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AUGMENTED CONCURRENT ERROR INFORMATION AND THE ACQUISITION OF THE CONTINUOUS GROSS MOTOR SKILL OF FORWARD OUTSIDE EDGES IN FIGURE SKATING

by

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ABSTRACT

An experiment was designed to test the effects of increased availability of FB cues through the use of augmented concurrent error information on the acquisition of the continuous, gross motor skill of consecutive forward outside edges in figure skating. Each of 2 groups of 10 Ss per group skated 20 trials, consisting of 6 consecutive outside edges, on each of 2 days. Percent time spent on edge was measured as the dependent variable. In addition to verbal KR, and instructional information, received from an instructor working in a double blind condition, the experimental group also received immediate, concurrent, response generated error information from a telemetric monitoring device. On day 2, all subjects from both groups performed an additional 10 trials, without the aid of KR, instructional information, or information from the monitoring device.

Two hypotheses were tested. Hypothesis 1, which stated that subjects having increased accessibility to relevant FB cues would show a faster rate of skill acquisition, was supported by the results of this study and is in keeping with closed-loop motor control theory. Hypothesis 2, which stated that artificially enhancing error information does not inhibit progress to the motor stage of skill acquisition, as reflected in performance maintenance when KR is withdrawn, was also supported by the results. There was no significant change in performance when KR and the telemetric monitoring device were withdrawn on Day 2 of the experiment.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The importance of edge control to the sport of figure skating cannot be overemphasized. The controlled, curving edge is the basis of virtually all skills required and must be mastered before proficiency in any area of the sport can be attained. To this point, therefore, it is of great importance to the figure skating coach that beginners in the sport acquire edge control with good technique as early in the skater's career as possible, in order that progression to advanced work can occur. Control and perfection of the edge is attained through training on compulsory figures, to which skaters dedicate many hours of practice.

In motor learning terminology, the skill of skating a compulsory figure is defined in terms of a continuous skill, requiring regulation by the skater during his/her performance (Fitts and Posner, 1967). The rules of the sport of figure skating require that only one edge of the hollow ground blade profile be in contact with the ice at one time during the execution of a compulsory figure. Violation of this procedure results in the occurrence of a flat, where both edges of the blade are in contact with the ice at the same time. A flat is defined by the rules of compulsory figure skating as an error, and can be readily identified by looking at the marks or tracing left by the skater on the ice as a result of the performance. A flat tracing is characterized by a double track as opposed to a single track left by a cleanly skated edge (Figure 2).

Thus the angle of the blade to the ice is critical throughout the performance of an edge. It is important that the skater makes use of kinesthetic information so that he can learn to "feel" the difference between an edge and a flat, and correct his performance when a flat occurs. This view is consistent with closed loop control theories of motor skill acquisition, where feedback arising from an ongoing response is compared to a central reference of correctness for error detection. The major function of a closed loop system is to minimize the extent of error in terms of the deviation of a system's output from a central reference of correctness or desired goal (Schmidt, 1976).

In skating edges, the difference between skating an edge and a flat usually only requires a very fine adjustment to the blade-ice angle, and thus for this refinement to occur, there must be a very accurate internal reference of correctness to detect the error. In Adams' Closed Loop

Motor Control Theory (1971), the internal reference of correctness is referred to as the perceptual trace (PT), and is said to be weak and ill-defined during early stages of learning. The PT consists of a 'pool' of traces or images from past performances, making it weak, unreliable, and subject to forgetting during early stages of learning where few past experiences with the task have occurred. Thus the detection of a flat based on the interaction of feedback and the PT is not necessarily dependable. Subjects at these early stages must rely heavily on peripheral rather than central mechanisms for error detection.

Adams claims that during these early stages of skill acquisition, learners use feedback (FB) in relation to knowledge of results (KR) to adjust their performances towards a criterion. This early dependence on KR is characteristic of what Adams has termed the verbal-motor stage of skill acquisition. KR is used to draw the performer's attention to appropriate FB cues which would otherwise go unattended. This allows the subject to form a strong perceptual trace which will act as a reference of the criterion response when KR is no longer available. When the performer can use the PT for the control of his performance in the absence of KR, and performance can be maintained, he is said to be functioning in the motor stage.

Traditionally, KR is given after a performance is completed. Studies by Bilodeau and Bilodeau (1958) show that KR delay does not affect learning except in cases of continuous tasks. In a continuous task, such as skating edges, performers must rely on some form of short term memory (STM) to retain the motor information of a performance so that it may later be used in relation to KR to be compared to a criterion response. During the period of time where a skater is holding information about a previously skated edge, his performance is continuing, thus adding more and more information to be retained and processed. Fitts and Posner (1967) define STM as a system which loses information rapidly in the absence of sustained attention. Due to the limited processing capacity of the central nervous system (CNS), individuals have to select pertinent items from this temporary store depending on the demands and goals of the current activity. Unattended information fades away so that it cannot be recalled, consequently, all environmental and sensory information face the same limitations due to the process of selective attention. Before a strong PT can be laid down, the learner has first to perceive the appropriate error information by attending to it, and then hold this attended information in memory so that at the end of the performance, it can be used in relation to KR to adjust subsequent responding. The learner will not attend to, hence not retain, information about an error if in fact he is not aware that an error has occurred. Information that is not attended to stands subject to fading and forgetting, and thus may not be avâilable for use in relation to KR.

Based on these theoretical considerations the efficiency of learning a continuous task under traditional KR delay methods can be questioned. It would seem plausible that in a situation where appropriate error information could be made available for attention immediately at the onset of the error, learning would occur at a faster rate.

This study was designed to investigate the effects of increased availability of FB information to a performer's attention on the acquisition of the continuous gross motor skill of skating consecutive forward outside edges.

Statement of the Problem

This study is a practical application of the theoretical rationale of closed-loop learning, as it pertains to the acquisition of the continuous gross motor skill of skating forward outside edges. The purpose of the investigation is two-fold. The first concern is to examine the effects of increased availability of relevant feedback cues to a performer's attention on the rate of acquisition of the self-paced continuous gross motor skill of skating forward outside edges. The second concern is to determine whether or not aid in recognizing the important feedback cues through a FB augmenting device will affect the progression of performers from the verbal motor stage of skill acquisition, to the motor stage, that is, will the learner develop a dependency which will debilitate performance once the device is withdrawn.

Hypotheses

The hypotheses are:

1. Subjects having increased accessibility to relevant FB cues will show a faster rate of skill acquisition, as reflected via a reduction in error scores.

2. Artificially enhancing error information will not inhibit progress to the motor stage, as reflected in maintenance of performance when KR and the monitoring device are withdrawn. A strong PT will be inferred from performance maintenance when KR is withheld.

Definitions

Closed-loop motor control. Behaviour which is self-regulated and accordingly adjusted for correctness by comparing current FB to a centrally established reference mechanism is considered closed-loop in nature (Adams, 1968,1971).

Knowledge of results (KR). Information which is externally provided relating discrepancies between desired and achieved responding is considered knowledge of results.

Feedback (FB). Sensory in nature, feedback refers to the internal after effects of responding.

Perceptual trace (PT). In Adams' closed-loop motor control theory (1968), the referential memory system which is made up of past movement consequences and is used to compare current FB against for the detection and adjustment of errors, is called the perceptual trace. The perceptual trace consists of a complex distribution of traces from a learning situation that consists of a series of trials (Adams, 1971).

Rate of learning. In this study, rate of learning will be determined by change in performance over trials, as reflected in error scores.

Edges. When a skate blade is sharpened the bottom of the blade is hollowed the length of the blade, producing two 'edges', one on either side of the hollow. The skater may tilt his blade slightly to lift one of these edges off the ice. When a skater leans his body so that his weight is on the lateral side of the foot, he has lifted the inside edge of the blade off the ice and is skating on the outside edge of the blade. Conversely, if a skater leans to that the weight is transferred to the medial side of the foot, he is skating on the inside edge.

During the execution of an 'edge', the skater must be on one foot skating on a controlled curve. In a test situation skaters are asked to skate consecutive inside or consecutive outside edges on alternate sides of a coincidental axis, thereby necessitating the changing of feet at the end of each completed half circle (Figure 1).

Flats. A flat occurs when both edges of the blade are in contact with the ice at the same time. In the execution of an edge, a flat is considered a fault and can be readily identified by the double track mark it leaves on the ice, as opposed to a single track mark left by an edge (Figure 2).

Novice skater. In this study, novice skater will refer to skaters who are capable of passing at least the first two National Skating Tests, but no higher than the fourth test.

Delimitations

1. The study is delimited to skaters ages 17 years and over who are not capable of passing any higher than the fourth National Skating Test.

2. Learning will be assessed over 40 trials, spread evenly over two days.

3. The study is delimited to the effects of wearing the telemetric monitoring device.

Assumptions

1. This study is based upon the assumption that Adams' closed-loop theory of motor control is valid and in this situation: the task of skating forward outside edges is subject to closed-loop control.

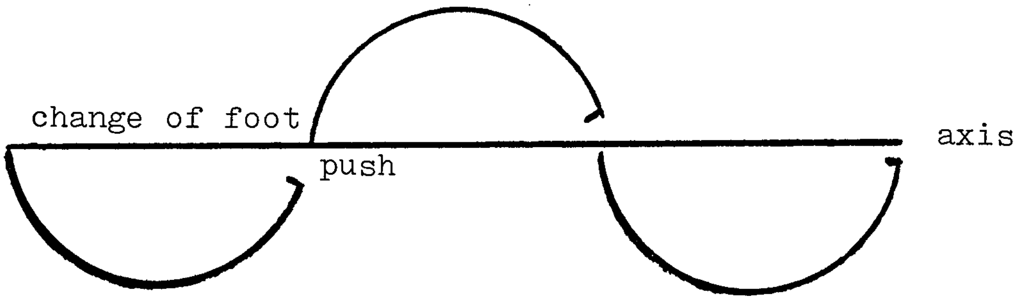

Figure 1. Edge pattern during test situations.

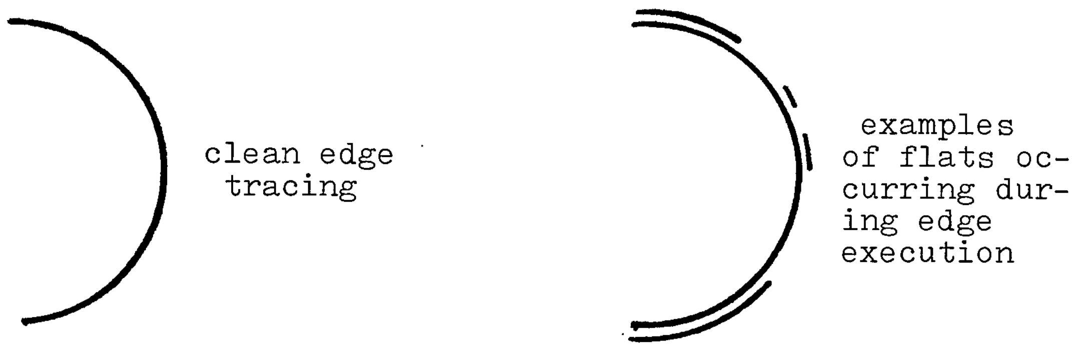

Figure 2. Comparison of flat and edge tracings.

