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Kaisu Mononen

The Effects of Augmented Feedback on Motor Skill Learning in Shooting

A Feedback Training Intervention among Inexperienced Rifle Shooters

JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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The present study focused on examining the effects of knowledge of performance (KP) on motor skill performance and learning within the context of precision rifle shooting. KP was based on the on-target trajectory of the alignment of the rifle, accompanied by visual or auditory feedback. The effects of KP were evaluated in terms of shooting accuracy, rifle stability, and postural balance. For this purpose, male conscripts (n=58) with limited shooting experience were randomly assigned to the one of the following five groups: a group receiving knowledge of results (KR) with visual KP after each trial, a group receiving KR with visual KP after 50% of the trials, a group receiving KR with auditory KP during 50% of the trials, a group with KR only after each trial, and a non-training control group. The four experimental groups accomplished a 4-week training period during which feedback was provided. No-feedback retention tests were administered at 2, 10, and 40 days after acquisition. The participants with auditory KP during 50% of the trials showed the highest shooting accuracy in all the retention tests. Visual KP after each trial benefited shooting accuracy when compared to reduced frequency of visual KP, or no KP. Furthermore, the participants with high frequency of visual KP performed with significantly lower maximal amplitude of sway when compared to the KR group. The indices for rifle stability did not differentiate among the groups with different visual KP conditions. In all, the present study demonstrated that augmented feedback describing the essential aspect of shooting performance was beneficial for the performance and learning of precision shooting. In particular, auditory KP during 50% of the trials seemed to promote shooting performance among inexperienced shooters. It is concluded that auditory feedback provided concurrently with aiming promoted a shooter's self-initiated error detection and correction abilities by directing his attention to the critical components of psychomotor regulation.

Keywords: motor skill learning, augmented feedback, knowledge of performance, shooting accuracy, rifle stability, postural balance

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following papers, which will be referred to by their Roman numerals.

Study I	Kaisu Mononen, Niilo Konttinen, Jukka Viitasalo, Pertti Era. 2007. Relationships between postural balance, rifle stability and shooting accuracy among novice shooters. Scandinavian Journal of Medicine & Science in Sports (in press).
Study II	Kaisu Mononen, Jukka Viitasalo, Niilo Konttinen, Pertti Era. 2003. The effects of augmented kinematic feedback on motor skill learning in rifle shooting. Journal of Sports Sciences 21, 867-876.
Study III	Kaisu Mononen, Niilo Konttinen, Pertti Era, Jukka Viitasalo. 2005. The effects of augmented kinematic feedback on rifle shooting performance. Journal of Human Movement Studies 48, 57-73.
Study IV	Niilo Konttinen, Kaisu Mononen, Jukka Viitasalo, Toni Mets. 2004. The effects of augmented auditory feedback on psychomotor skill learning in precision shooting. Journal of Sport & Exercise Psychology 26, 306-316.

In addition some unpublished data are presented.

1 INTRODUCTION

Motor skill learning plays a crucial role in the performance of everyday tasks. The experiences of motor skill learning may range from relearning to walk after a stroke to coping with a demanding surgical operation or acquiring a complex sport skill. It is widely known that task performance appears to improve in a consistent manner with practice (i.e. Fitts 1964, Adams 1987, Schmidt & Lee 1999, Magill 2001). It is, however, not just the amount of training, but also the training conditions and quality of practice that can have a significant effect on the rate of learning and final performance (e.g. Schmidt & Lee 1999).

With regard to the quality of practice, a potential way to support the learning process is to provide a learner with augmented task-related feedback that supplements the response-produced inherent feedback obtained from vision, audition, and proprioception. The learner can achieve a certain skill level with task-intrinsic feedback, but in order to attain a higher level of expertise, augmented feedback is needed (Magill 1994). In the tasks where the information from intrinsic sources does not provide the feedback needed to determine the appropriateness of the performance, or when the information critical to learning the skill cannot be adequately accessed by the learner, augmented feedback can play an essential role in effective skill acquisition (see Magill 1994).

For decades, researchers examining motor learning have been interested in augmented feedback, which provides the learner with information about the outcome of a movement in relation to the environmental goal after response completion. This type of feedback is called knowledge of results (KR) (Bilodeau et al. 1959, Adams 1971, Salmoni et al. 1984, Adams 1987). In the early studies, frequent presentation of KR was regarded as critically important for motor learning, and its effectiveness was mainly investigated by using simple, one-degree of freedom tasks (Bilodeau et al. 1959). Currently, it has been believed that the effects of augmented feedback depend not only on feedback frequency but on a number of other factors: nature, mode, frequency, precision, amount, and timing of feedback are thought to interact with task complexity and the learner's task-related experience (Magill 1994, Wulf & Shea 2002).

Another form of augmented feedback provides the learner with information about the nature of the movement in question. It is called knowledge of performance (KP). KP has been shown to be relevant, especially in everyday settings with reasonably complex tasks (Schmidt & Young 1991). Furthermore, KP has been suggested to be more important than KR alone in tasks where an appropriate outcome depends on interaction among movement segments (e.g. Newell & Walter 1981, Newell & Carlton 1987, Schmidt & Young 1991, Schmidt & Lee 1999).

Precision rifle shooting offers a good example of a motor task in which augmented feedback may be thought to facilitate skill acquisition. The naturally available sources of information in shooting are vision and proprioception. The primary determinant of the success of the task is the shooting result, and the task-intrinsic feedback does not always provide the information necessary to determine the success of the performance. Information about the movement pattern in shooting has mainly been based on a coach's subjective observations of the subject's shooting technique or a videotape of the performance. Furthermore, in precision rifle shooting the goal is not isomorphic with the movement pattern; i.e., the movement pattern can be separated from the performance goal (see Schmidt & Young 1991). Therefore, a distinction between feedback about the movement pattern and the environmental goal can be made. Moreover, the effects of augmented feedback can be evaluated using the shooting result, which is an unambiguous measure of performance outcome. On the basis of these considerations, rifle shooting seems to be an appropriate target for examining the effects of augmented feedback.

The primary purpose of the current study was to examine whether augmented KP on the essential characteristics of performance would have an effect on the environmental goal (shooting accuracy) and movement pattern (postural balance and rifle stability) among inexperienced rifle shooters. The aim was to extend the knowledge on the effects of augmented information feedback on complex skills in the early phase of learning. An attempt was also made to find means to assist an inexperienced shooter to enhance his or her performance.

2 REVIEW OF THE LITERATURE

2.1 Motor learning

Motor learning is a set of internal processes associated with practice or experience leading to relatively permanent changes in the capability for movement (Schmidt & Lee 1999). It is suggested that motor learning is an ongoing process in which a learner passes through distinct phases during skill acquisition.

2.1.1 Motor learning theories

In the learning of a motor skill, several theoretical approaches have been introduced. Adams's closed-loop theory (Adams 1971, Adams 1987) states that the learner acquires a reference of correctness (perceptual trace) with practice, and that improvement in performance is a result of the learner's increased capability to use the reference in movement control. Adams's closed-loop theory has usually been used to explain the control of slow, deliberate movements, and the use of feedback and the activity of error detection and correction processes are strongly emphasized. Schmidt's schema theory (Schmidt 1975, Schmidt 2003) proposes that slow movements are feedback-based, but rapid movements are program-based and structured and driven centrally. According to the schema theory, with learning the subject is able to develop rules (schemas) that allow the generation of new movements. From the dynamical systems perspective (see Williams et al. 1999 for an overview) the human movement system is a highly complicated network of co-dependent sub-systems, and movement patterns appear through general processes of self-organization found in these systems (Newell et al. 1991, Kelso 1995, Schmidt & Fitzpatrick 1996). The dynamical systems theory emphasizes the role of environmental information in the interaction between the sensory-perceptual system and the motor-control system; hence, the account of feedback is considered less important (Magill 1994).

In the present study, precision rifle shooting is considered as a slow, deliberate closed-skill performance, during which errors can be detected and corrections can be made. Furthermore, as the environment in precision shooting is stable and predictable, the shooters are not required to adapt their movements in response to the dynamic properties of the environment.

2.1.2 Stages of motor learning

The acquisition of motor skills can be introduced in terms of three phases of practice: the cognitive stage, associative stage and autonomous stage (Fitts & Possner 1967). The goal of learning is to gradually automate the skill through these stages. In the *cognitive stage* the learner concentrates on performing the skill. The focus is on discovering what to do, and there is high variability and a large number of errors in performance because the learner is trying many different ways of solving the problem. Therefore, it has been proposed that the use of instructions, models and augmented feedback are particularly beneficial during this stage of learning (Schmidt & Lee 1999). Instructions may help a learner to see the similarity of the elements between previously learned tasks and the new task to be learned, and demonstrations or visual models may provide a learner with information about the desired movement pattern. In the *associative stage*, the learner is able to detect and considerably correct the errors of performance. The learner focuses on the dynamics of the skill in order to perform smooth and refined actions. He or she also demonstrates more consistency and efficiency in performance because strategies for skill refinement become more subtle. In this phase, feedback and instructions should be more precise and focus on those aspects of the movement the learner is attempting to refine (Schmidt & Wrisberg 2000). The *autonomous stage* can be reached after extensive practice. In this stage, the learner does not have to concentrate on the skill and is able to perform the skill without paying attention to the movement itself. In this stage the performer only makes small errors but is now able to detect and correct them and produce an optimal performance. Performance improvements are somewhat difficult to detect during this stage, as the learner is reaching the limits of his or her capabilities. When the performance becomes characterized by increased automaticity, it allows a learner to process information from other aspects of the task, such as strategy, or the form or style of the movement (Schmidt & Lee 1999).

