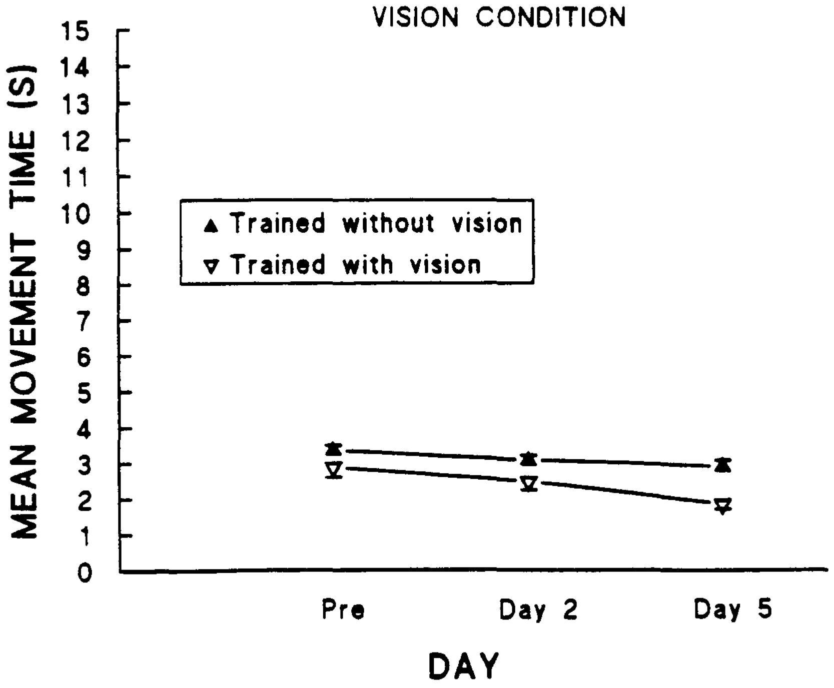
Figure 10. Total form errors as a function of skill, amount of practice and vision condition in Experiment 2.

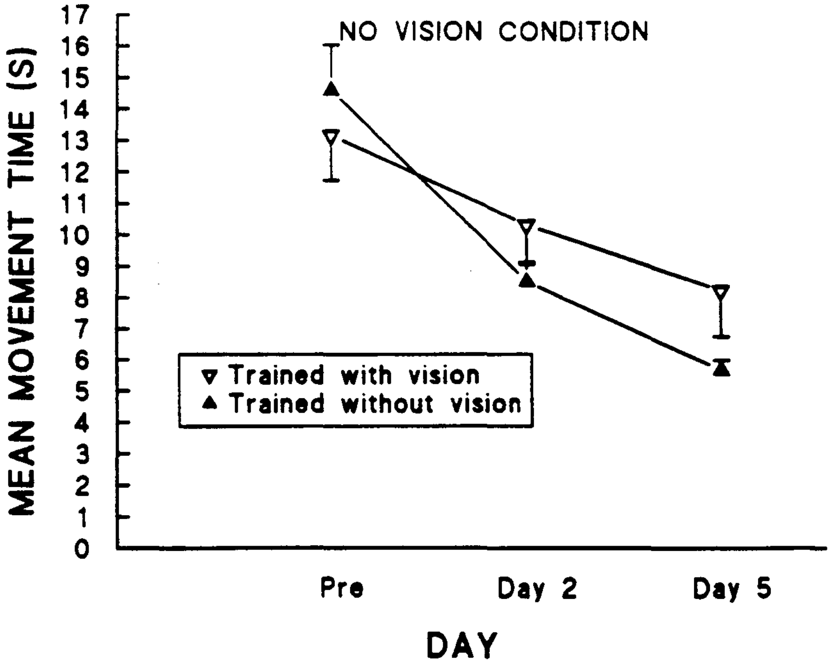
Figure 11. Percent improvement in mean movement time as a function of amount of practice and vision condition in Experiment 2.