2. An internal reference of correctness such as the perceptual trace does exist, and development of the perceptual trace results in learning.

Limitations

1. This study is limited by the sample size of twenty subjects.

2. This study is limited to novice skaters age seventeen years and over.

CHAPTER II

REVIEW OF THE LITERATURE

It is the intention of this review of literature to outline Adams' closed-loop motor control theory as a theoretical framework upon which this study is based, and to review related theoretical areas.

Adams' Closed-Loop Motor Control Theory

In 1971, Adams proposed a closed-loop motor control theory for self-paced motor behaviour which differed from previous attempts to explain this process in that it afforded feedback (FB) a joint learning and performance role. Until this theory was introduced, views on the role of FB in controlling motor behaviour were clearly divided. One group of researchers, lead by James (1890) with his response chaining hypotheses, gave FB a pure performance regulation role, with no lasting effects on behaviour. As an alternative to the response chaining hypotheses, Lashley and his associates (Lashley, 1917, 1951; Lashley and Ball, 1929; Lashley and McCarthy, 1926) proposed a motor programming theory, following the concept of some central internalized control plan being laid down for each movement sequence. Clearly, Lashley and his associates saw FB as a pure learning variable.

It is beyond the scope of this study to discuss all the theories and studies on FB and learning. (For a complete review of FB theories, see Adams, 1968).

In an attempt to overcome the inadequacies and problems of either a continuous response produced stimulus controlled theory (such as James, 1890), or an open-loop motor program theory (such as Lashley, 1917), Adams introduced his theory of motor control where feedback serves two functions (Adams, 1968, 1971). In its first role, feedback provides input for the formation of an error detection mechanism called the perceptual trace, the function being a referential memory system against which future responding can be evaluated. This referential memory system is made up of past movement consequences. It is not a single trace as its name implies, but rather a complex distribution of traces in a learning situation that has a series of trials (Adams, 1971). In a discussion of Adams' theory, Marteniuk (1976) describes the perceptual trace as

> .... the image of environmental and response produced stimuli, a large part of which is kinasthetic in origin, which acts as an individual's reference level when determining the appropriateness of a response.

Evidence for a centrally represented image formed by feedback that influences a motor response has been found in studies by Greenwald and Albert (1968), and Zeloznik and Spring (1976), who in similar experiments found that passive subjects could learn a given response by watching active subjects performing the response. The results from these studies suggest that subjects form an image of the required response from the visual cues of the active subjects. Studies by Adams and Goetz (1973) and Marshall (1972) show that this image is used after a response to detect error, fitting a closed-loop schema.

Once this error detection mechanism is formed, the second function of feedback is to provide input to the above mechanism for comparison and evaluation so that errors can be detected.

Within his closed loop framework, Adams (1971) proposes two memory states that are individually responsible for the initiation of an appropriate response when a stimulus occurs, and for the regulation and evaluation of the response in terms of correctness. The concept of two memory states was derived from verbal learning research where differences between recognition and recall states have been demonstrated (Luh, 1922; Bahrick, 1965; Postman, Jenkins and Postman, 1948; Kintch, 1968).

Evidence of the existence of separate recall and recognition states in motor memory can be found in Adams and Goetz (1973), Christina and Merriman (1977), Marshall (1972), Newell (1974), Newell and Chew (1974), Schmidt and White (1972), and Schmidt and Wrisberg (1973a, b). The medium of motor recall in Adams' theory is the memory trace which is responsible for the selection and initiation of the appropriate response to a given stimulus. The memory trace is a limited, open-loop motor program which determines the initial direction of a response. The recognition medium of a movement in Adams' theory is the perceptual trace and, as previously discussed, operates in a closed-loop manner as the reference mechanism against which current feedback is compared for response evaluation. The strength of the recognition mechanism, henceforth called the PT is a function of the amount of relevant feedback stimuli and the amount of exposure to them (Adams, Goetz, and Marshall, 1972; Adams, Gopher and Lintern, 1977; Marshall, 1972; Newell, 1974; Wallace, De Oreo and Roberts, 1976; Zelaznik and Spring, 1976). On any given trial, feedback stimuli from an ongoing response are compared against perceptual traces from previous responses. Thus, both stimuli, which persist from past trials through learning, as well as momentary stimuli from a current trial, determine behaviour giving feedback a dual learning and performance role.

Before the PT can act as the primary response control mechanism in a motor skill situation, it must be developed. In early stages of learning where the perceptual trace is weak and ill-defined, knowledge of results (KR) is used in addition to feedback to direct subjects towards the criterion response to be learned (Adams, 1971). Bilodeau and Bilodeau (1961) consider KR to be the strongest variable involved in learning and performance.

A well established principle in motor learning is that KR is necessary for learning, hence improvement in performance, to occur (Adams, 1971). As early as 1927, Thorndike, using a line drawing task, found no improvement in performance scores for subjects who were not given KR. Trowbridge and Cason (1932) asked blindfolded subjects to draw a three inch line, and found that in situations where no augmented KR was given, subjects failed to improve. Similar findings have been reported by Baker and Young (1960), McGuigan, Hutchens, Eason and Reynolds (1964), Elwell and Grindley, (1938).

Bilodeau and Bilodeau (1958) used a lever positioning task to show that withdrawing KR in early trials of learning led to a substantial decrement in performance. However, after sufficient practice, performance was maintained on KR withdrawal trials. Newell (1974) indicated the need for KR in early practice trials, using a linear, ballistic displacement task. Adams, Goetz and Marshall (1972) conducted a self-paced linear positioning task experiment, varying amounts of KR and practice, and found that skill acquisition was best in situations where KR was highly augmented.

A second principle of KR is that the rate of improvement depends on the preciseness of KR (Adams, 1971; Magill, 1980). Trowbridge and Cason (1932) varied the amount and precision of KR in a line drawing task and found improvement was best in conditions of more precise KR. A study by Smoll (1972) using a bowling skill showed better results were achieved by groups receiving more precise KR. However, the amount of time needed to make use of KR information has been found to be dependent on the preciseness of the KR. Too precise KR can actually be detrimental to learning (Rogers, 1974) unless sufficient time is allotted for information processing.

A third principle of KR concerns the frequency of its occurrence. Findings in this area show the more frequently

KR is given, the better learning and performance become. (Bilodeau and Bilodeau, 1958; Magill, 1980; Marteniuk, 1976).

The fourth principle of KR is of particular importance to this study and regards the timing of KR. In a learning situation there are two time periods which are of concern. The first period is the time between performance and KR and is called the KR delay interval. Most studies in this area have been conducted using discrete motor tasks and have found that KR delays of up to one hour do not affect learning. However, where performance involves repetitions of the movement, learning is adversely affected if a repetition occurs between the original movement and delivery of its related KR (I. Bilodeau, 1956; Lavery and Suddon, 1962). Thus, the timing of KR in regards to the KR delay interval seems of particular importance to continuous motor skills where acquisition is adversely affected by KR delay. However, there are few studies documenting this effect, since the bulk of studies dealing with KR delay have used discrete motor tasks.

The second time period of importance is called the post KR delay interval and refers to the time which elapses between KR and the start of the next performance. The findings from studies on post-KR delay indicate that there must be sufficient time for information processing to occur. The time needed for information processing will vary with the preciseness of KR, and the stage of learning of the performer.

In summary, KR as information to direct error correction is necessary for learning to occur in early stages of skill acquisition (Elwell and Grindley, 1938; Bilodeau and Bilodeau, 1961; Newell 1974; Magill, 1980; Stelmach, 1970; Baker and Young,1960; McGuigan, Hutchens, Eason and Reynolds, 1964; Thorndike, 1927). There is no tendancy for responding to move towards a precise criterion when KR is absent. KR helps to ensure the proper development of a representative model of criterion responding. This is achieved through matching sensory FB from a performance with KR. This process enhances the acquisition of a skill by facilitating the learning process, when used over a relatively large number of KR trials

According to Adams' theory, subjects use FB in relation to KR to adjust subsequent responding towards a criterion performance. Sufficient practice with KR allows feedback to lay down a strong PT that will act as a reference of the criterion when KR is no longer available.

In situations where KR is not forthcoming, the PT becomes the dominant response control mechanism, acting as an internal, subjective form of KR.

The shift in response control from KR to PT after sufficient criterion level practice in Adams' theory is defined in terms of two stages. The first, or the verbal motor, stage is characterized by a weakly defined PT due to lack of exposure and practice with appropriate and relevant stimuli. The subject is forced to use feedback cues in relation to KR from outside sources in order to form verbal strategies pursuant to future performances. During the verbal motor stage, response accuracy deteriorates if KR is withheld (Adams, Goetz and Marshall, 1972; Bilodeau, Bilodeau, and Schumsky, 1959; Boulter, 1964; Newell, 1974; Bilodeau and Bilodeau, 1958) because of the weak perceptual trace and its susceptibility to forgetting or progressive ambiguity in the absence of verbal intervention. In the motor stage, a strong PT has been formed over a relatively large number of KR trials and takes over as the dominant control mechanism of motor performance. Subjects can rely on matching current feedback to the PT for error detection without external directives. In the motor stage, response accuracy will not deteriorate if KR is withdrawn. This effect has been shown by Bilodeau and Bilodeau (1958), Newell (1974) and Bilodeau, Bilodeau and Schumsky (1959).

In summary, the key variables for strengthening the PT are the amount of relevant feedback stimuli (quantity) and the amount of practice (frequency) with them. The learner must perceive the relevant stimuli from amongst the many irrelevant stimuli which bombard him from the environment before strengthening of a representative PT can occur. Beginners experience difficulty in learning a new skill due to their inability to determine for themselves what their errors are and how to correct them. In early stages of skill acquisition, the learner uses FB in relation to KR to attend to relevant stimuli, determine errors and develop an internal reference of correctness. The process by which this identification and selection of pertinent information eventually occurs is called selective attention.

Selective Attention Implications

In a skill situation relevant cues from the environment must be attended to before information processing can proceed. Gentile (1972) refers to these relevant cues as the regulatory stimulus subset, as opposed to non-regulatory information within the learning environment. These cues are referred to as regulatory since the movement pattern must conform to them if the predetermined goal is to be accomplished. The process whereby an individual attends to the regulatory stimulus subset at the exclusion of other environmental information is called selective attention with perception being the end result. Selective attention is necessary due to the limited information processing capacity of our central nervous system.