There are several factors that have effects on the motor learning process, of which two of the most powerful are practice and feedback. In the current study, the aim was to affect quality of practice by providing participants with augmented feedback during training. The feedback intervention was directed to the early phase of learning, i.e. the cognitive stage and the subsequent transition phase, in which augmented feedback has been thought to be especially beneficial.

2.2 Feedback

In the context of motor skill learning, the term feedback refers to performance-related information that the learner receives during and after performing the task. Two general types of feedback in motor skill learning situations are task-intrinsic and task-extrinsic or augmented feedback. The role of intrinsic information that arises as a natural consequence of producing movement is indispensable for motor performance and learning. Intrinsic feedback is sensory information that can come from sources outside of the body (exteroception), or from inside the body (proprioception). Exteroceptors provide information about the movement of the objects in the environment, mainly with the help of vision and audition. Proprioceptors provide information about the movement of one's own body, such as signals of body and limb movement, and position. This occurs via the vestibular system, and muscle, joint and cutaneous receptors (Schmidt & Lee 1999). Individuals are able to perceive intrinsic feedback without special assistance from other sources, such as instructions or devices. Although in many cases intrinsic feedback requires no evaluation, in some cases an individual has to learn how to evaluate sensory information, such as joint angle or limb position (Schmidt & Lee 1999). Artificial feedback that supplements the intrinsic feedback is called extrinsic or augmented information feedback (see Swinnen 1996).

2.2.1 Types of augmented feedback

The presentation of augmented information feedback, or augmented feedback, has been considered essential for motor learning. Two types of augmented feedback have been usually used in the context of motor learning: knowledge of results, and knowledge of performance. Knowledge of results (KR) is commonly defined as post-response, augmented information about the success of performance in relation to an environmental goal. In contrast to KR, knowledge of performance (KP) defined as extrinsic, post-response kinematic or kinetic information refers to aspects of the movement pattern (Gentile 1972, Newell & Walter 1981, Newell & Carlton 1987, Schmidt & Young 1991). The types of KP common to motor skill instructions are verbal cueing (Hebert & Landin 1994), modeling (Carroll & Bandura 1990), videotape (Emmen et al. 1985, Van Wieringen et al. 1989, Kernodle & Carlton 1992, Hebert & Landin 1994, Tzetzis et al. 1999, Guadagnoli et al. 2002, Hodges et al. 2003) graphical representation (Newell & Carlton 1987), and visual feedback (Proteau 1992).

Research on KR has been prolific when compared that on KP (see Salmoni et al. 1984) and therefore, the knowledge concerning augmented feedback in general derives from KR research. Although KR and KP refer to different aspects of performance it has been suggested that the mechanisms of both KR and KP are essentially the same (Gentile 1972, Schmidt & Young 1991, Schmidt

& Lee 1999). Thus, in the present study, the principles that have been discovered for KR are regarded as applicable to KP as well.

Augmented feedback can play different roles in the motor skill learning process (Schmidt & Lee 1999). Firstly, it may provide the learner with task-related information about the skill being performed or just performed. This information can be either general, describing whether the performance was successful or not (descriptive role), or more specific informing the performer about the errors made and the actions the learner should do to correct those errors (prescriptive role). Secondly, augmented information feedback may motivate or energize individuals by making the task seem more interesting, thereby leading learners to increase their efforts to achieve their learning goals (motivational role) (see Adams 1987, Little & McGullagh 1989, Annesi 1998, Silverman et al. 1998).

Augmented feedback is typically conveyed to the learner by some outside source, such as instructor, videotape, or kinematic information about the movement after the motor task has been completed. It has been shown that in learning motor skills which require the appropriate scaling of a single degree of freedom of movement, KR usually specifies all the information that is needed (see Salmoni et al. 1984, Newell et al. 1987, see Swinnen 1996, for a review). In more complex tasks, however, when the appropriate outcome depends on interaction among movement segments, KP describing movement kinematics or kinetics has been demonstrated to be more important than KR alone (e.g. Newell & Walter 1981, Newell & Carlton 1987, Schmidt & Lee 1999). Given that the precision shooting in the present study can be considered a complex task, movement kinematics during the aiming phase was selected as the content of KP.

Kinematic feedback

Kinematic feedback gives information about some aspect of the learner's movement pattern, i.e., kinematics, such as the position, velocity, or acceleration of the limbs, usually as a function of time (Schmidt & Young 1991). The effectiveness of kinematic feedback has been shown to be dependent on the relevance of the information to the success of the movement or task goal. Furthermore, the benefit of kinematic feedback may be optimised if its content specifies information that cannot otherwise be generated from other sources, such as intrinsic sources (Schmidt & Lee 1999). Kinematic feedback has usually been delivered as graphic visual information about movement kinematics during (Schmidt & Wulf 1997, Wishart et al. 2002) or after performance (Mulder & Hulstijn 1985, Young & Schmidt 1992, Brisson & Alain 1996, Brisson & Alain 1997, Ivens & Marteniuk 1997). Information about the movement pattern has also been delivered as an auditory signal, mainly during performance, and as response-correct information (Gauthier 1985, Clarkson et al. 1986, Takeuchi 1993, Jagacinski et al. 1997, Baundry et al. 2006), although also prior to the response (Keele & Summers 1976).

Young and Schmidt (1992) have pointed to two challenges concerning kinematic feedback research: first, the use of retention or transfer tests and, second, the use of tasks in which the movement goal is isomorphic with the pattern of action necessary to produce the goal. The tasks used in feedback research have mainly been simple, single degree of freedom tasks which are easy to accomplish in a laboratory environment. In these settings, however, the environmental goal and the movement pattern are often identical making KR and kinematic feedback redundant. Furthermore, generalizing the results of these studies to more complex tasks, where new movement patterns must be learned, is not straightforward (Schmidt & Young 1991, Wulf & Shea 2002).

2.2.2 Frequency of augmented feedback

It has been suggested that the frequency of augmented feedback is an essential variable when delivering feedback. In the literature, it has been examined whether the absolute frequency (feedback given for a specific number of trials) or relative frequency of augmented feedback is more important for motor learning (see Salmoni et al. 1984). According to the early research on KR (e.g. Bilodeau & Bilodeau 1958), absolute feedback frequency was crucially important for motor learning. Furthermore, learning was thought to be optimised when feedback was provided frequently. More recently, a number of studies with retention tests have showed that reduced relative feedback frequency leads to better learning effects (e.g. Salmoni et al. 1984, Wulf & Schmidt 1989, Winstein & Schmidt 1990, Sparrow & Summers 1992, Wulf et al. 1994, Weeks & Kordus 1998). Adding an extra degree of difficulty for the learner during practice, such as withholding augmented feedback on some practice trials, has been argued to be beneficial for learning, because it forces the learner to develop his or her own internal error detection and correction mechanisms (see Wulf & Shea 2002). Since the Winstein and Schmidt (1990) study, there have been attempts to find out whether there exists an optimal frequency of augmented feedback that benefits motor skill learning (e.g. Wulf et al. 1994, Lai & Shea 1999). The results suggest that the optimal feedback frequency, however, depends on a number of factors, such as the characteristics of the skill being learned and the learner's task-related experience (Wulf et al. 1998).

In addition to positive effects, frequent augmented feedback has also been found to have detrimental effects which have been explained by the guidance hypothesis proposed by Salmoni et al. (1984). According to this hypothesis, frequent augmented feedback may guide the learner to correct performance when it is available, but it may also have detrimental effects on learning when it is no longer available. Three explanations have been introduced for the negative effects of guidance in motor learning (Schmidt 1991, Young & Schmidt 1992, see also Anderson et al. 2005). First, frequent feedback can encourage a learner to ignore important sources of intrinsic sensory feedback (Salmoni et al. 1984, Schmidt 1991). Second, when augmented feedback is presented too frequently (or it is too easy to use), a learner might become too dependent on feedback and bypass the processing of other important sources of feedback (e.g. intrinsic feedback) which may be essential in developing error detection and correction mechanisms. Third, frequent feedback may encourage a learner to make too many corrections during practice (see Schmidt 1991), which may hinder the recognition and production of stable behaviour when feedback is withdrawn.