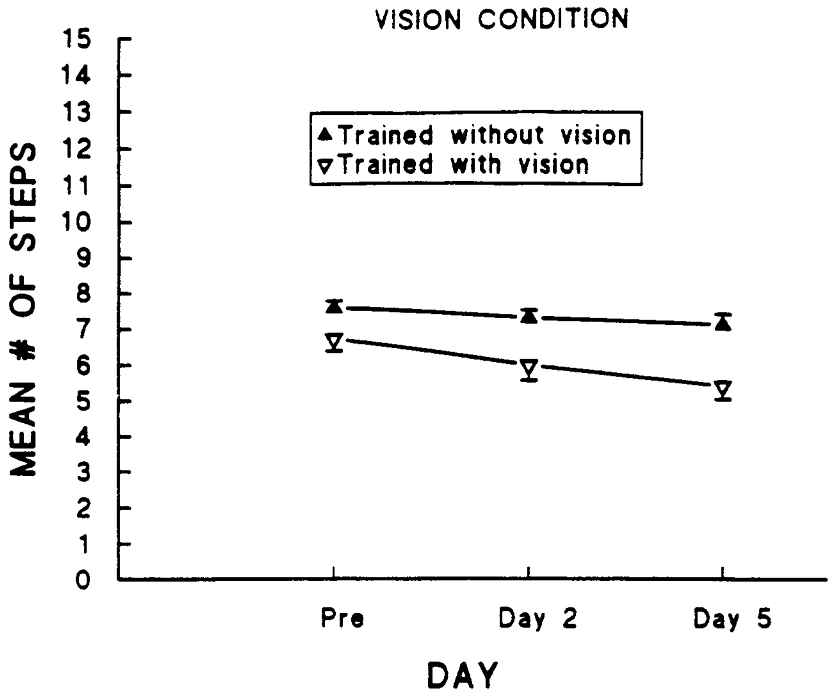

MEAN MOVEMENT TIME (S)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
▲ NOVICE
▽ EXPERT
Full
No
Distorted Left
Distorted Right
VISION CONDITION

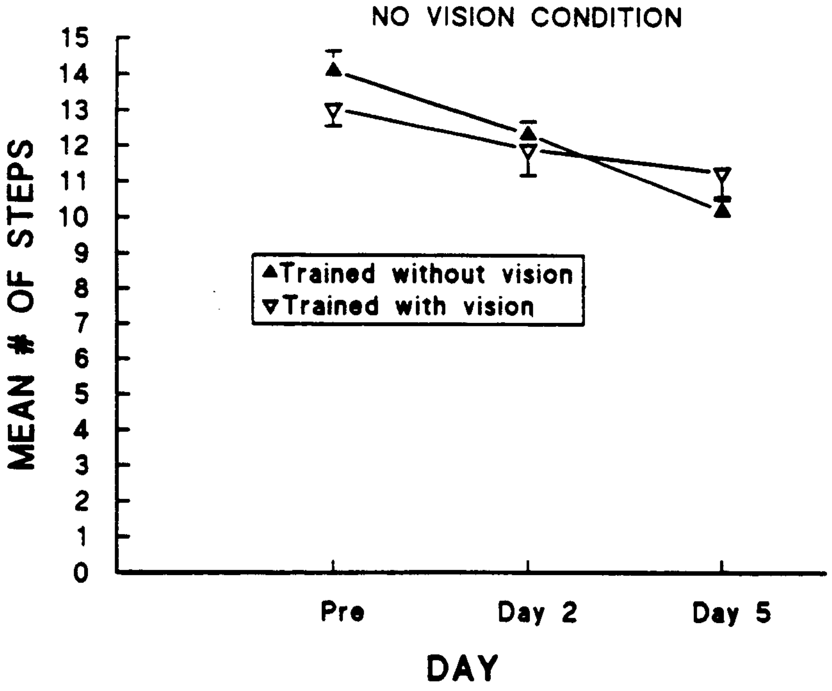

MEAN # OF STEPS
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
▲ NOVICE
▽ EXPERT
Full
No
Distorted Left
Distorted Right
VISION CONDITION

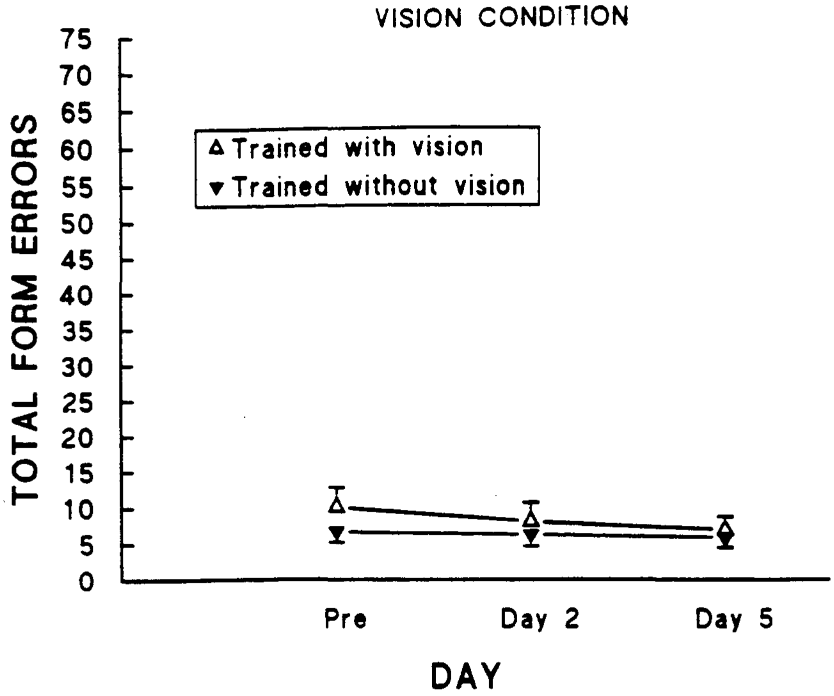

TOTAL FORM ERRORS
0
10
20
30
40
50
60
70
▲ NOVICE
▽ EXPERT
Full
No
Distorted Left
Distorted Right
VISION CONDITION