Allocation of Attention

Early studies on selective attention (Broadbent, 1958; Moray, 1959; Cherry, 1953) show consistently that an unattended signal has little chance of reaching memory or conscious awareness. Moray (1959) presented two different messages simultaneously (one to the right ear and one to the left) to subjects, asking them to repeat the message of one ear. The results from this study indicate that there was no memory for the unattended message. Similarly, Cherry (1953) presented two simultaneous messages to subjects asking them to pay attention to the message in one ear by repeating what they heard. At the end of the messages subjects were asked questions about what they heard on the unattended ear. Subjects noticed only very general characteristics of the messages such as changes in language spoken, voice, etc., with almost no recall of its verbal content. Mowbray (1953) showed that even when subjects were asked to attend to two messages, they were unable to divide their attention between them. Consistently, recall on one of the two messages was poor.

In a perceptual motor skill situation the performer is bombarded with simultaneously presented information from a variety of sources. Due to the limits imposed by selective attention, an inexperienced motor performer finds himself severely handicapped in his ability to process relevant information and, therefore, perform a specific skill. Studies by Cherry (1953) and Mowbray (1953) show dramatic limitations in our abilities to deal with simultaneously presented information. Results of these studies show that when two messages arrive simultaneously and only one is attended to, the unattended message is poorly analyzed with almost no specific characteristics available for recall. In a complex motor skill, a novice performer must deal with information from his environment, plus many appropriate feedback cues from his response. Results from selective attention studies suggest that the novice performer may be unable to attend to more than one source of information and thus the many mistakes characteristic of a novice performance may be the result of perceptual limitations imposed by poor utilization of selective attention

(Marteniuk, 1976). Further, the fact that a performer can detect, recognize and compare information does not guarantee that he will attend to the information that is relevant for a successful performance. The performer must learn from past experience and/or external information sources to attend to and select the relevant cues while disregarding or attenuating the others. Not yet capable of distinguishing what is relevant from what is not, the early learner begins, (Adams' 'verbal-motor' stage) and he is forced to rely on KR from outside sources to draw his attention to the relevant feedback cues. In turn, the individual uses the information gained from KR, in relation to FB cues, to evaluate his performance in order to modify future attempts. If the performer is unable to retain feedback information from his previous attempt, evaluation and subsequent modification of performance is not possible. Thus, we are concerned with the performer's ability to retain information over short periods of time so that the information can be used to evaluate and modify his motor performance, when used in relation to KR.

Studies by Bilodeau (1956) and Lavery and Suddon (1962) have shown that in motor tasks where repetitions of the movement take place between the original movement and its KR, learning is adversely affected. This effect is presumably due to the limits imposed by the capacity and duration of short term memory (STM) and subsequent information processing. In the case of skating edges, where a skater is holding information in memory about a previously skated edge, his performance is continuing, adding more and more information to be retained in STM for post-performance analyzing and processing. Short term memory is a storage system that is limited in its operation, capacity and duration. Fitts and Posner (1967) define it as a system which loses information rapidly in the absence of sustained attention. A classic experiment by Sperling (1960) demonstrated that much more information is accessible to STM that can be recalled. He demonstrated that while subjects were identifying items in memory, other items were being lost. For items where attention had not been focussed, recall was very poor. Peterson and Peterson (1959) and Broadbent (1954), in similar experiments, showed that forgetting in STM is due to lack of attention. Thus, if an item is not attended to in STM it will fade within a very short period of time so that it is no longer available for recall. If an early learner doesn't attend to the proper feedback cues, he will find it difficult to use KR in comparison to them in his attempt to create the proper PT.

Some Considerations

The limits imposed by selective attention and STM severely handicap the early learner in the development of the PT which is necessary for the eventual progression to the motor stage of skill acquisition. In a situation where augmented error information could be generated to draw attention to the appropriate and relevant cues, one would expect a more positive performance and an accelerated learning curve. In an attempt to show this affect, Goldstein and Rittenhouse (1954) produced disappointing results. Using a target shooting task, subjects in the experimental group received a buzzer when their guns were on target. As would be expected, the performance of the experimental group was much better than the control group, who received no error correction. However, performance dropped off considerably when the buzzer produced KR was removed. This suggested that the buzzer had acted as a performance regulating factor rather than as a learning aid. The major drawback of this experiment was that the researchers did not provide subjects with true error information. Rather than receiving critical error information, the subjects had only to wait to hear the buzzer and fire. In early stages of learning, performers do not try to repeat the previous behaviour, but instead they attempt to modify their behaviour to make it more correct.

When learners make errors early in learning, and KR values are large, they are not responding on the basis of movements that they recognize as having made before, because this would cause them to repeat past errors. For learning to occur, performers must use KR to make the next response different from the previous one; he must use the perceptual trace in relation to KR from an outside source (the criterion reference standard) and adjust the response accordingly on the next trial (Adams, 1971). The information provided in the Goldstein and Rittenhouse experiment let performers repeat rather than correct past performances. The subjects became reliant on a cue which was not a part of the desired task and that was only relevant to the ongoing performance. It seems logical that had the buzzer sounded when subjects were in error, the subjects would become more sensitive to the right response in order to eliminate the sound of the buzzer, i.e., error. In a similar study by Annett (1959), utilizing a target pressure task, augmented, concurrent FB resulted in much better performance scores, but when withdrawn, performance deteriorated rapidly and dramatically indicating no learning effect.

It is hypothesized that had these studies employed the augmented error information in such a way as to allow subjects to modify previous responses, i.e., learning FB versus performance of action FB, the withdrawal trials would not have produced the performance decrements observed.

The following experiment examined the effects of increased availability of FB cues through the use of immediate, concurrent, augmented KR on the acquisition of the continuous gross motor skill of skating forward outside edges.

CHAPTER III

METHODS AND PROCEDURES

The continuous, self-paced motor skill used in this study was that of skating consecutive forward outside edges along a coincidental axis.

Subjects

Twenty female volunteer novice skaters, ages 17 and over, were recruited from the University of British Columbia's student and staff population. Subjects were randomly divided into two groups of ten per group.

Apparatus

A telemetric monitoring device was designed to monitor a skater's blade position and activity on the ice, in terms of blade/ice angle, during the attempted execution of forward outside edges along a coincidental axis. Error information based on the measurement of the skater's performance was provided to the skater during performances in the form of a non-irritating, electronic beeping noise. The apparatus consisted of an outrigger styled, ice angle sensor which was fastened to the skater's blade prior to performance and, via a small battery pack attached to the skater's belt, transmitted signals both to an earphone worn by the skater and to a telemetry receiver with its associated recording equipment (see Appendix A for a detailed description). In particular, an audible tone was generated through the earphone whenever the blade-ice angle exceeded a predetermined value. This predetermined value was the angle at which both edges of the blade contacted the ice at the same time resulting in a flat, or beyond this point where only the inside edge of the blade was in contact with the ice. The error tone generated through the earphone persisted until the blade-ice angle was corrected and brought back into the critical range of the desired movement, thus producing the execution of an acceptable outside edge.

The ice-angle sensor was constructed of aluminum for its durable and light weight characteristics, and was of an outrigger design that clipped onto the top of the skate blades, where it would not impede performance, and would run along the ice surface parallel to the control blade.

During each trial the telemetry signal was transmitted to a data collection station where blade activity in terms of edge/flat times was recorded on a strip chart for purposes of the monitoring and future analysis of performance (see Figure 3).

The total system consisted of a pair of sensors to convert the blade-ice angle to an electrical signal, a detector to analyze the angle signal, an earphone, and assorted standard devices to transmit and record the detector output (see Appendix A).

Experimental Design

The experiment consisted of two phases. In the first phase, subjects were required to skate twenty trials on each of two days, for a total of forty trials. Each trial consisted of six consecutive forward outside edges, performed across the width of the ice surface (Figure 4). An average experimental session from phase one of this experiment required approximately 25 minutes to complete.

In the second phase of the experiment, which occurred on the second day of testing after trials 21 - 40 were completed, subjects were required to perform an additional 10 trials while wearing, but without receipt of any in-

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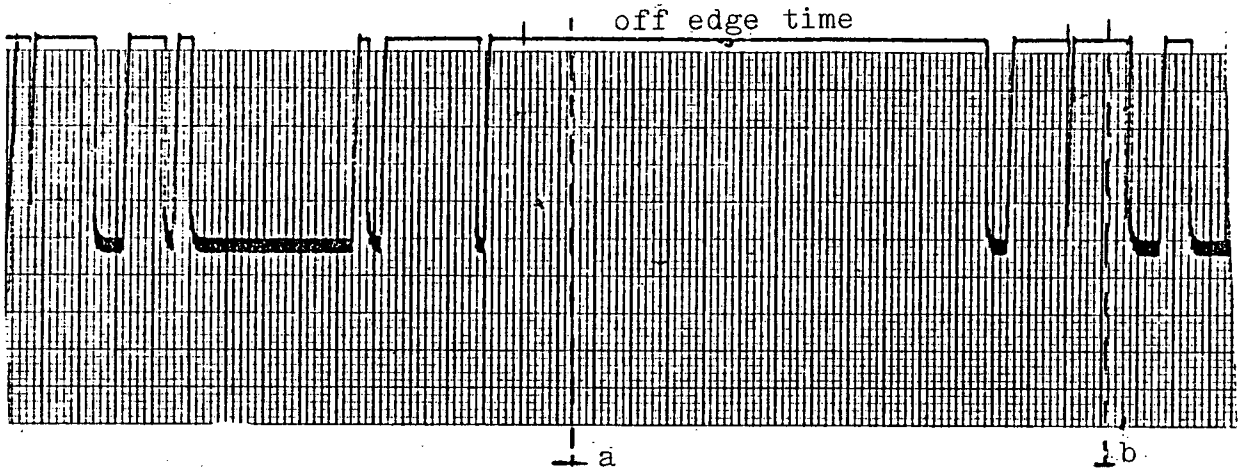
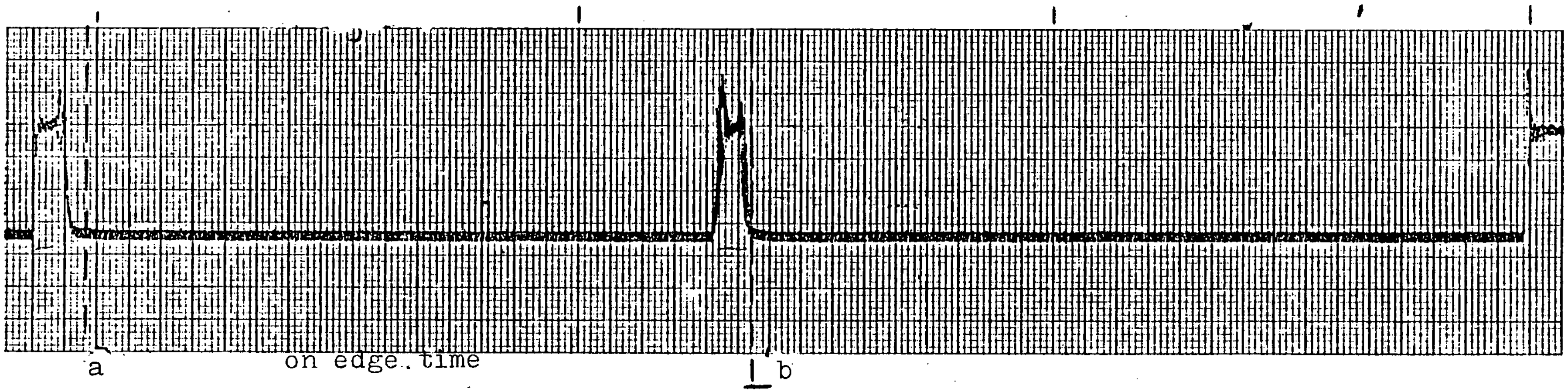


1. A sample strip chart produced by the performance of forward outside edges by a novice skater. Points a and b indicate a change of skating foot.