In order to avoid the negative effects of frequent augmented feedback various techniques have been applied. In addition to simply reducing the relative frequency of augmented feedback, for example by delivering feedback systematically on every third trial (Weeks & Kordus 1998), other techniques such as fading, bandwidth, summary, average or self-controlled schedules, have been used. In the fading schedule, the relative frequency of feedback presentation is high during the initial stages of performance and faded toward to the end of acquisition (Wulf & Schmidt 1989, Winstein & Schmidt 1990, Wulf et al. 1998). Bandwidth technique refers to the providing of feedback only if the performance errors are outside the predetermined range of correctness; however, the no-feedback condition is also informative, indicating that the performance is approximately correct (Sherwood 1988, Lee & Maraj 1994, Goodwin & Meeuwsen 1995, Lai & Shea 1999, Badets & Blandin 2005). In the summary schedule, feedback on all the trials is provided after a certain number of trials have been completed, the idea being that the learner receives the same amount of information as in every trial feedback, but at the reduced frequency (Lavery 1962, Schmidt et al. 1989, Schmidt et al. 1990, Guadagnoli et al. 1996). Average feedback may be considered as a variant of summary feedback, in which feedback consists of averaged information on trials (Young & Schmidt 1992, Yao et al. 1994, Wulf & Schmidt 1996). In the self-controlled frequency technique, the learner asks for augmented feedback when he or she desires (Janelle et al. 1995, Janelle et al. 1997, Chiviakowsky & Wulf 2002, Chiviakowsky & Wulf 2005).

The frequency of augmented feedback has been shown to interact with different variables in affecting motor skill learning, such as task complexity and learner' s task-related experience (see Wulf & Shea 2002, for a review). There is some evidence that the learning of simple motor tasks may benefit from a reduction in augmented feedback (Winstein & Schmidt 1990, Schmidt & Wulf 1997, Lai & Shea 1999). One explanation for this could be that when the task and the performance measure are isomorphic, as is often the case in simple tasks, learners do not need augmented feedback on every trial (Magill 1994). It has been also suggested that the learning of a simple task might be enhanced by making practice more difficult or challenging for the learner by reducing feedback frequency (Wulf & Shea 2002). In contrast, it has been proposed that more frequent feedback may advance the learning of more complex skills which can not be mastered in single session and have several degrees of freedom (Schmidt et al. 1990, Yao et al. 1994, Guadagnoli et al. 1996, Wulf et al. 1998, Wulf & Shea 2002). It has been also suggested that when the task involves several possible performance characteristics on which the augmented feedback is given, more frequent feedback is beneficial (Magill 1994). Furthermore, the learning of complex skills with inherently high attention, memory or control demands may not benefit from increasing the demands imposed on the learner, such as reducing feedback frequency (see Wulf & Shea 2002).

Wulf and Shea (2002) proposed that because different components have to be coordinated to produce skilled performance, augmented feedback in complex tasks is generally not as prescriptive as in simple tasks. Therefore, the learner has also to rely on intrinsic feedback sources, thereby reducing dependence on feedback. With respect to the learner's task-related experience, Wulf and Shea (2002) suggested that although reduced frequency may benefit the learning of simple tasks for both novices and experienced individuals, frequent feedback might be more effective in learning a complex task, especially for novices.

2.2.3 Timing of augmented feedback

The time when augmented feedback, both KR and KP, is delivered has been found to be one important issue affecting motor performance and learning. Augmented feedback has mainly been delivered either terminally, after the task has been completed or concurrently, during the actual movement.

Feedback is most commonly delivered after an individual has completed the performance of the skill. Terminal augmented feedback has not shown strong guidance properties (see Lai & Shea 1999). This has been shown in studies where reduced and high KR frequency groups have not differed in performance during acquisition (Winstein & Schmidt 1990). With regards to the timing of terminal feedback, two important time intervals have been introduced: the time that occurs between the end of the trial and the presentation of the augmented feedback (KR-delay interval), and the time between the presentation of the augmented feedback and the next trial (post-KR interval). It should be noted that, although these two terms used here with respect to KR, they also apply to KP (Magill 2001). Although the KR-delay interval does not appear to have much effect on skill learning (Adams 1971), it has been suggested that in order to achieve permanent changes in performance, there seems to be minimum amount of time that must pass before feedback (KR) is delivered (Swinnen et al. 1990). It has been proposed that the post-KR interval is critical for skill learning, because during that period the learner receives both intrinsic feedback and augmented feedback on the just-completed performance, and he or she can then use this information in developing a plan of action for the next trial. Similarly, with respect to the KR-delay interval, it seems to be beneficial that minimum amount of time elapses between the presentation of the augmented feedback and the beginning of the next trial (Weinberg et al. 1964, Rogers 1974). Depending on the type of the task, the activity done during these time intervals may have no influence, may interfere with or may benefit learning (Hogan & Yanowitz 1978, Lee & Magill 1983, Benedetti & McGullagh 1987, Swinnen et al. 1990, Liu & Wrisberg 1997).

Concurrent augmented feedback, delivered during the actual movement, can be presented discontinuously as a signal that a certain level of performance has been achieved, or continuously, indicating a momentary performance error (Schmidt & Wulf 1997). Concurrent feedback can be given as a kinetic or kinematic representation of the movement, as biofeedback or as the real time representation of a coordination pattern (Gentile 1972, Swinnen 1996, Schmidt & Lee 1999). It has been suggested that concurrent augmented feedback is effective, as it guides the learner to the correct response, minimizes errors, and maintains behaviour on target (Schmidt & Wulf 1996). More precisely, concurrent augmented feedback may facilitate on-line control through the establishment of a direct link between the desired outcomes and the participant's intrinsic information (Swinnen et al. 1997). On the other hand, although concurrent feedback has shown to have strong performance-enhancing effects when it is available during practice, the gains in performance have been shown to disappear when the feedback has been removed in a retention or transfer test (Vander Linden et al. 1993, Winstein et al. 1996, Schmidt & Wulf 1997; see also Park et al. 2000). It has been suggested that concurrent feedback may direct the learner's attention away from critical task-intrinsic feedback (guidance hypothesis), which is manifested as a decline in performance in transfer and retention tests (Vander Linden et al. 1993, Kohl & Shea 1995, Schmidt & Wulf 1997). Consistent with the predictions of the guidance hypothesis it has been suggested that lower relative frequencies might enhance learning as trials without feedback may cause the learner to engage in additional important cognitive processes such as those related to error detection (Winstein & Schmidt 1990), although contrary results have been also found (Baudry et al. 2006). With regard to complex motor tasks, a number of studies have found that the performance and learning of a skill, such as dance routines (Clarkson et al. 1986), cycling (McLean & Lafortune 1988, Sanderson & Cavanagh 1990, Broker et al. 1993), and swimming (Chollet et al. 1988), is enhanced when concurrent feedback is provided. These studies indicate that augmented feedback in real time can have powerful effect on performance in certain sport tasks.

2.3 Precision shooting

Precision shooting is an example of a discrete complex task, which has several degrees of freedom and which cannot be mastered in a single session but requires extensive practice (see Wulf & Shea 2002). It allows separation between the environmental goal and movement pattern. The environmental goal is to hit the centre of the target with the pellet, and the shooting score describes how well this goal is achieved. In turn, the movement pattern is clearly distinct from the shooting score, and can be expressed, for example, in terms of the shooter's postural balance, the stability of the gun, or other kinematic characteristics of performance. In shooting, there is no single optimal movement pattern, but different movement patterns can be used to produce a similar outcome, i.e., the same shooting score.

It has been suggested that shooting is a motor task that demands many perceptual-motor attributes, including good postural stability (Niinimaa & McAvoy 1983, Aalto et al. 1990, Era et al. 1996, Konttinen et al. 1999) and a high level of eye-hand co-ordination (Mason et al. 1990, Zatsiorsky & Aktov 1990, Konttinen et al. 1998, Ball et al. 2003b, Mononen et al. 2003). With respect to the psychological factors, the performer's ability to achieve and maintain a state of alert immobility has been established as an important contributor to successful shooting performance (see Konttinen et al. 1998). From the psychophysiological point of view, placement of the shot within the cardiac cycle has been shown to affect the shooting result (Landers 1984), and to differ according to the shooters skill level (Helin et al. 1987). Moreover, the brain slow waves associated with less successful and successful performance have been shown to differ from each other (Konttinen et al. 1995).

2.3.1 Augmented feedback in precision shooting

The information sources naturally available in shooting are vision (i.e. aiming) and proprioception (i.e., gun-holding and postural regulation). Augmented feedback during shooting training has traditionally consisted of information about achieving the environmental goal, that is, KR in terms of the shooting score and location of the hit point. KP has mainly consisted of verbal instructions based on a coach's subjective observations of shooting technique during alive or videotaped performance.

One of the first studies that examined the effects of KP on shooting performance was the study by English (1942), in which the aim was to teach military recruits the optimal squeezing technique for rifle shooting by means of a rubber bulb and tube inserted in the stock in the area pressed by the fingers. Boyce (1991) examined rifle shooting learning among novices and found that verbal KP concerning the behavioural performance of rifle shooting (the length of the trigger pull sequence) supported shooting performance. More recently, in Mononen et al. (2001) inexperienced shooters were provided with KR, KR supplemented with instructions or KR supplemented with both instructions and with KP concerning the shooter's behavioural performance. Although there was some evidence that KP had positive effects, no significant differences between the groups were found either in shooting accuracy or rifle movement kinematic characteristics. In the study by Konttinen et al. (2002), inexperienced shooters were provided with either KR, or KR supplemented with concurrent auditory and terminal visual KP on rifle movement during the 8-week training period. The participants with auditory-visual KP on rifle movement improved their shooting accuracy, and also showed a greater improvement in their postural stability and rifle hold compared to the KR -group.