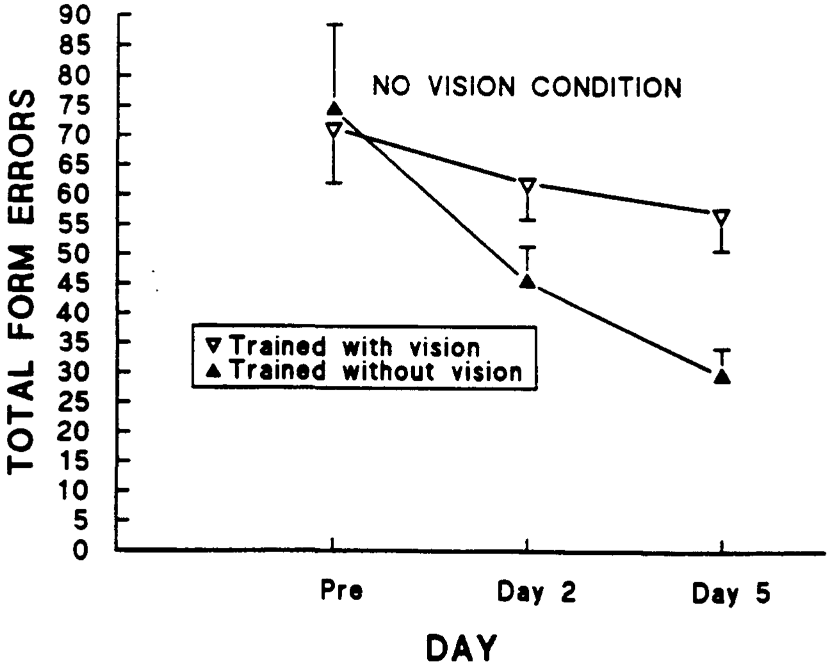

VISION CONDITION
MEAN MOVEMENT TIME (S)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
▲ Trained without vision
▽ Trained with vision
Pre
Day 2
Day 5
DAY

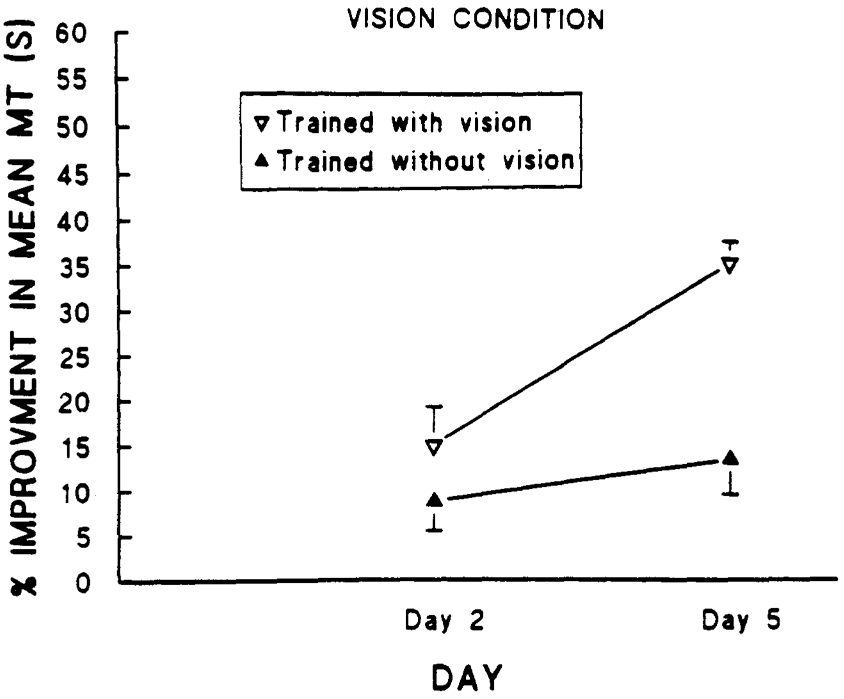

NO VISION CONDITION
MEAN MOVEMENT TIME (S)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
▽ Trained with vision
▲ Trained without vision
Pre
Day 2
Day 5
DAY