2. A sample strip chart produced by the performance of forward outside edges by a skilled skater. Points a and b indicate a change of skating foot.

Figure 3. Strip chart recordings for edge/flat times.

formation from, the telemetric monitoring device or the instructor. An experimental session from phase two required approximately 35 minutes to perform.

Each subject's total trial time varied as did his time per arc. The error information recorded on the strip chart permitted the precise measurement of each attempt, thus each trial. From this chart recording all calculations were made possible and the percentage trial time spent on edge was recorded as the dependent measure of this study.

The data was analyzed as a 2 X 2 X 20 randomized groups design using analysis of variance, with repeated measures on the last two factors, e.g., 2 groups, 2 days, 20 trials per day. In addition, the last five trials of phase two of the experiment were analyzed with the last five trials of phase one in a 2 X 2 X 5 randomized groups design with repeated measures on the last factor for the purpose of detecting any changes in performance when the monitoring device was removed.

Procedures

The experimental group in this study wore the telemetric monitoring device which provided Ss with instantaneous error information every time response execution was imperfect, i.e., they went 'off-edge'. In addition, at the end of each trial each subject received verbal KR about the success of their performance, as well as teacher generated instructional information on how to improve the next performance. The instructor for the experiment was unaware of the group (experimental or control) to which the subject belonged. This experiment was conducted in this blind manner in order to control experimenter bias. The control group also wore the telemetric monitoring device for the performance recording purposes but did not receive the error generated tone through the earphone from it.

Prior to the start of an experimental session the angle sensors were attached to the skate blades and the critical angles were set by manually manipulating the skates on a flat surface and adjusting the angle threshold controls. The Ss then put their skates on and the critical angles were rechecked.

Prior to each session each skater was given the same verbal instructions which were read to them by the experimenter. The skater's task was to learn to skate six consecutive forward outside edges (three right, three left) along a coincidental axis as cleanly as possible (see Figure 4).

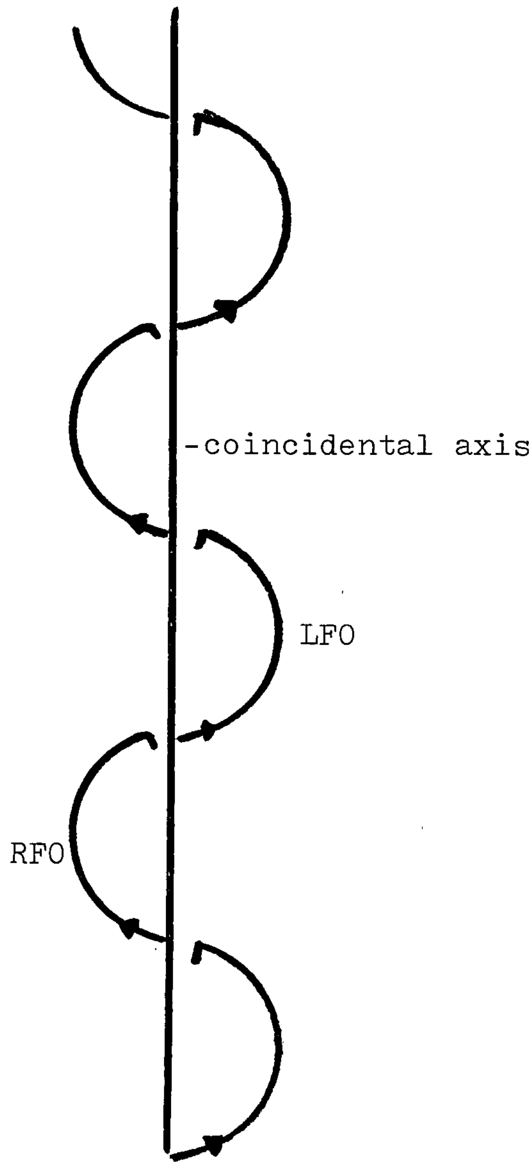


Figure 4. Skaters were asked to skate consecutive forward outside edges along a coincidental axis.

After receiving their instructions, the skaters observed a demonstration of a sample trial and then attempted the appointed task for themselves.

Subjects were instructed to commence the next trial immediately after receiving information from the instructor regarding the previous performance, i.e., an effort was made to control the duration of the intertrial interval.

Only one subject was present during an experimental session to prevent Ss from overhearing FB being given to other Ss. All subjects were given the same directions prior to the experiment (see Appendix B).

CHAPTER IV

RESULTS AND DISCUSSION

Results From Experiment 1

Results from Experiment 1, as shown in Table 1, clearly indicate performance of the experimental group was better than that of the control group, as indicated by higher percentage on-edge scores. A 2 X 2 X 20 analysis of variance was employed and confirmed a signficant groups effect ($p < .001$) (Table 2). While the mean performance over both days for the experimental group was approximately 77%, it was only 39% for the control group, averaged over the same period of time. In fact the experimental group means for each of the performance days greatly exceeded those of the control group.

The ANOVA further confirmed a significant trials effect showing general improvement of performance scores over time (Figure 5). The nature of the trials effect within days was different between Day 1 and Day 2, and this difference was not constant between groups, resulting in a significant Groups X Days X Trials interaction effect

Table 1

Mean Percentage On-Edge Time for Groups on Day 1 and Day 2 in Experiment 1.

	Group 1 (Control)	Group 2 (Experimental)
Day 1	$\bar{x}$=38.16%	$\bar{x}$=70.09%
Day 2	$\bar{x}$=39.89%	$\bar{x}$=84.37%
	$\bar{X}$=39.02%	$\bar{X}$=77.23%

Table 2

ANOVA Table for Experiment One

Source	Sum of squares	Degrees of freedom	Mean square	F	p<
G	357299.85	1	357299.85	37.00	0.0001
Error	173843.12	18	9657.95		
D	3107.08	1	3107.08	0.82	0.3764
D X G	979.92	1	979.92	0.26	0.6167
Error	67974.77	18	3776.38		
T	20889.29	19	1099.44	5.60	0.0001
T X G	1987.75	19	104.62	0.53	0.9472
Error	67150.42	342	196.35		
D X T	4622.30	19	243.28	1.49	0.0867
D X T X G	6125.82	19	322.41	1.97	0.0094
Error	55916.48	342	163.50		

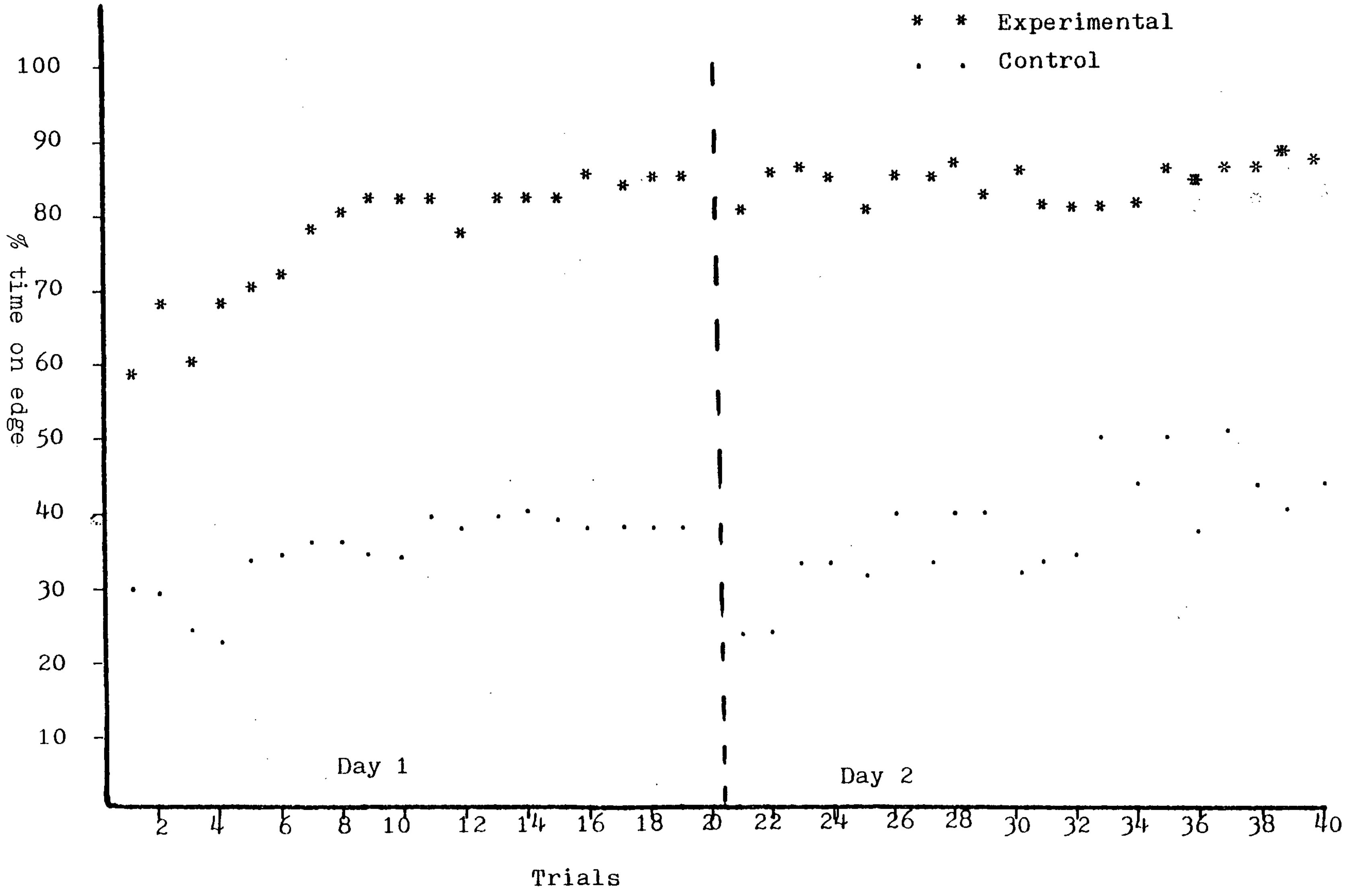


Figure 5. Significant trials effect showing general improvement of performance scores over time.