3 FRAMEWORK AND AIMS OF THE STUDY

3.1 Framework of the study

The theoretical framework of the present study is based on the information processing approach (see Schmidt & Lee 1999, see Magill 2001). Accordingly, a performer is considered as an active learner who takes in, processes and responds to information. The stimuli (sensory input) enter through exteroceptors (vision, audition) or/and proprioceptors (vestibular system, muscle receptors, joint receptors, cutaneous receptors). Attention works as a neural filter that allows the performer to focus on what is essential while ignoring less important information. The three stages of information processing (perception, decision and action) result in movement accomplished by the neuro-muscular system and, finally in outcome. The performer is provided with intrinsic (i.e. inherent) feedback from muscles, movement and outcome, and extrinsic (i.e. augmented) feedback from movement (knowledge of performance) and outcome (knowledge of results, knowledge of performance). The augmented feedback is then processed and plan of the corrections to be introduced in the next trials can be made. Motivation, abilities, past experiences and present stage of learning all affect the information processing of the performer.

Information processing capabilities differ according to the performer's level of expertise (Starkes & Deakin 1984, Anshell 1990). Early learners and skilled performers differ in terms of ability, past experience, cognitive style, and motivation. Less skilled performers spend more time observing a stimulus prior to its identification and visualise each stimulus individually rather than in larger chunks. Lack of experience also shows in the low speed and lack of efficiency with which information is processed and the response carried out. Moreover, early learners have a limited capability to make use of augmented feedback.

It has been suggested that practice conditions that motivate the learner to additional cognitive effort (Lee et al. 1994) or to engage in additional information processing activities, might be most effective for motor skill learning (Wulf & Shea 2002). Examples of such conditions are randomisation of trials within practice sequence (random practice) or delaying or withholding augmented feedback. In line with this notion, in the present study KP was delivered in different frequencies. Moreover, as increased difficulty is thought to hinder learning if the task requires high attention, memory and/or motor demands, or when learner is relatively inexperienced (Wulf & Shea 2002), the practice condition was kept constant. Hence, additional demands were minimised so as not to overload the information processing system of inexperienced learners.

3.2 Aims of the study

Previous empirical research has shown that task-related KP facilitates motor skill performance and learning. It has been suggested that especially in the early phase of learning a complex motor task, the learner could gain extra benefits from KP (Wulf & Shea 2002). The present study focused on the effects of augmented KP on a complex motor skill within the context of precision rifle shooting.

The present research consisted of a series of studies where novice shooting performance and learning was approached from different perspectives. The primary aims of this study derive from the following research questions:

1. Are shooting accuracy, postural balance and rifle stability associated?
2. What are the effects of different augmented KP conditions on shooting accuracy?
3. What are the effects of different augmented KP conditions on a shooter's behavioural performance?

The main aim was to examine if augmented KP, describing the essential characteristics of successful shooting performance, would facilitate shooting performance and learning when compared to the condition with no KP.
More specifically, the aims of the present work were:

1. To examine the relationships between shooting score, postural balance and rifle stability on both the intra- and inter-individual levels.
2. To investigate the effects of terminal visual and concurrent auditory KP on shooting accuracy.
3. To examine the effects of terminal visual KP on the shooter's postural balance and rifle stability.

3.3 Hypotheses of the study

The general hypothesis tested here was that augmented KP would enhance the shooting performance of inexperienced shooters when compared to the condition with no KP. The specific hypotheses of each of the four different studies were following:

In Study I, it was hypothesized that postural balance and rifle stability would be related to shooting score. Additionally, it was expected that the relationships between shooting accuracy, postural balance and rifle stability would differ depending on the level (inter-individual vs. intra-individual) at which the data are analyzed.

In Study II, it was hypothesized that the participants provided with visual KP during acquisition would show a greater improvement in shooting accuracy and rifle stability when compared to the group receiving only KR during the training period. Additionally, given that the participants in the present study were inexperienced shooters, it was hypothesized that high frequency of KP would be more beneficial than a reduced frequency of KP.

In Study III, it was hypothesized that the group receiving visual KP on rifle barrel movement during acquisition would display better postural balance and preparatory rifle stability during the pre-trigger period than the group receiving no KP.

In Study IV, it was hypothesized that the participants provided with auditory KP during acquisition would show a greater improvement in shooting accuracy relative to the participants receiving only KR during training period.

4 METHODS

4.1 Participants

Participants in the present study were male conscripts from the Air Force C3 Systems School, Tikkakoski. They were randomly selected from a group of 120 conscripts completing non-commissioned officer training. All the participants had undergone standard military shooting training, which includes of 100 shots under simulated combat conditions and 150 shots on a shooting range. As at least 10 years of practice is required to achieve expertise in a complex skill (Ericsson & Charness 1994) such as precision shooting, the participants in the present study were regarded as inexperienced shooters. During the study, all the participants received the same standard military training, in domains such as command, control and communications, both indoors and outdoors.

In study I, the data on all participants were pooled for purposes of analysis (n=58). For studies II, III, and IV the participants were randomly assigned to one of six groups, five of which were included in the present study (see Table 1). The groups were a) a group receiving KR after each trial supplemented with 100% relative frequency of terminal visual KP (VIS100), b) a group receiving KR after each trial supplemented with 50% relative frequency of terminal visual KP (VIS50), c) a group receiving KR after each trial supplemented with 50% relative frequency of concurrent auditory KP (AUD50), d) a group receiving KR after each trial, but no KP (KR), and e) a non-training control group (CO). The results of the 6^{th} group receiving auditory KP on postural balance will be reported elsewhere.

TABLE 1 The number of participants (n) in each group in each of the four studies.

	Groups					
Study	VIS100 (n)	VIS50 (n)	AUD50 (n)	KR (n)	CO (n)	Σ (n)
I			pooled 58			58
II	9	10		8	7	34
III	9			7	8	24
IV			8	8	8	24

Note. VIS100=group with KR after 100% of the trials and visual KP after 100% of the trials, VIS50=group with KR after 100% of the trials and visual KP after 50% of the trials, AUD50=group with KR after 100% of the trials and auditory KP during 50% of the trials, KR=group with KR after 100% of the trials, CO=non-training control group.

4.2 Measurements and data reduction

In the shooting test, the participants were instructed to shoot in the standing position with an assault rifle at a stationary air rifle target on an indoor 10-m shooting range. The assault rifle was a SAKO 7.62 (Sako Co., Finland). Task performance was assessed in one session before the acquisition phase (pre-test), and 2, 10, and 40 days after completing the acquisition phase (retention tests).

The participants arrived at the shooting range in groups of four. The testing situation was supervised by two experimenters who provided the participants with a standardized set of instructions. In the test the participants performed five sighting shots followed by three blocks of ten shooting trials ('dry-firing') in a standing position at a distance of 10 m from the target. Between the sets of trials, a 3-minute rest in a sitting position was allowed. The participants were not given any feedback on their performance during or after a single shooting trial or a trial block. Following the tests each participant received information about his shooting scores. The variables used in the present study are shown in Table 2.

TABLE 2 The variables used in the present study.

Variables	Study	Reference
Shooting performance		
Shooting score	I, II, IV	Konttinen et al. 1998
RMSE	II	Schmidt and Lee 2000
Rifle stability		
Horizontal deviation	I, II	Mononen et al. 2003
Vertical deviation	I, II	Mononen et al. 2003
Pre-trigger rifle movement	III	Mononen et al. 2003
Postural balance		
Anteroposterior velocity	I	Era et al. 1996
Mediolateral velocity	I	Era et al. 1996
Maximal amplitude of sway	III	Era et al. 1996
Velocity moment	III	Era et al. 1996
Combined Balance	I	

4.2.1 Shooting accuracy (Study I, II, IV)

Shooting accuracy was measured and analysed with a commercial optoelectronic shooting training and analysis system, Noptel ST 2000 Sport (Noptel Co., Finland). The system consisted of an optical unit (containing a transmitter and a receiver, weight 140 g) attached to the end of the rifle barrel, an optical target (a reflector) fitted next to the conventional target, and a computer. The optical unit was connected to the serial port of the computer via an analyser unit, which converted data into digital form for display, analysis and storage. The system does not require the use of live ammunition.

The *shooting score* (points) (Cronbach's Alpha=0.772), corresponding to the accuracy of a shot, was used as an index of performance outcome (0.0-10.9) and indicated the distance between the hit point and the centre of the target: the bigger the score, the more accurate the shot.

The *root mean square error* (RMSE), including both the constant and variable errors (Schmidt & Lee 2000), was applied as a total variability measure for shooting score in the retention data.