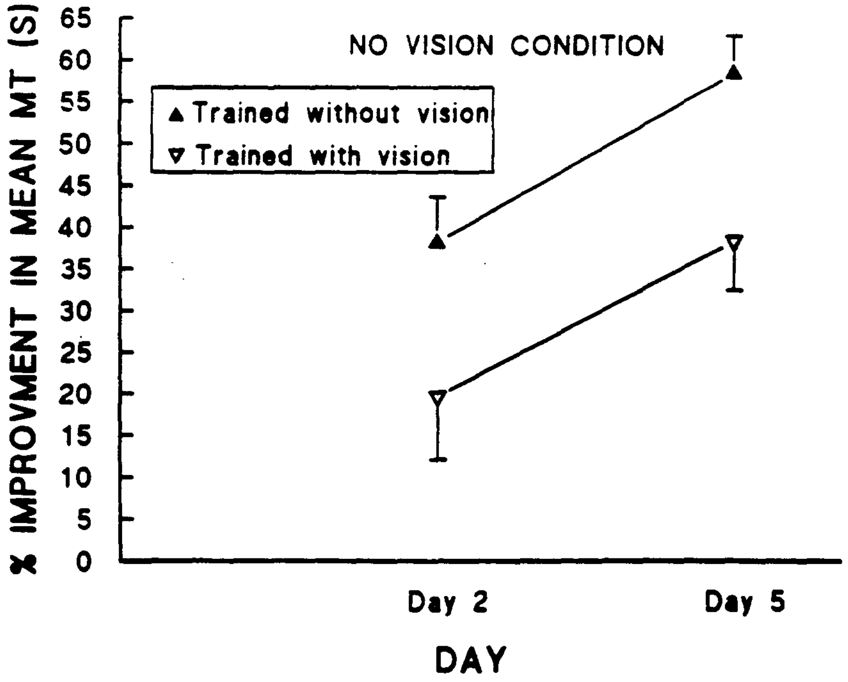

VISION CONDITION
▲Trained without vision
▽Trained with vision
MEAN # OF STEPS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Pre
Day 2
Day 5
DAY

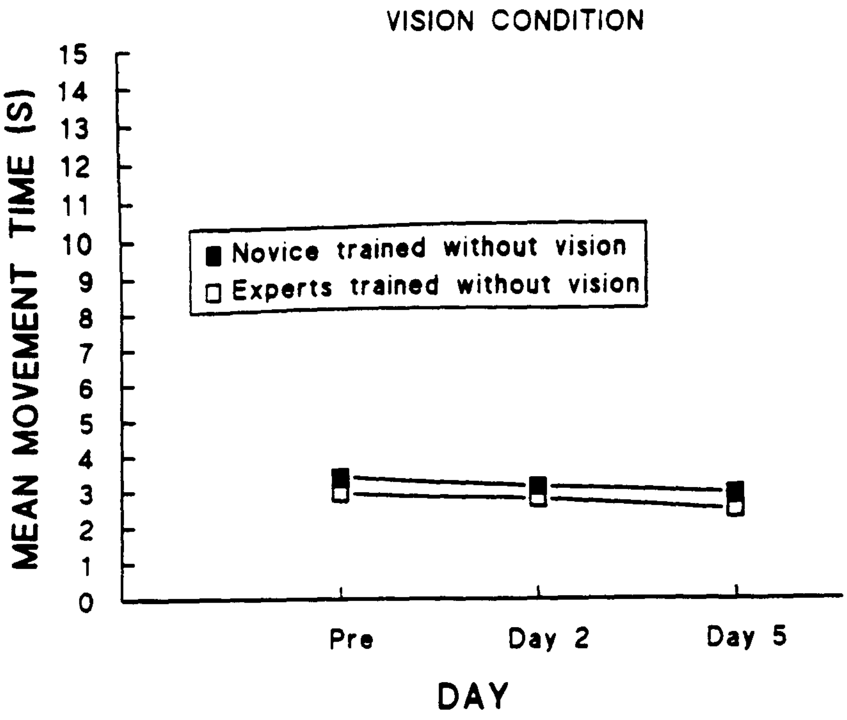

NO VISION CONDITION
▲Trained without vision
▽Trained with vision
MEAN # OF STEPS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Pre
Day 2
Day 5
DAY