($p < .01$). This interaction effect was due primarily to a G X D X T linear component. On Day 1 the performance of the experimental group improved by approximately 26% from trial 1 to trial 20, while the control groups' performance only improved by approximately 12%. A linear regression analysis revealed the slope of the experimental group's improvement scores on Day 1 to be 1.3, as compared to the control group's slope of only .63. By Day 2, the experimental group's performance had stabilized (slope =.12), while the control group showed erratic but steady improvement (slope =1.09) (Figure 6).

Discussion of Results from Experiment 1

The purpose of Experiment 1 was to determine the validity of hypothesis one which stated subjects having increased accessibility to relevant FB cues through immediate, concurrent KR would show a greater rate of skill acquisition as reflected in error scores. The mean performance score of the control group for each of the trials at no time matched or even approached the mean performance of the experimental group.

Initial inspection of the data caused concern over the large difference (approximately 26%) which existed between the experimental group and the control group

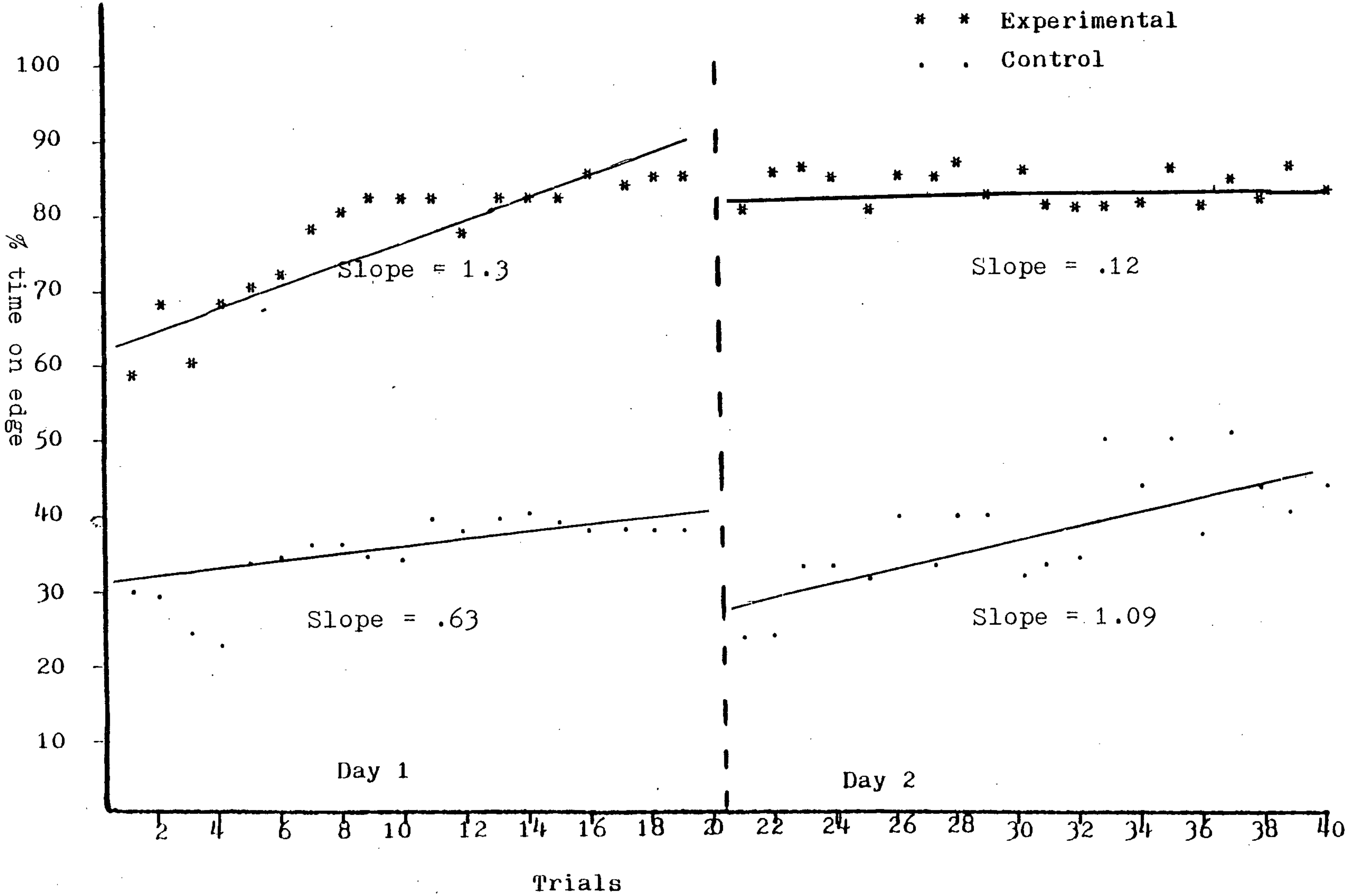


Figure 6. Slopes of learning curves for experiment one.

after the first trial and the effectiveness of the randomization procedure for assignment of subjects to groups was questioned. In light of the fact that one trial consisted of 6 consecutive edges, it was conceivable that much information was lost about the performance of the initial attempts at skating an edge. When the information recorded on the strip chart (blade activity in terms of on-edge/off-edge times per trial) for the first trial was broken down into segments of one quarter and the on-edge time measured for each segment the resulting analysis saw the initially reported difference between the two groups reduced to approximately 7% after the first quarter (Figure 7). In addition, the experimental group demonstrated a very steady improvement rate, while the control group displayed erratic changes that were not always positive. Due to the considerable improvement in performance scores demonstrated by the experimental group throughout trial one, it is certainly reasonable to assume that the large difference observed between the two groups after trial 1 was in fact attributable to considerable learning already having taken place throughout trial 1 by the experimental group.

Clearly, the experimental group's performance was significantly better than that of the control group, as reflected in error scores; the result of a faster rate of

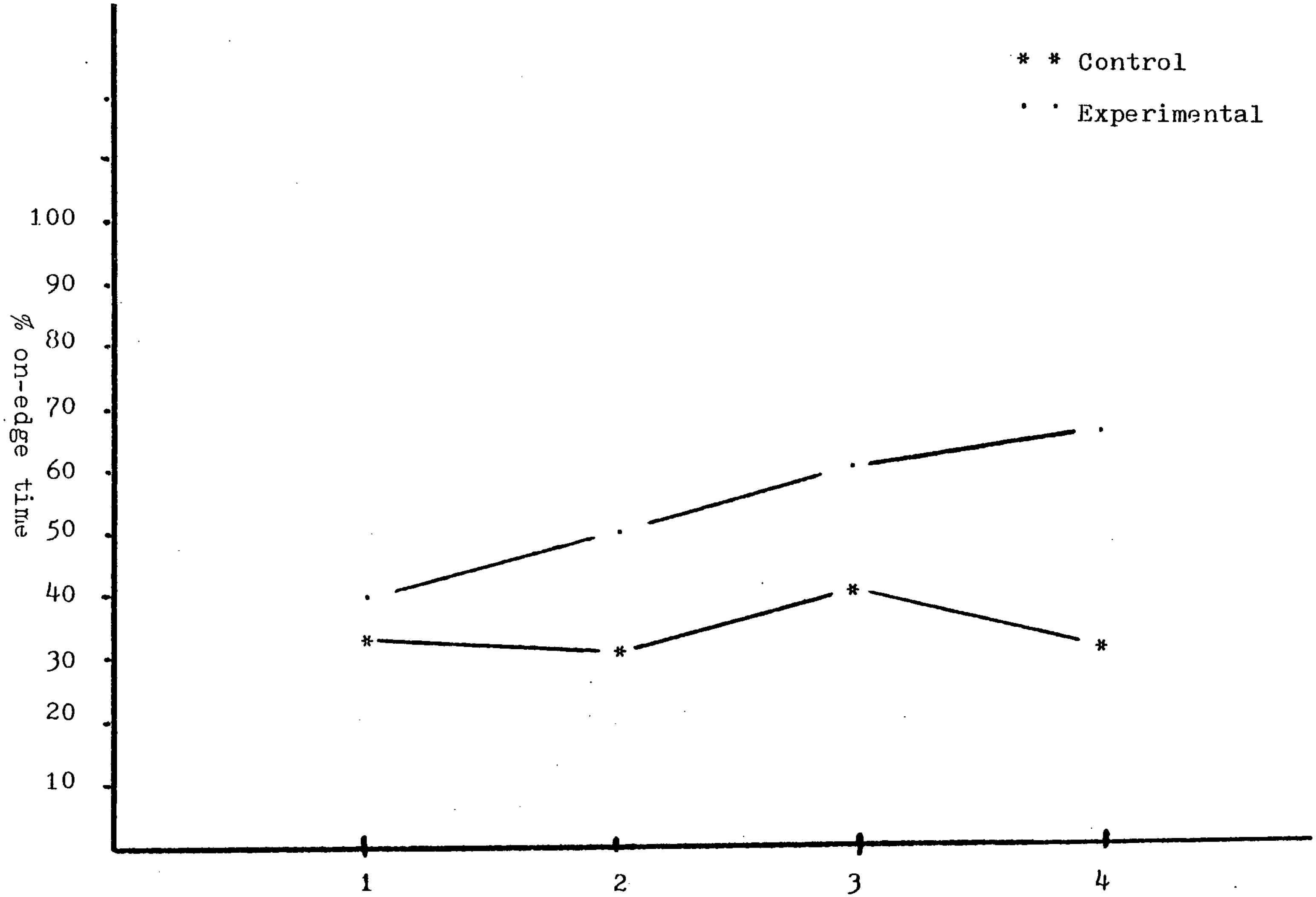


Figure 7. Quarter segments of trial 1, more accurately presenting intergroup differences at the commencement of the experiment.

learning. This finding is in keeping with Adams closed-loop motor control theory, and with the findings of Thorndike (1927), Bilodeau, Bilodeau and Schumsky (1959), Bilodeau (1956), Goldstein and Rittenhouse (1954), and Annett (1959), where KR, used in relation to FB, produced accelerated learning.