4.2.2 Rifle stability (Study I, II, III)

In addition to shooting accuracy, the Noptel ST 2000 Sport monitors and stores the on-target trajectory of the rifle barrel alignment, also referred to as aiming trajectory, at a sampling rate of 100 Hz with an accuracy of 0.1 mm. The system permits the trajectory data to be visualised on a monitor as the shooter's aiming trajectory in relation to the target surface. The aiming trajectory can also be accompanied by an auditory sound that varies with the location of the aiming mark on the target area, indicating the distance between the shooter's aiming point and the centre of the target. For the data analysis, the information on the aiming trajectory was reduced variables describing movement of the rifle barrel.

The *horizontal* and the *vertical movement of the rifle barrel* (Cronbach's Alpha 0.886 and 0.912, respectively) were indicated separately for the horizontal and vertical axis by the means of the horizontal and vertical deviation of the rifle barrel, respectively. The variables were expressed as deviations in relation to the central point of the aiming trajectory. The interval between the two consecutive rings of the target (target ring) was used as a unit of measurement describing the extent of the horizontal and vertical deviations in absolute terms. The deviations were calculated over the last 5-second period preceding triggering and were determined separately for each shot.

The *pre-trigger rifle movement* (Cronbach's alpha=0.860) was determined during the last 200 ms before the pull on the trigger and described the absolute movement of the aiming point, indicating movement of the rifle barrel during the pre-trigger period. The measurement unit was the target ring; the lower the value, the less movement in the gun barrel.

4.2.3 Postural balance (Study I, III)

Postural balance was measured using the Good Balance measurement system (Metitur Ltd, Finland). The Good Balance measurement system consists of an equilateral triangular-shaped force platform with side 800 mm in length and electronic unit including amplifier and a 12-byte analogue-to-digital converter. The platform is furnished with strain-gauge transducers in each corner. The analogue signals were amplified and converted to digital form at a sampling rate of 50 Hz and passed to the microcomputer via serial port. Data were filtered and processed in digital form by Good Balance software. The data from each channel were filtered separately using a 7-point median filter and low-pass infinite impulse response filter with a cut-off frequency of 20 Hz in order to reduce impulse noise and noise emanating from the measurement system, respectively (see Aalto 1997).

The x- and y-coordinates of the displacement the centre of pressure (COP) were calculated from the filtered data. On the basis of the COP coordinates the postural balance outcome variables were determined. The variables were determined over last three seconds preceding the pull on the trigger.

The a*nteroposterior* and *mediolateral sway velocities* ($mm \cdot s^{-1}$) (Cronbach's Alpha 0.964 and 0.936, respectively) were calculated by dividing the total displacement of COP in each direction by the measurement time (s). It should be noted that the shooters were standing almost transversely in relation to the target, upper part of the body facing in the shooting direction. Therefore, anteroposterior direction refers to the sagittal direction for the upper part of the body only.

The v*elocity moment* ($mm^2 \cdot s^{-1}$) (Cronbach's Alpha=0.923) refers to the first moment of velocity calculated as the mean area covered by the movement of the COP during each second of the test (Era et al. 1996). This measure takes into account both the distance from the geometrical midpoint across the whole test and the speed of the movement during the same time period (see Era et al. 1996).

The m*aximal amplitude of sway* (mm) (Cronbach's Alpha=0.880) describes the length of the square side (mm), including 90% of all the measurement points corresponding to the largest amplitude of body sway (see Era et al. 1996, see Konttinen et al. 1999).

The c*ombined balance* was calculated as the sum of the anteroposterior and mediolateral sway velocities for every shot.

4.3 Experimental task

The experimental task was in the standing position to shoot with an assault rifle at a stationary air rifle target on an indoor 10-m shooting range. The practice conditions (guns, sights, targets, shooting distance) were identical to those used in the test situation.

4.4 Training protocol

The shooters in the experimental groups underwent a 4-week acquisition phase, during which augmented feedback was delivered. The acquisition phase consisted of 11 practice sessions which lasted on average 30 minutes each (in all 5.5 hours). In each session, the participants shot four blocks of 10 trials, making a total of 440 practice shots.

Visual KP feedback consisted of the visualised aiming trajectory of the rifle barrel from the time of aiming, indicating rifle stability. Visual KP was available on a target surface displayed on a PC monitor. The different aiming phases were expressed as different colours on the aiming path. A yellow line indicated the aiming trajectory during the last second before triggering. A red line visualized the trajectory before the last second (i.e. yellow line), and a blue line the trajectory after triggering. Before the acquisition phase, the content of the aiming trajectory information was carefully explained to the participants to ensure that they understood how to interpret it. During the training sessions, in addition to the instructions for interpreting visual KP, written cues were distributed to focus the shooter's attention on the essential features of the feedback. Visual KP was provided as terminal feedback after single trial.

Auditory KP was delivered binaurally through wireless headphones (AKG Acoustics GMBH, Germany) concurrently with the aiming phase. The auditory KP consisted of feedback on the participant's movement patterns in relation to the balancing of the rifle. The auditory signal of 80 dB was provided in the form of a continuous auditory signal ranging from 800 to 2400 Hz, which increased in audible frequency as the distance between the aiming point and the centre of the target decreased.

KR consisted of the location of the hit point of the just-completed trial on a target surface displayed on a PC monitor. The numerical value of the hit in the upper left-hand corner of the same display panel was also given. KR was provided as terminal feedback after each trial.

4.5 Study design

Study I examined the relationships between shooting accuracy and the shooter's behavioural performance. The aim of this cross-sectional study was to clarify the associations between shooting accuracy, postural balance, and rifle stability both on the intra- and inter-individual levels. Postural balance and rifle stability were assessed in terms of horizontal and vertical sway velocity, and horizontal and vertical movement of the rifle barrel, respectively.

The purpose of Study II was to examine the effects of a 4-week shooting training period with three different visual KP conditions on shooting performance and learning. The effects of KP were evaluated in terms of shooting accuracy (shooting score, variability of shooting score) and rifle stability (horizontal and vertical deviation in rifle barrel movement). The three experimental groups differed from each other with respect to the amount of KP: a) the VIS100 group received KR after each trial supplemented with visual KP after each trial (100% relative feedback frequency), b) the VIS50 group received KR after each trial supplemented with visual KP for every other set of trials (50% relative feedback frequency), i.e. after shots 1-10 and 21-30, and c) the KR group received KR after each trial, but no KP. The non-training control group (CO) took part only in the tests.

Study III investigated the effects of a 4-week shooting training period with two augmented information feedback conditions on postural balance and rifle stability preceding the pull on the trigger. The two experimental groups differed from each other with respect to the amount of KP: the VIS100 group received KR after each trial supplemented with visual KP after each trial (100% relative feedback frequency) and b) the KR group received KR after each trial, but no KP. The non-training control group (CO) took part only in the tests.

Study IV was designed to examine the effects of auditory KP on the shooter's performance and learning. The effects of KP were evaluated in terms of shooting accuracy. The two experimental groups differed from each other with respect to the amount of KP: a) the AUD50 group received KR after each trial supplemented with auditory KP during every other set of trials (50% relative feedback frequency), i.e. during the shots 1-10 and 21-30, and b) the KR group received only KR after each trial. The non-training control group (CO) took part only in the tests.

4.6 Statistical analyses

Standard procedures were applied to calculate the means and standard deviations of the variables. The normality of the distributions was analysed with the Kolmogorov-Smirnov test. Cronbach's Alpha coefficient was calculated for the pre-test to determine the internal consistency of the variables. To further investigate the magnitude of the differences in treatment, effect sizes were calculated in standard deviation units where $ES = (M_1 - M_2)/SD_{POOLED}$ (Thomas & Nelson 1996). Values indicating measurement errors and some extreme outliers were excluded from the analyses. Statistical analyses were performed using the SPSS-PC 10.1.3 (SPSS Inc., Chicago, IL) statistical package. Level of significance for all analyses was established at $p < .05$.

In Study I, correlation analysis, multiple regression analysis and multivariate analysis of variance were employed to analyze the associations between shooting accuracy, rifle movement and postural balance. The data were analysed both on the inter-individual and intra-individual levels. The inter-individual relationships were analysed according to the average value of the variables for each participant. The intra-individual relationships were analysed, first, as the pooled single trial data for all the participants and, second, across the trials for each subject separately. In order to determine to what extent the correlations between shooting score and the rifle stability variables were explained by the variation in postural balance, partial correlation analysis was employed. For this analysis, variable Combined balance was chosen to indicate the between-subject differences in the variability and thus to illuminate the effects of a shooter's postural behaviour on the relationships between shooting accuracy, and the degree of postural sway and rifle stability. First, Balance variability was calculated as the standard deviation of the Combined balance. Second, on the basis of the median value for Balance variability, the shooters were classified into two groups: a Low Balance Variability group and a High Balance Variability group. The interrelationships between shooting score, the postural balance variables and the rifle stability variables were calculated separately for the subgroups.

In Study II, separate one-way analyses of variance was applied to determine the pre-test differences between the groups in shooting score, horizontal deviation in movement of the rifle barrel, and vertical deviation in movement of the rifle barrel movement. The mean value of the variables for each participant for each session was used as the dependent measure. The effects of the intervention on performance (acquisition) and learning (retention) were determined by a separate analysis of variance (Repeated measures).