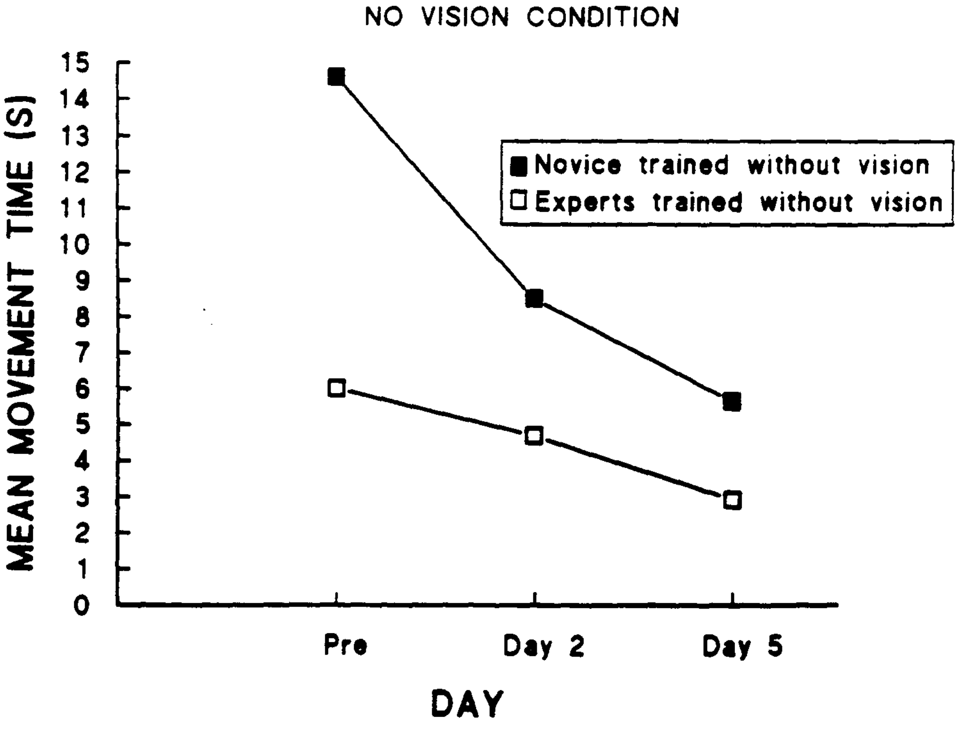

VISION CONDITION
TOTAL FORM ERRORS
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
△ Trained with vision
▼ Trained without vision
Pre
Day 2
Day 5
DAY