While the analysis showed no significant Days, Days X Groups, or Days X Trials effects, these effects must be interpreted in light of the Days X Groups X Trials effect, where the nature of the trials effect within days was different between Day 1 and Day 2 and this difference was not constant between groups.

Results from Experiment 2

Experiment 2 was performed after all trials from experiment 1 had been completed by the performer. Experiment 2 consisted of ten trials on Day 2 performed without the access to the error information produced by the device. Results from the last five trials of Experiment 1 and the last five trials of Experiment 2 were analyzed in a 2 X 2 X 5 ANOVA to investigate performance maintenance.

Analysis of the results failed to reveal significant Trials, Groups X Trials, Conditions X Trials, or Groups X Trials X Conditions effects (Table 3). Thus there was no change in performance over the five trials of either condition. Further, the data analyzed over groups fails to show any significant change in performance from condition 1 to condition 2, and whatever small changes did occur, both groups changed in the same way in their mean performance over the two conditions (Figures 8 and 9).

Results from the analysis indicate a significant Groups effect, with the mean for the experimental group being approximately 87% on edge, and the mean for the control group being approximately 48% on edge (Table 4).

Discussion of Results from Experiment Two

The purpose of Experiment 2 was to determine the validity of the hypothesis that artificially enhancing error information will not inhibit progress to the motor stage of skill acquisition, as reflected by performance maintenance when KR and the added FB are withdrawn. The absence of significant Groups X Trials, or Groups X Conditions effects demonstrates performance maintainance by both groups and can be interpreted as demonstrating successful progression of the experimental group from the

Table 3

ANOVA Table for Experiment Two

Source	Sum of squares	Degrees of freedom	Mean square	F	$p <$
G	76061.70	1	76061.70	19.06	0.0004
Error	71849.21	18	3991.62		
Cond	258.78	1	258.78	0.54	0.4710
CG	3.15	1	3.15	0.01	0.9361
Error	8588.98	18	477.17		
T	499.30	4	124.83	1.29	0.2824
TG	949.16	4	237.29	2.45	0.0537
Error	6972.41	72	96.84		
CT	722.50	4	180.63	2.45	0.0535
CTG	123.49	4	30.87	0.42	0.7942
Error	5301.13	72	73.63		

Table 4

Means for Experiment 2, Showing Performance Stability by both Groups from Experiment 1 to Experiment 2.

	Group 1 (Control)	Group 2 (Experimental)
Condition 1	$\bar{x}$=46.51%	$\bar{x}$=85.76%
Condition 2	$\bar{x}$=49.03%	$\bar{x}$=87.78%
	$\bar{X}$=47.77%	$\bar{X}$=86.77%

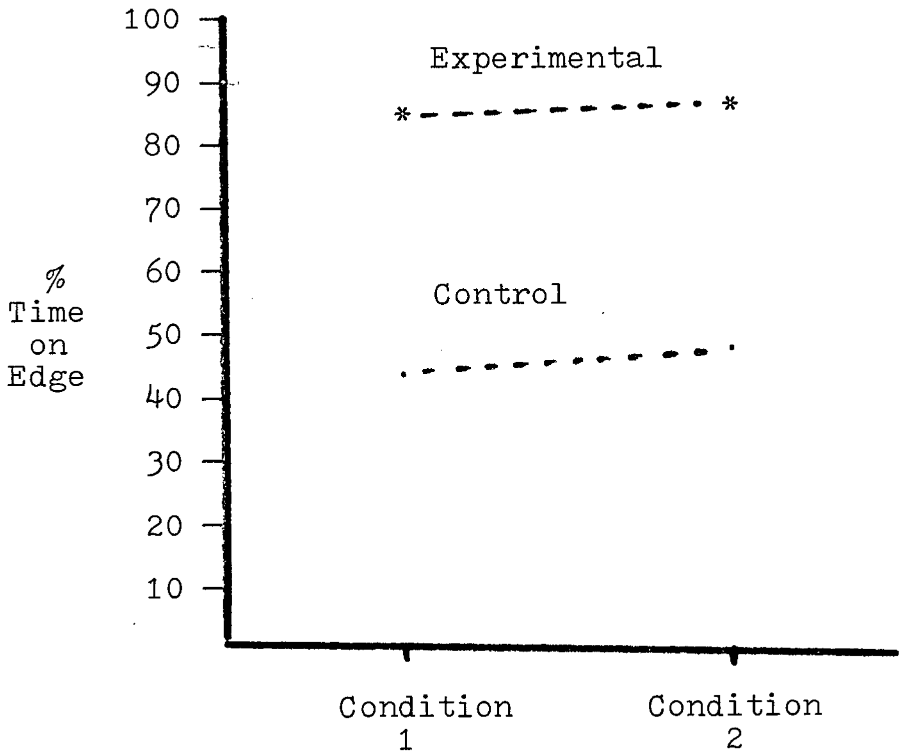


Figure 8. Average performance score by groups and conditions

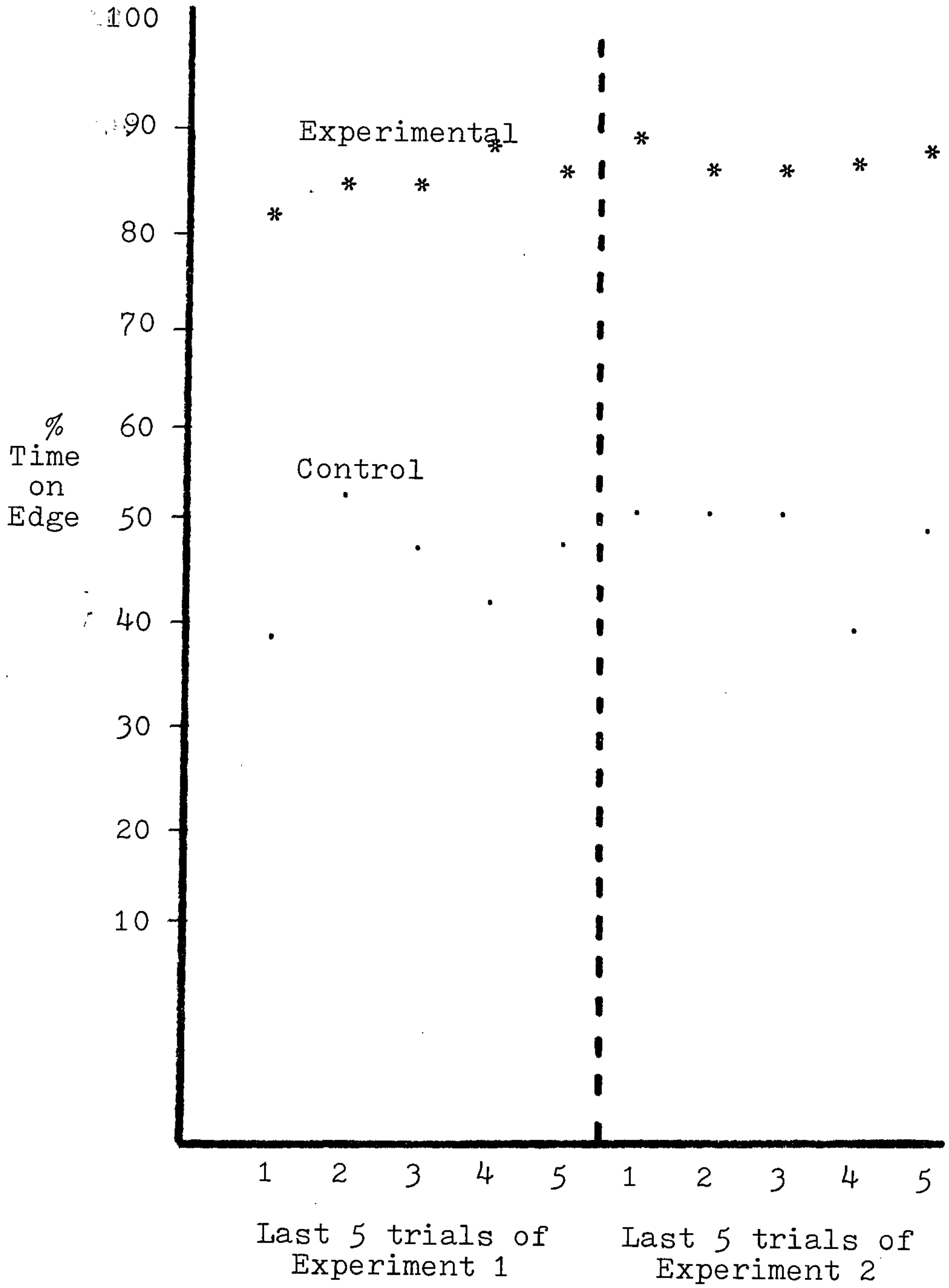


Figure 9. Results from Experiment 2. Comparison of the performance of both groups over the last five trials of Experiment 1 and the last five trials of Experiment 2.

verbal motor stage to the motor stage of skill acquisition, where withdrawal of KR does not affect performance. The findings from Experiment 2 are in keeping with studies by Newell (1974), Bilodeau, Bilodeau and Schumsky (1959) and Bilodeau and Bilodeau (1958). These findings are also in agreement with Adams' closed-loop theory. Presumably, a strong representative PT has been formed by the experimental group over the relatively large number of KR trials and thus became a reliable performance control mechanism when KR was withdrawn.

Summary of Results

Analysis of the results obtained from Experiments one and two are in agreement with closed-loop motor control theory for self-paced motor tasks. Fundamental to Adams' closed-loop motor control theory is the development of a strong and representative PT. Consistent and appropriate responding without the aid of KR infers the existence of a strong and representative PT. The development of a PT is said to be affected by the amount and practice with relevant feedback cues. Thus, exposure to greater amounts of relevant FB cues permits accelerated development of a strong PT, resulting in a faster rate of skill acquisition. A faster rate of skill acquisition is reflected in a steeper, positive learning curve which plateaus with high and stable performance scores. This investigation provides support for the effects of additional amounts of relevant FB cues on the development of a representative PT. The existence of a strong PT is inferred by accelerated learning curves by the experimental group in experiment one.

Maintenance of consistently high performance scores by the experimental group in experiment two can be interpreted as performers functioning in the motor stage of Adams' closed-loop control theory, where control shifts from peripheral to central and KR withdrawal does not affect performance. In this stage, performers rely on a strong perceptual trace as their performance regulation device.

CHAPTER V

SUMMARY AND CONCLUSIONS

The main objective of this investigation was to study the effects of enhancing the accessibility of relevant FB information on the rate of skill acquisition of the continuous self-paced motor skill of skating forward outside edges. Based on the theoretical framework of Adams' closed-loop motor control theory experimentation was conducted in accordance with the hypothesis that subjects having increased accessibility to relevant performance scores (via FB) in a motor skill situation would show a faster rate of skill acquisition.