In Study III, separate one-way analyses of variance were applied to determine the pre-test differences between the groups in maximal amplitude of sway, velocity moment, and rifle movement during the pre-trigger period. The group differences in the dependent variables during the retention test were analysed with a separate one-way analysis of variance. The within-subject trials served as the unit of observation.

In Study IV, learning effects were analyzed with multivariate analysis of covariance. To study the differences between the experimental groups in more detail, a one-way analysis of covariance procedure was conducted separately for each of the dependent variables. In the analyses, learning was indicated by the residual gain scores, i.e. the values of the dependent variable, when the covariate is partialled out.

5 RESULTS

5.1 Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters (Study I)

5.1.1 Inter-individual analysis

All the behavioural performance variables were significantly associated with the shooting score on the inter-individual level (Table 3). Mediolateral sway velocity and vertical movement of the rifle barrel accounted for 26% of the variance in shooting score (Multiple R= 0.51; Adjusted R= 0.48; $F(2, 55) = 9.75$; $p < 0.001$). In postural balance, the very strong positive relationship ($r=0.80$) between the mediolateral and anteroposterior sway velocities indicated that these two variables measure the same general balance. Although the positive relationship between the two rifle barrel movement variables was strong ($r=0.42$), it was weaker when compared to the association between the postural balance variables. This may indicate that the horizontal and the vertical movement of the rifle barrel reflect two different aspects of aiming.

TABLE 3 Inter-individual correlations between shooting score (HIT), horizontal movement of the rifle barrel (DEV_H), vertical movement of the rifle barrel (DEV_V), mediolateral sway velocity (VEL_{ML}), and anteroposterior sway velocity (VEL_{AP}) among the participants (n=58).

	HIT (points)	DEV_H (target ring)	DEV_V (target ring)	VEL_{ML} ($mm \cdot s^{-1}$)	VEL_{AP} ($mm \cdot s^{-1}$)
HIT	1				
DEV_H	-0.426**	1			
DEV_V	-0.291*	0.422**	1		
VEL_{ML}	-0.450**	0.467**	0.330*	1	
VEL_{AP}	-0.434**	0.592**	0.395**	0.804**	1

Note. ** = p<0.01, * = p<0.05

The relationships between shooting score and the rifle movement variables (DEV_H, DEV_V) decreased below the limit of statistical significance when the Combined balance variable was partialled out from the correlations. The partial correlations between shooting score and Combined balance, controlling for either horizontal or vertical rifle barrel movement of the rifle barrel were lower than the zero-order correlations, but still statistically significant ($p< 0.01$).

Among the participants with Low balance variability the relationships between the measured variables were stronger than among the participants with High balance variability (see Table 4). In the Low balance variability group, mediolateral sway velocity and vertical movement of the rifle barrel accounted for 40% of the variance in the shooting score (Multiple R= 0.63, Adjusted R= 0.59, $F(2,26)= 8.65$, $p< 0.001$), being somewhat higher than in the whole group. In the High balance variability group the multiple correlation was not statistically significant.

TABLE 4 Inter-individual correlations between shooting score (HIT), horizontal movement of the rifle barrel (DEV_H), vertical movement of the rifle barrel (DEV_V), mediolateral sway velocity (VEL_{ML}), and anteroposterior sway velocity (VEL_{AP}) in the High balance variability (n=29, right-hand side of the diagonal, bolded values) and the Low balance variability groups (n=29, left-hand side of the diagonal).

	HIT (points)	DEV_H (target ring)	DEV_V (target ring)	VEL_{ML} ($mm \cdot s^{-1}$)	VEL_{AP} ($mm \cdot s^{-1}$)
HIT	1	**-0.196**	**-0.176**	**-0.185**	**-0.306**
DEV_H	-0.483**	1	**0.146**	**0.137**	**0.327**
DEV_V	-0.276	0.467*	1	**0.135**	**0.140**
VEL_{ML}	-0.601**	0.528**	0.285	1	**0.704****
VEL_{AP}	-0.440*	0.723**	0.430*	0.566**	1

Note. ** = p<0.01, * = p<0.05

5.1.2 Intra-individual analysis

In the intra-individual analyses, the relationships between shooting score and behavioural performance variables were negligible (pooled r=-0.07– -0.01). The behavioural performance variables were significantly ($p=0.05$) related to shooting score in 3.4 - 6.9% of participants, indicating that there are few individuals for whom a relationship would exist between their shooting score their behavioural performance variables. The relationships between horizontal and vertical movement of the rifle barrel, and between mediolateral and anteroposterior sway velocity were significant (p= .01), but lower than the corresponding inter-individual correlations. The relationship between horizontal and vertical movement of the rifle barrel was positive and statistically significant for 41% of participants. The relationship between mediolateral and anteroposterior sway velocity was positive and significant for 59% of participants. The other pooled within-subject correlation coefficients between the four behavioural performance variables were not significant, although 12-19% of the individual relationships were significant, indicating that the relationships between the behavioural performance variables may vary from individual to individual.

5.2 The effects of augmented kinematic feedback on motor skill learning in rifle shooting (Study II)

The mean values and standard deviations for shooting score, variability of shooting score, and horizontal and vertical movement of the rifle barrel for each group are presented in Table 5.

TABLE 5 Mean values (Mean) and standard deviations (S) of shooting score (HIT), variability of shooting score (RMSE), horizontal movement of the rifle barrel (DEV_H) and vertical movement of the rifle barrel (DEV_V) for VIS100, VIS50, KR and CO during the shooting tests.

	VIS100		VIS50		KR		CO	
	Mean	S	Mean	S	Mean	S	Mean	S
Pretest								
HIT	4.50	1.07	4.44	1.15	4.44	1.28	4.43	0.10
DEV_H	5.98	1.14	6.14	1.33	5.82	1.67	6.25	1.70
DEV_V	7.78	2.50	8.72	2.06	7.04	1.73	9.44	2.28
2 day retention								
HIT	7.12	0.54	6.16	0.65	6.34	0.67	5.10	0.89
RMSE	4.36	0.62	5.30	0.68	5.27	0.55	6.45	0.92
DEV_H	3.89	0.55	3.84	0.29	3.94	0.69	5.77	1.52
DEV_V	4.80	1.72	4.85	0.99	5.19	1.40	9.35	3.97
10 day retention								
HIT	6.11	0.39	6.06	1.05	5.84	0.69	5.55	0.77
RMSE	5.47	0.48	5.45	1.12	6.35	1.09	6.24	0.87
DEV_H	5.05	0.86	4.72	0.87	4.71	1.18	6.81	2.40
DEV_V	5.83	1.93	5.88	1.77	5.73	1.75	10.1	2.92

Shooting accuracy

All experimental groups improved their shooting score significantly ($F(10, 294)=8.93$, $p<0.01$) throughout the training sessions (see Figure 1, Acquisition). The groups did not differ from each other, indicating that the skill acquisition patterns among the three information feedback conditions were similar.

In retention (see Figure 1, Retention), the groups differed significantly from each other ($F(3, 30)=5.76$, $p<0.01$). In the 2-day retention test, VIS100 (ES=2.86), VIS50 (ES=1.37), and KR (ES=1.59) had significantly higher shooting scores than CO. Moreover, VIS100 performed significantly better than VIS50

(ES=1.61) and KR (ES=1.27). In the 10-day retention test no significant differences were found.

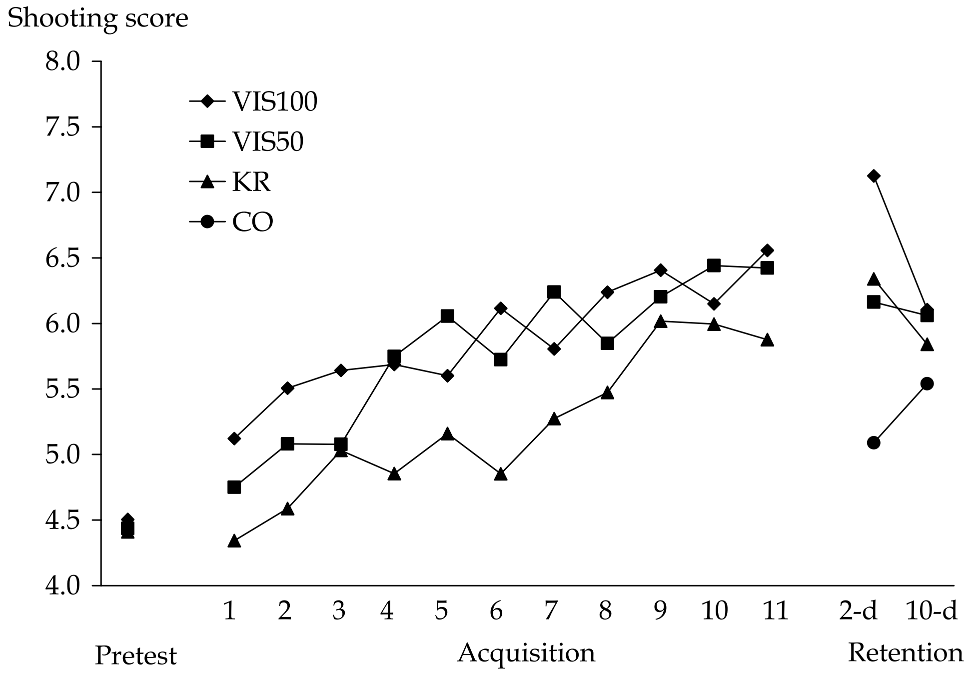

FIGURE 1 Mean shooting scores (points) for VIS100, VIS50, KR, and CO in the pre-test, during practice (Acquisition 1-11), and in the retention tests (Retention, 2-day retention=2-d, 10-day retention=10-d).