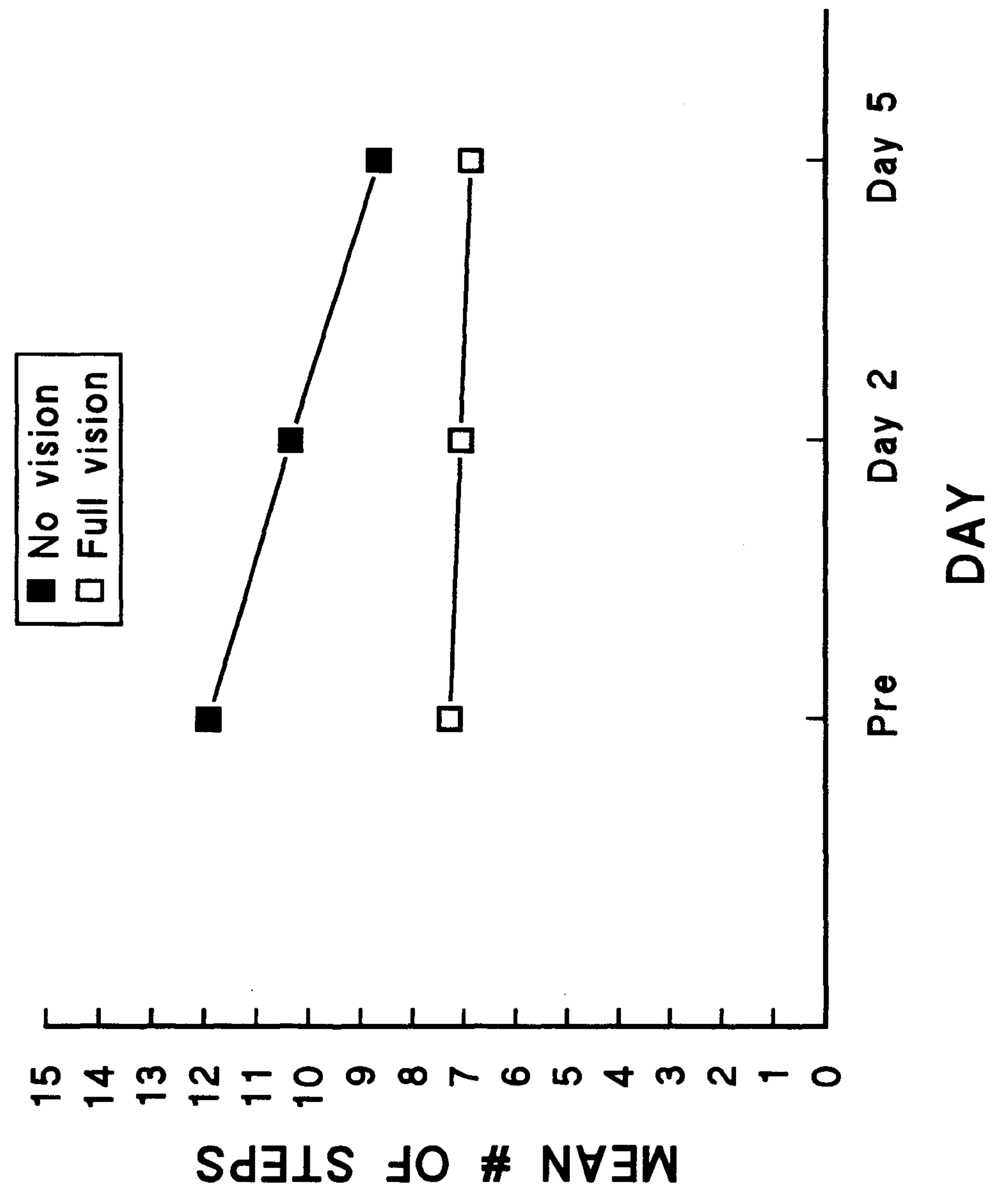

NO VISION CONDITION
TOTAL FORM ERRORS
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
▽ Trained with vision
▲ Trained without vision
Pre
Day 2
Day 5
DAY

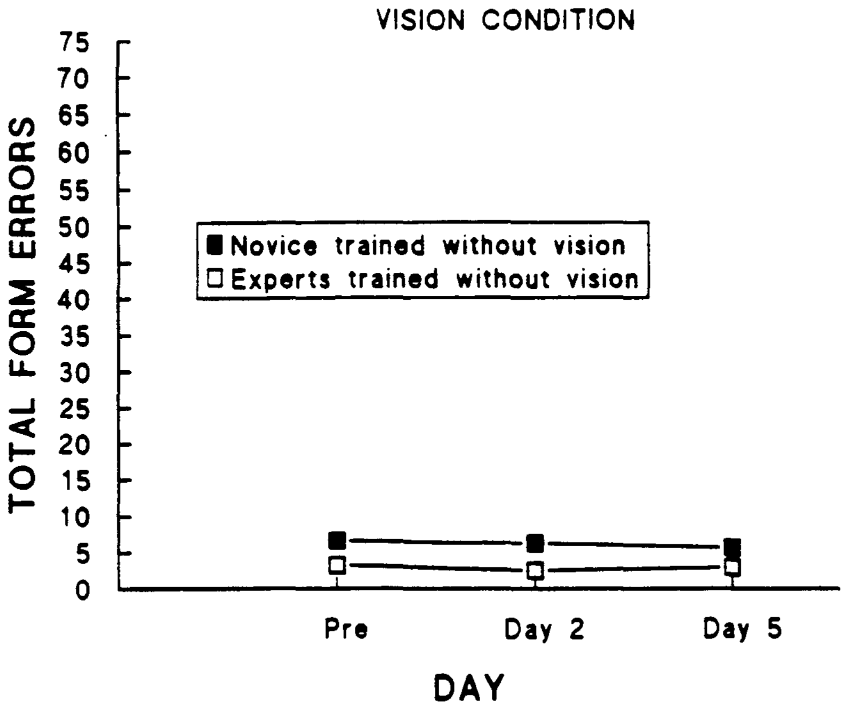

VISION CONDITION
% IMPROVMENT IN MEAN MT (S)
60
55
50
45
40
35
30
25
20
15
10
5
0
▽ Trained with vision
▲ Trained without vision
Day 2
Day 5
DAY