This experiment involved 20 volunteer novice skaters, performing the self-paced motor skill of skating consecutive forward outside edges along a coincidental axis. Skaters were required to skate twenty trials of six consecutive outside edges on each of two days (6 X 20 X 2 = 240). The experimental group received error information instantaneously from a specially designed telemetric monitoring device (worn by both groups) every time their performance varied from the criterion reference, i.e., they went 'off edge'. Skaters of both groups received appropriate KR from an instructor, who was teaching/coaching/ evaluating in a double blind condition.

There was initial concern that the artificial enhancement of the accessibility of relevant information by use of a FB device might cause performers to become dependent on the device, rather than on FB cues inherent to the task, i.e., a regulating rather than a learning effect. Such an effect would not allow a representative PT to be established and, therefore, hinder progression from the verbal motor to the motor stage of skill acquisition. Thus, a subproblem related to this study examined the effects of withdrawal of information provided by such a FB device. To investigate this subproblem, a second experiment in this study was performed in accordance with the hypothesis that artificially enhancing error information would not inhibit progress to the motor stage of skill acquisition, as reflected in the maintenance of performance levels when KR and the information from the FB device were withdrawn. In this experiment, subjects were required to perform an additional ten trials of six consecutive outside edges (10 X 6 = 60) on day two, where the augmented FB and KR were withheld. Performance was analyzed over the last five of these ten trials, and compared with the last five trials of experiment one.

Conclusions

The conclusions formulated from this investigation are as follows:

1. The provision of concurrent, response generated, relevant FB information results in a faster rate of skill acquisition for the task of skating consecutive forward outside edges. This conclusion is in keeping with closed-loop motor control theory for self-paced motor tasks.

2. Artificially enhancing error information through the use of a telemetric monitoring device does not inhibit progress to the motor stage of skill acquisition.

Discussion

The results and findings of this study are of particular interest to the figure skating coach. Expedient acquisition of sound manoevers and technique are necessary in order that progression to more advanced work can proceed. The device designed for this study has allowed acquisition of the fundamental skill of skating forward outside edges in significantly less time than is normally experienced.

In its present form, the device used in this study would not be practical as a learning aid in a beginner's figure skating program. The time required to fasten the equipment to the skater and set the electronic controls defeats its practicality. Likewise, the presence of bulky wires, although taped out of the way in this experiment, are too cumbersome for the young, beginning figure skater. Sophistication of the device to a point where its operation was completely telemetric, eliminating the bulky wires, and reducing set-up time would make it a valuable aid for the novice learning and mastering compulsory figures. The rewards reaped from use of such a device could be substantial. Although impossible to put an accurate time value on the acquisition of clean, controlled edges, it is safe to say that under normal learning conditions, we are dealing with at least several months of practice time to develop a 'feel' for the difference between flats and edges. This experiment produced this 'feel' after only one and one half hours of practice for most experimental subjects.

A further application of this device would be for skaters who are experiencing difficulty in the performance of a compulsory figure due to flats. Error information can be gained from the device without an instructor having to be present. This saves valuable time for both the skater and coach, as well as many dollars in lesson fees. Application of the device in this manner extends its use beyond the beginning skater to those learning new figures as a result of progression to more advanced work and those experiencing difficulty with particular aspects of more advanced levels of the figure eight in regards to edge control, e.g., flats to center or changes of edge during an inside push-off.

Rapid acquisition of controlled edges (as can be produced with this device) would have tremendous beneficial effects on all aspects of figure skating (freeskate, dance and compulsory figures) as the curving edge is the basis of virtually all skills in figure skating.

Suggestions for Further Research

The literature available for testing closed-loop learning for motor performance deals only with performance of discrete motor tasks. There is no literature available testing the theoretical concerns of closed-loop learning for continuous self-paced motor skills. Research in this area would help to extend the theoretical base of our knowledge of skill learning and be of value to practitioners dealing with instructional methods for continuous motor tasks.

Further, it is suggested that research similar to the present study, but involving more subjects, groups and varying KR and FB enhancement withdrawal periods be employed to determine where progress to the motor stage from the verbal-motor stage occurs during the accelerated rate of learning. It is further suggested that the device used in this experiment might prove useful in remedial skill learning situations, and further experimentation in the remedial area be conducted. Further experimentation should also occur using different age groups to determine the applicability and practicality of the device in different learning situations based on age.

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APPENDIX A

Apparatus

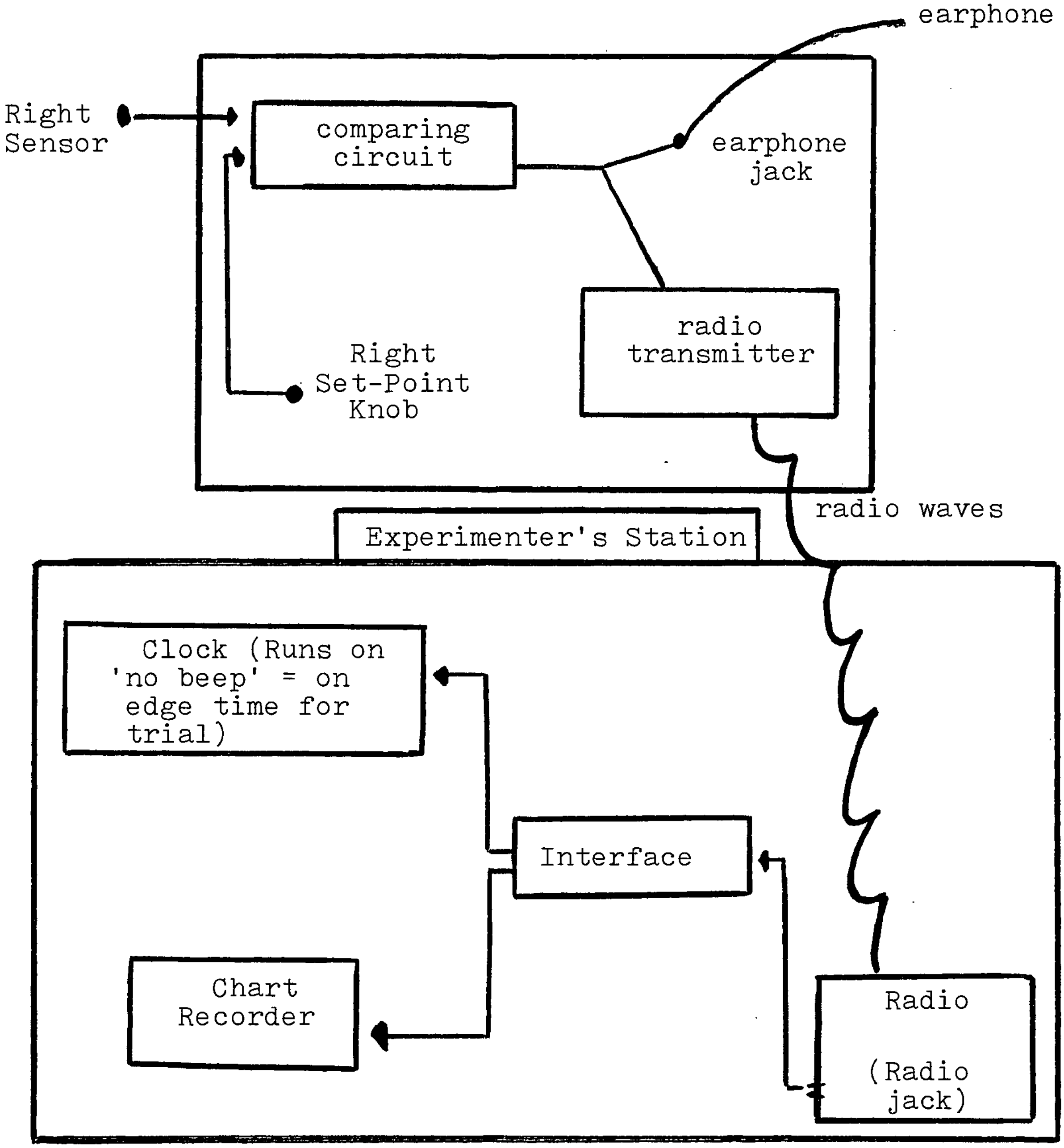

Figure A-1. Device Architecture

The apparatus used consists of a pair of sensors to convert blade-ice angle to an electrical signal, a detector to analyze the angle signal, a headphone and assorted standard devices to transmit and record the detector output.

Input Generator

Blade-ice angle is measured by a mechanical sensor that is attached to the skate blade. The sensor is equipped with a pair of outrigger-styled ice-tracking arms that are arranged to rotate the shaft of a potentiometer which is connected so as to output a voltage that is a monotonic function of blade-ice angle. Since the ice manouevers executed by the subject uses left and right feet alternately, one blade-ice angle sensor is fitted to each skate. The right skate sensor is equipped with a switch that determines whether the left or the right sensor signal drives the apparatus. When the right skate blade is on the ice, the right skate sensor signal is used, when the right skate blade is lifted off the ice the left skate sensor is used.

Tone Generator

The sensor signals are processed by a portable, adjustable threshold detector. When the active sensor signal exceeds the set point value, the detector emits an audio-frequency tone signal that simultaneously transmitted to the subject via an earphone and to the experimenter's station via frequency modulated VHF radio telemetry link. Separate threshold adjustments exist for each skate. As a functioning unit the sensor-detector set provides signals to the subject and experimenter whenever blade-ice angle of the currently active skate exceeds the critical value.

Recording Equipment

Equipment at the experimenter's station consists of a telemetry receiver that drives the measuring equipment. Current measuring equipment configuration includes a chart recorder with simple manual event marker, used for general session history recording and for measurement of session duration, and a high resolution event timer, used for measuring total time spent over the blade-ice angle threshold in each session.

Procedure

At the start of an experimental session the angle sensors are attached to the skate blades and the critical angles are set by manually manipulating the skates on a flat surface and adjusting the threshold controls. Value of the critical angle is set before the skates are put on.

APPENDIX B

Instructions to Subjects

Prior to the commencement of each subject's performance the experimenter read the following instructions:

"You will be asked to perform the skating skill of forward outside edges along the red line on the ice. An outside edge consists of a one foot glide on a curve, where the foot that is off the ice will be on the outside of that curve. This will be demonstrated for you.

You will be asked to perform a total of 50 trials, 20 today, and the rest on one other day within the week. Each trial consists of 6 consecutive outside edges across the ice, alternating from right to left foot, and starting on the right foot. Your starting position will be given to you, and an example of a trail will be demonstrated.