With regards to the variability of their shooting scores, the groups differed significantly from each other (F(3, 30)=3.57, p<0.05). In the 2-day retention test, in CO the RMSE was significantly higher than in VIS100 (ES=2.70), VIS50 (ES=1.46), and KR (ES=1.53). Further, VIS100 had a significantly lower RMSE when compared to VIS50 (ES=1.43). In the 10-day retention test, no significant differences were found between the groups.

Rifle stability

During acquisition, both the horizontal (F(4, 294)=19.5, p<0.001) and vertical (F(4, 294)=11.6, p<0.001) movement of the rifle barrel decreased significantly in all three experimental groups (see Figures 2 and 3, Acquisition). The groups did not differ from each other.

In retention, the horizontal movement of the rifle barrel was significantly lower in VIS100 (2-day retention ES=0.80, 10-day retention ES=1.04), VIS50 (2-day retention ES=1.59, 10-day retention ES=1.26) and KR (2-day retention ES=1.59, 10-day retention ES=1.14) than CO (see Figure 2). The vertical movement of the rifle barrel was significantly lower in VIS100 (2-day retention ES=1.57, 10-day retention ES=1.77), VIS50 (2-day retention ES=1.71, 10-day retention ES=1.83) and KR (2-day retention ES=1.50, 10-day retention ES=1.85) than CO (see Figure 3).

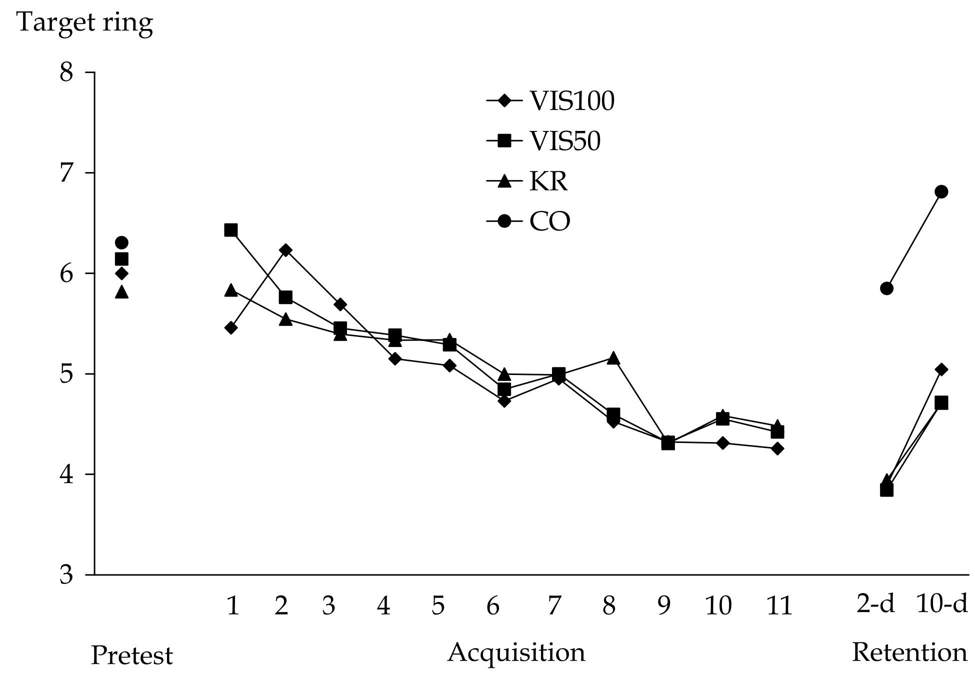

FIGURE 2 Mean horizontal rifle barrel movement (target ring) for VIS100, VIS50, KR, and CO in the pre-test, during practice (Acquisition 1-11), and in the retention tests (Retention, 2-day retention=2-d, 10-day retention=10-d).

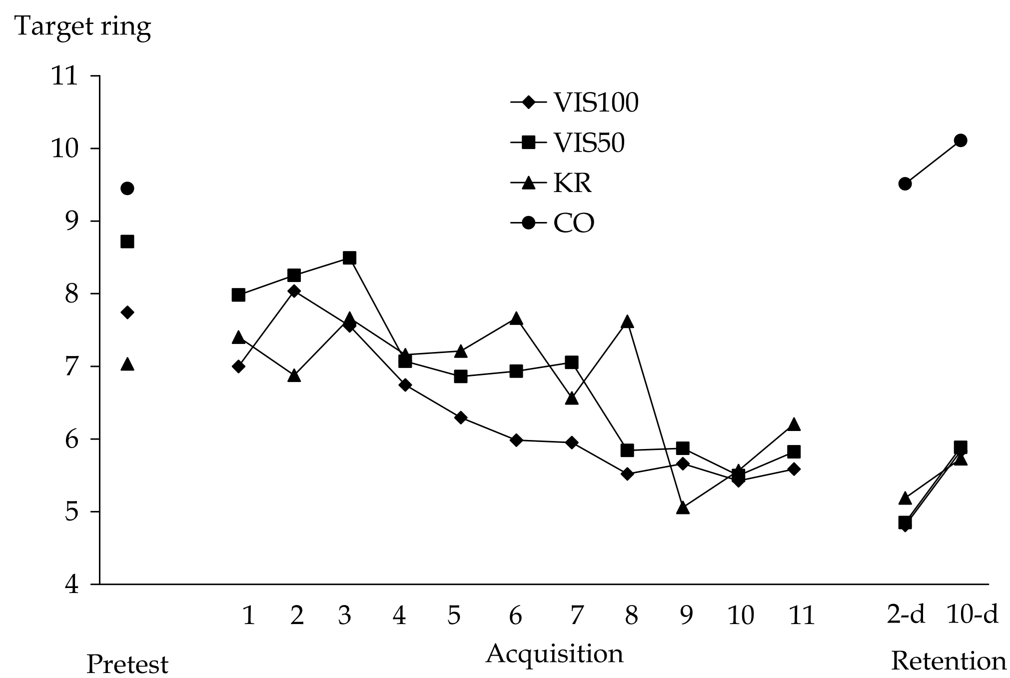

FIGURE 3 Mean vertical rifle barrel movement (target ring) for VIS100, VIS50, KR, and CO in the pre-test, during practice (Acquisition 1-11), and in the retention tests (Retention, 2-day retention=2-d, 10-day retention=10-d).

5.3 The effects of augmented kinematic feedback on rifle shooting performance (Study III)

The values for the maximal amplitude of sway, velocity moment, and rifle movement during the pre-trigger period for each group in the pre-test and in the 2-day retention test are shown in Table 6.

TABLE 6 Mean values (Mean) and standard deviations (S) of the maximal amplitude of sway (Maximal amplitude), velocity moment (Velocity moment), and rifle movement during the pre-trigger period (Rifle movement) for VIS100, KR and CO in the pre-test (Pre) and in 2-day retention test (Ret).

		Maximal amplitude (mm)			Velocity moment ($mm^2 \cdot s^{-1}$)			Rifle movement (target ring)		
Group	Test	Mean	S	Trials (n)	Mean	S	Trials (n)	Mean	S	Trials (n)
VIS100	Pre	8.7	3.6	264	7.2	6.8	264	2.3	1.2	264
	Ret	6.5	2.8	264	3.1	2.9	264	1.5	0.7	264
KR	Pre	9.3	4.2	202	6.5	6.5	202	2.5	1.2	202
	Ret	7.2	2.9	202	3.7	3.3	202	1.7	0.8	202
CO	Pre	9.0	4.3	217	7.1	6.6	217	2.5	1.4	217
	Ret	9.2	4.4	217	7.8	10.0	217	2.3	1.3	217

In the 2-day retention test (see Figure 4), significant differences between the groups were revealed in maximal amplitude of sway ($F(2, 680)= 38.6$, $p<0.001$), mean velocity moment ($F(2, 680)= 39.3$, $p<0.001$), and rifle movement during the pre-trigger period ($F(2,680)= 49.4$, $p<0.001$). In VIS100, the maximal amplitude of sway was significantly lower than in KR (ES= 0.25), and CO (ES=0.74). In velocity moment, VIS100 differed from CO (ES=0.64), but not from KR. KR differed significantly from CO both in maximal amplitude of sway (ES= 0.53) and in velocity moment (ES=0.56). Rifle movement during the pre-trigger period was significantly lower in VIS100 than CO (ES= 0.82). Moreover, KR differed from CO in rifle stability (ES= 0.65).