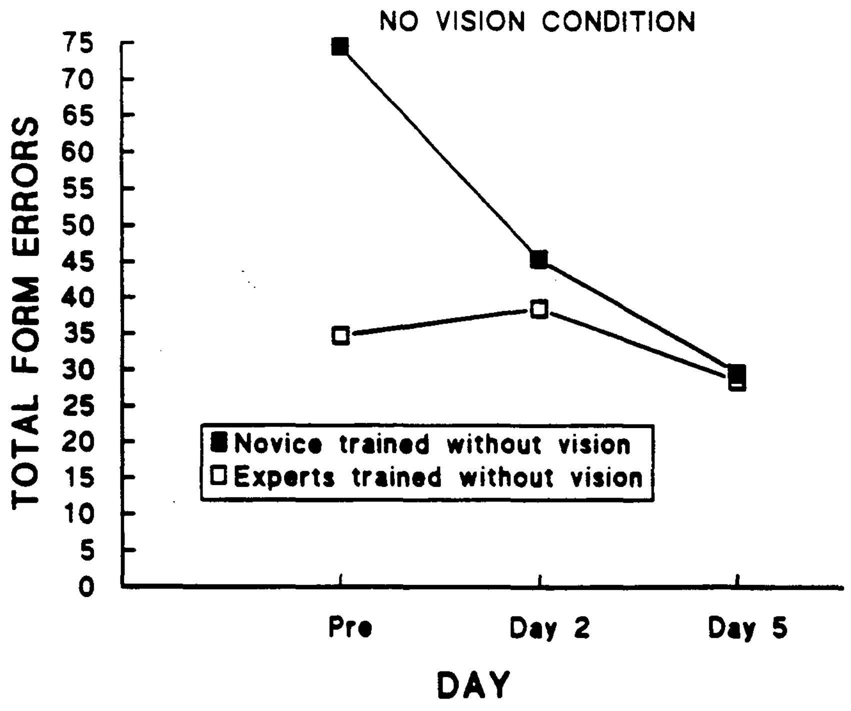

NO VISION CONDITION
% IMPROVMENT IN MEAN MT (S)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
▲ Trained without vision
▽ Trained with vision
Day 2
Day 5
DAY

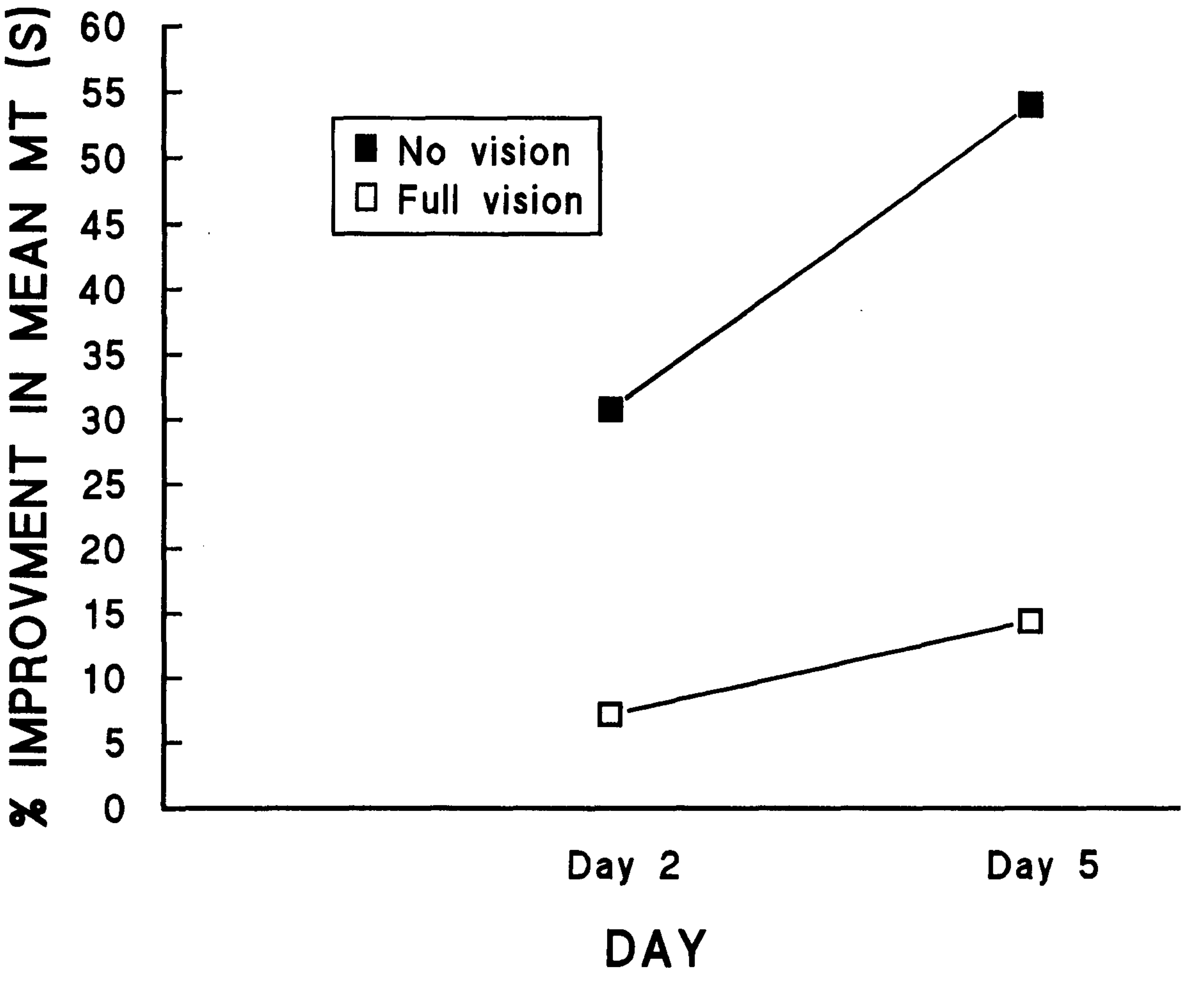

VISION CONDITION


NO VISION CONDITION


■ No vision
□ Full vision
MEAN # OF STEPS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Pre
Day 2
Day 5
DAY