You will receive instructions about how to improve your performance throughout the trials. The object of this exercise is to stay on the outside of the blade for the entire curve that you are skating (minus your pushing time). This requires that you keep your foot tilted to the outside. If you receive a tone from the earphone, this means you are not on edge. To shut the tone off, you must correct your foot position by holding your ankle up over the edge. This will be demonstrated. As soon as you go back on edge, the tone will cease. It is important to your final score that you try to stay on edge as much as possible.

Only the experimental group of this study will receive the beep from the apparatus. The instructor is not aware of which group you are in. It is important to the results of this experiment that this information is kept from her at all times."

APPENDIX C

Trial Scores by Subjects

Table A-1

Percent On-Edge Time by Subject for the Experimental Group in Experiment 1.

Day 1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	51.8	91.5	55.5	72.2	25.6	62.6	50.0	10.3	71.5	92.4
T2	47.6	74.6	54.9	89.2	24.7	76.2	94.3	31.8	63.1	93.5
T3	38.1	79.3	36.9	64.2	40.6	69.5	92.4	38.4	78.4	47.8
T4	45.4	36.8	90.5	75.2	83.6	68.8	66.0	10.2	84.2	91.9
T5	20.9	47.2	82.2	65.6	56.3	75.0	97.6	86.9	92.4	95.7
T6	38.6	57.9	81.6	69.0	61.0	88.5	95.8	69.9	93.5	92.8
T7	66.7	39.8	95.8	81.2	84.5	74.4	96.2	69.8	86.0	69.9
T8	74.2	71.3	88.5	74.5	77.3	77.2	93.4	75.7	90.9	94.2
T9	81.8	84.2	83.5	78.0	84.5	94.0	96.8	73.9	86.2	96.1
T10	87.8	94.9	85.4	64.1	96.3	77.1	94.9	77.9	73.6	96.3
T11	70.7	97.5	91.0	77.8	76.9	75.9	98.9	90.9	69.6	95.1
T12	69.1	90.0	75.2	68.3	76.1	66.8	97.5	68.3	75.1	93.4
T13	70.4	97.7	88.9	74.6	68.0	73.5	97.1	95.0	77.5	87.6
T14	77.5	94.7	95.1	75.9	64.6	69.0	94.6	91.1	79.7	94.9
T15	74.1	94.6	92.9	64.6	87.0	66.5	99.1	95.8	70.7	92.9
T16	74.5	92.3	94.4	82.7	89.1	74.6	98.9	97.1	72.2	85.2
T17	75.5	97.4	95.7	69.3	87.0	70.7	92.9	96.3	67.9	91.6
T18	72.9	97.6	76.6	76.6	93.1	82.0	93.4	91.1	97.5	87.7
T19	84.1	98.0	88.9	62.0	96.7	83.3	74.5	90.8	97.4	87.2
T20	73.4	94.8	87.9	71.9	90.2	77.5	74.4	95.9	97.0	84.6

Table A-1 (Continued)

Percent On-Edge Time by Subject for the Experimental Group in Experiment 1.

Day 2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T21	44.8	97.8	87.1	78.5	90.4	82.9	57.9	87.2	87.9	94.6
T22	64.3	95.1	89.6	85.2	95.1	83.9	67.3	75.3	96.2	92.4
T23	76.9	91.2	83.9	88.4	96.0	78.1	70.8	90.5	89.9	92.5
T24	68.4	83.3	91.3	86.6	94.4	84.2	62.1	91.1	92.5	91.4
T25	67.4	63.6	92.0	80.5	85.3	85.0	70.0	85.9	84.2	93.8
T26	70.4	93.4	92.2	93.8	98.9	84.2	54.2	83.2	93.3	94.7
T27	66.1	92.3	80.0	90.2	95.8	89.5	51.6	88.9	90.6	92.8
T28	74.9	91.1	89.4	89.6	95.7	93.3	55.5	93.0	87.8	93.5
T29	59.3	84.7	89.0	94.6	93.0	93.2	62.1	88.7	97.4	94.3
T30	69.6	94.3	86.0	98.0	92.1	94.0	56.1	93.8	92.2	95.5
T31	64.5	91.9	81.9	85.4	88.8	91.1	60.2	79.7	82.0	86.7
T32	62.3	89.7	81.7	89.1	92.3	92.1	42.9	91.4	79.3	89.3
T33	91.9	88.1	87.1	90.4	91.4	92.6	28.2	88.4	68.5	92.3
T34	93.4	92.1	83.3	90.9	89.9	78.1	21.0	92.9	83.3	91.6
T35	94.6	88.7	91.8	90.9	95.6	90.0	52.6	97.7	85.5	87.7
T36	95.9	96.5	91.1	88.2	84.9	93.7	21.4	97.9	71.1	91.6
T37	98.2	93.9	86.0	92.4	90.5	93.7	29.2	95.8	86.0	89.4
T38	95.6	95.0	84.8	92.5	91.5	91.7	23.4	95.8	92.0	91.3
T39	90.9	95.1	90.3	93.2	98.2	95.4	64.9	96.5	68.0	94.6
T40	90.7	94.5	78.8	82.4	95.1	93.8	53.1	94.8	83.7	93.2

Table A-2

Percent On-Edge Time by Subject for the Control Group in Experiment 1.

Day 1	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	44.1	02.7	69.3	00.0	54.1	43.6	00.6	09.7	29.0	71.5
T2	34.5	05.0	64.9	00.8	58.4	56.7	00.2	13.3	60.9	33.1
T3	13.6	04.9	65.3	02.3	37.0	61.1	00.6	07.3	56.8	39.3
T4	17.5	01.7	69.3	06.4	51.8	48.4	01.0	07.2	32.1	37.6
T5	14.6	02.6	58.9	17.1	68.6	58.5	00.8	06.6	79.0	34.6
T6	18.6	02.4	84.1	09.5	60.9	43.9	00.8	26.2	82.5	40.4
T7	35.6	01.9	78.6	04.2	62.1	59.9	03.0	26.7	89.7	29.1
T8	35.3	07.1	64.2	05.3	65.1	50.8	00.1	20.3	94.6	51.1
T9	53.3	01.3	79.6	03.9	41.5	50.0	00.0	23.2	92.9	42.0
T10	44.3	00.5	90.3	01.7	68.0	31.0	00.5	26.2	88.5	35.9
T11	28.3	48.5	61.2	09.1	67.7	52.3	02.6	26.4	87.8	34.6
T12	28.4	46.9	62.4	06.9	43.8	46.3	01.0	21.9	91.6	42.2
T13	24.5	37.0	48.1	06.4	65.6	57.7	04.2	23.9	92.0	51.1
T14	26.7	41.5	68.3	07.6	64.2	55.1	02.9	38.4	86.4	63.4
T15	22.6	41.3	65.9	02.7	72.6	60.4	01.8	38.0	42.3	71.4
T16	27.1	29.1	64.8	01.6	76.9	55.8	00.5	40.1	59.9	52.4
T17	35.5	28.8	60.2	00.3	58.3	63.0	04.7	45.1	72.1	48.7
T18	36.6	34.1	69.4	15.6	50.8	48.7	05.2	46.5	56.8	52.1
T19	27.2	32.2	56.8	04.1	49.5	50.1	13.5	51.3	70.3	52.9
T20	35.1	30.4	49.8	07.9	66.1	52.6	13.3	31.7	73.7	45.3

Table A-2 (Continued)

Percent On-Edge Time by Subject for the Control Group in Experiment 1.

Day 2	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T21	00.1	03.4	15.0	07.6	75.3	00.9	22.9	31.8	77.6	25.3
T22	00.2	06.2	23.3	00.8	63.1	00.6	17.5	50.6	79.1	44.0
T23	00.0	01.8	63.6	07.5	70.3	01.5	16.7	50.0	83.4	36.1
T24	00.7	01.5	51.8	08.0	67.5	05.3	18.4	48.4	88.1	40.5
T25	00.0	06.0	42.0	01.7	71.0	03.5	09.8	51.5	85.9	48.1
T26	12.8	19.4	08.0	05.1	56.6	01.2	10.4	66.2	94.2	40.5
T27	14.5	26.6	29.0	13.5	23.9	00.8	15.9	80.3	88.9	43.6
T28	22.7	18.5	17.9	13.1	65.1	53.7	24.7	84.7	84.9	40.8
T29	02.5	08.8	06.7	15.2	52.5	54.1	40.5	85.5	84.9	48.8
T30	12.8	20.3	29.6	15.8	20.3	44.9	22.8	64.2	87.0	28.0
T31	08.5	39.0	21.5	20.8	54.8	54.2	04.9	65.9	90.6	17.8
T32	05.1	50.8	20.1	44.7	61.1	53.1	08.9	50.6	85.0	19.3
T33	11.5	47.5	37.0	66.3	76.7	50.2	25.5	84.4	83.0	20.9
T34	08.8	36.0	57.8	63.4	23.5	50.3	12.2	61.8	82.7	44.4
T35	12.7	54.2	60.0	37.5	53.9	52.7	21.4	82.4	84.2	49.8
T36	12.4	18.3	26.0	55.2	19.3	75.8	05.6	67.5	84.1	28.5
T37	56.1	32.3	23.1	65.8	60.7	78.6	23.4	68.1	87.1	37.2
T38	33.8	55.9	17.6	63.6	68.7	66.1	16.0	51.9	87.5	17.2
T39	00.4	46.6	35.9	45.5	37.2	72.0	10.7	66.9	86.9	33.5
T40	02.0	51.5	29.0	58.6	60.0	77.6	13.5	73.8	87.5	33.0

Table A-3

Percent On-Edge Time by Experimental Subjects in Last Five Trials of Experiment 2.

Trials	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T6	82.5	96.2	96.3	95.2	94.4	92.6	67.8	91.6	86.2	89.5
T7	82.5	96.8	72.6	94.9	90.5	92.8	69.0	95.8	76.6	90.4
T8	76.8	97.6	68.7	88.1	94.9	94.9	78.1	89.4	86.7	94.3
T9	82.1	94.4	76.3	91.9	92.6	84.5	82.0	94.2	88.6	91.1
T10	86.2	96.6	96.9	94.1	91.6	94.0	77.0	71.8	85.9	93.6

Table A-4

Percent On-Edge Time by Control Subjects in Last Five Trials of Experiment 2.

Trials	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T6	02.3	52.9	37.0	26.9	62.7	94.5	23.8	74.4	98.4	40.7
T7	02.5	18.0	50.7	52.6	62.9	92.2	36.2	79.0	81.5	40.6
T8	14.2	33.8	33.3	23.5	67.9	96.4	25.4	73.8	98.6	43.4
T9	04.7	33.4	33.4	14.1	18.2	92.3	10.3	71.0	94.5	31.3
T10	01.7	52.4	34.6	33.4	49.2	96.7	34.9	83.4	79.7	42.0