VISION CONDITION


NO VISION CONDITION



% IMPROVMENT IN MEAN MT (S)
60
55
50
45
40
35
30
25
20
15
10
5
0
■ No vision
□ Full vision
Day 2
Day 5
DAY

# APPENDIX

## Summary of Questionnaire

After completion of Experiment 2 of paper 1 and Experiment 1 of paper 2, a questionnaire (p. 94) was given to all subjects to assess any differences between experts' and novices' approach to the task, especially fear.

To analyze these data, the means of the novices and experts were compared using multiple t tests. None of the means were different between the two groups. Therefore we assume that both groups approached the task in a similar way.

# TABLE OF QUESTIONNAIRIE RESULTS

| QUESTIONS | MEANS OF NOVICES | MEANS OF EXPERTS |
|---|---|---|
| EXPERIMENT 1 | | |
| 1 | 3.25 | 2.89 |
| 2 | 2.22 | 1.56 |
| 3 | 2.11 | 2.00 |
| 4 | 3.61 | 4.67 |
| 5 | 1.11 | 2.44 |
| 6 | 2.11 | 2.63 |
| 7 | 1.11 | 1.11 |
| 8 | 2.78 | 2.11 |
| 9 | 3.89 | 4.78 |
| EXPERIMENT 2 | | |
| 1 | 3.89 | 3.56 |
| 2 | 3.11 | 1.56 |
| 3A | 5.00 | 4.00 |
| 3B | 6.00 | 4.00 |
| 3C | 2.00 | 5.00 |
| 3D | 0.00 | 0.00 |
| 4 | 4.90 | 4.11 |
| 5 | 2.00 | 2.33 |
| 6 | 4.11 | 4.89 |
| 7 | 3.11 | 2.33 |

# QUESTIONNAIRE

Read each statement carefully and indicate the degree to which you agree or disagree with the statement by circling the appropriate number. Circling a (1) indicates you strongly agree, circling a (5) indicates you strongly disagree with the statement.

| | strongly agree | | | | strongly disagree |
|---|---|---|---|---|---|
| Example: I feel 10 dollars is a fair price to participate in this experiment. | 1 | 2 | 3 | 4 | 5 |

## EXPERIMENT 1 - DELAY

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. | I follow a visual image of the beam when vision isn't available. | 1 | 2 | 3 | 4 | 5 |
| 2. | When vision isn't available I pay more attention to the position of my body in space. | 1 | 2 | 3 | 4 | 5 |
| 3. | I use the feel of the beam to guide my movement when vision isn't available. | 1 | 2 | 3 | 4 | 5 |
| 4. | I was afraid when vision wasn't available. | 1 | 2 | 3 | 4 | 5 |
| 5. | I felt confident that I would not injure myself. | 1 | 2 | 3 | 4 | 5 |
| 6. | Waiting in darkness for awhile before crossing the beam was more difficult. | 1 | 2 | 3 | 4 | 5 |
| 7. | I felt confident with vision. | 1 | 2 | 3 | 4 | 5 |
| 8. | I felt confident without vision. | 1 | 2 | 3 | 4 | 5 |
| 9. | I saw my feet most of the time. | 1 | 2 | 3 | 4 | 5 |

EXPERIMENT 2 - DISTORTED IMAGE

1. The monocular full vision trials were harder than the binocular full vision trials in the previous experiment. 1 2 3 4 5

2. When the visual image was distorted I still used it to guide my movement. 1 2 3 4 5

3. When the visual image was distorted I tried to disregard it and use another strategy to cross the beam. 1 2 3 4 5

If this was true what strategy did you use:

A) concentrate on the feel of the beam surface
B) concentrate on feeling balanced
C) concentrate on the position of my body parts in space
D) other ______________________________

4. When the visual image was distorted I was worried about injuring myself. 1 2 3 4 5

5. I got used to the distorted images during the course of the experiment. 1 2 3 4 5

6. I saw my feet often. 1 2 3 4 5

7. I got frustrated. 1 2 3 4 5

OTHER COMMENTS, THOUGHTS, SUGGESTIONS.

______________________________________________

______________________________________________

Thank-you for your participation.