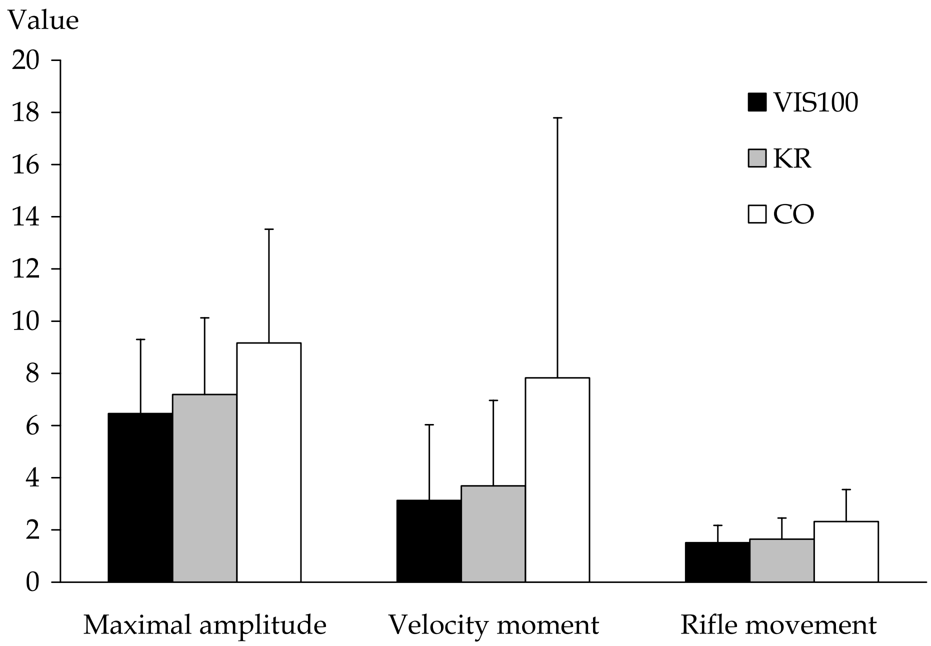

FIGURE 4 Mean values for maximal amplitude of sway (mm), velocity moment ($mm^2 \cdot s^{-1}$), and rifle movement (target ring) during the pre-trigger period in the 2-day retention test in VIS100, KR and CO.

5.4 The effects of augmented auditory feedback on psychomotor skill learning in precision shooting (Study IV)

During acquisition, AUD50 performed at a higher level across the whole acquisition phase when compared to KR (see Figure 5). The shooting score in the KR trials across the eleven practice sessions was significantly higher in AUD50 than KR ($t=2.51$, $df=14$, $p< 0.05$). In AUD50, the shooting score of the trials with auditory KP and trials with KR-only did not differ from each other.

In the retention tests, the gain score profiles of the shooting scores differed significantly between groups ($F(4, 34)=3.38$, $p<0.05$) (see Figure 6). Significant differences between the experimental groups were found in the 2-day ($F(2,20)=18.1$, $p<.0.001$), 10-day ($F(2,20)=6.86$, $p<0.01$), and 40-day ($F(2,17)=6.41$, $p<0.01$) retention tests. In all three retention tests, the gain score profile of AUD50 was significantly higher than those of the profiles of KR and CO. KR differed from CO only in the 2-day retention test.

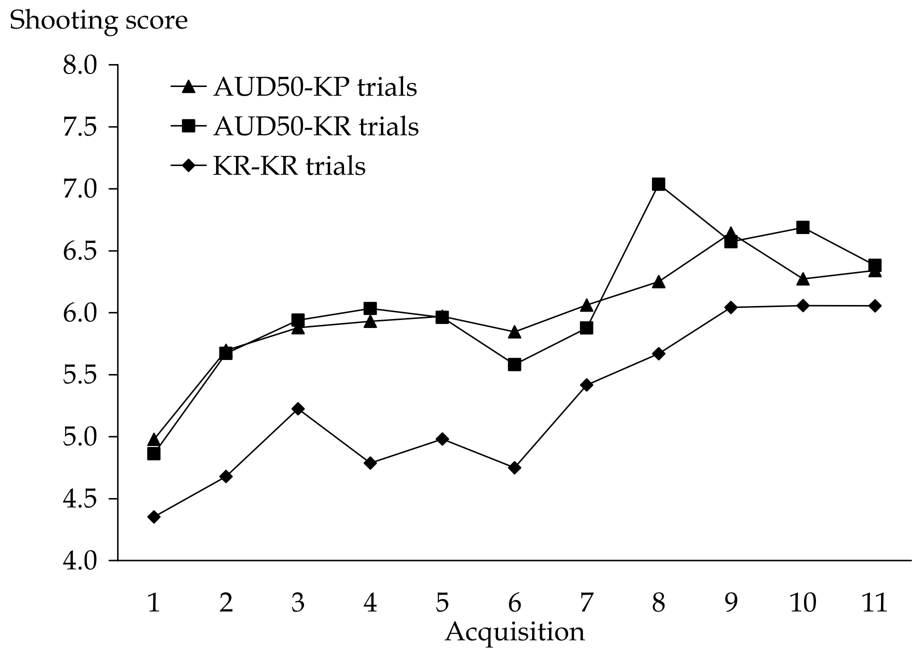

FIGURE 5 Mean shooting scores (points) during acquisition in AUD50 and KR. The label 'AUD50 - KP trials' refers to shots during which the shooters in AUD50 received augmented auditory feedback (trial blocks 1 and 3). The label 'AUD50 – KR trials' refers to shots during which the shooters in AUD50 received only the knowledge of results (trial blocks 2 and 4). In KR, all the trials in every practice session were KR trials, and the data points represent the mean shooting result calculated across 40 trials.

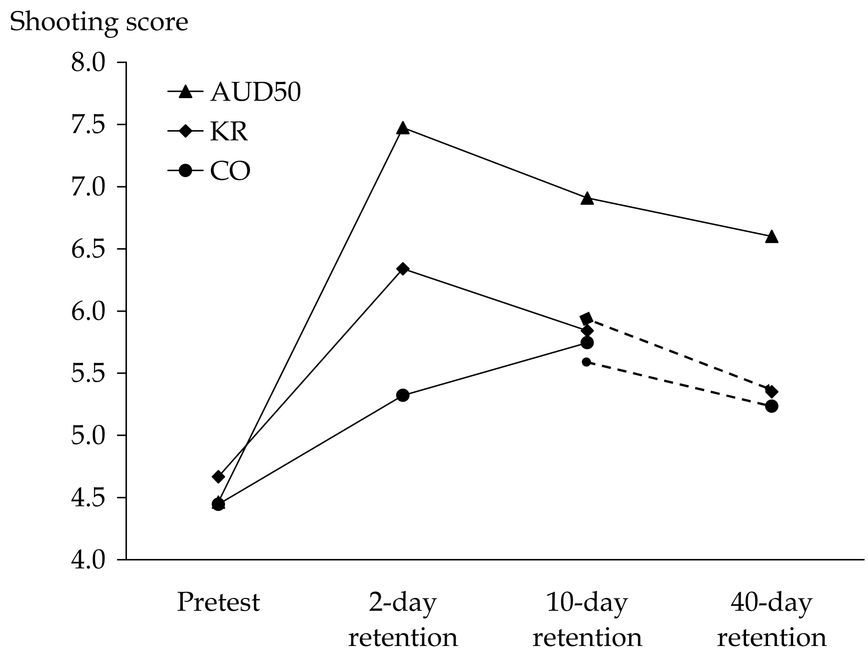

FIGURE 6 Mean shooting scores (points) for AUD50, KR, and CO in the pre-test and in the retention tests. Since some of the participants were absent during the 40-day retention, the corresponding means are not comparable with those of the pre-test, 2-day retention, and 10-day retention tests. In the case of KR and CO, the means of the 10-day retention were recalculated using only the data on those participants who also participated in the 40-day retention (dashed lines).

6 GENERAL DISCUSSION

This section discusses the effects of augmented information feedback on shooting performance in inexperienced rifle shooters. The discussion focuses on the effects of knowledge of performance on shooting accuracy, as the results obtained demonstrated that providing inexperienced shooters with knowledge about rifle stability appears to be beneficial for the learning of a precision shooting task.

6.1 Main findings

Study I showed that that shooting accuracy, postural balance, and rifle stability were interrelated, but only on the inter-individual level. Both good postural balance and the ability to keep the rifle stable appeared to be prerequisites for superior shooting performance among inexperienced shooters. The strength of the association between shooting accuracy and the behavioural performance variables appeared to depend on the variability in the shooter's postural behaviour.

Study II demonstrated that the shooting accuracy of the participants who received visual KP after each trial was significantly higher than that of the group receiving 50% relative frequency of visual KP, the group with KR only, and the non-training control group. This effect, however, was apparent only during the two days after completing the acquisition phase, and disappeared in the subsequent retention test. Visual KP after 50% of the trials did not facilitate performance when compared to the group with KR only. With respect to the acquisition phase, the shooting scores of the experimental groups did not differ from each other. The indices for rifle stability did not differentiate between the experimental groups during either the acquisition phase or in the retention tests.

Study III showed that the maximal amplitude of sway of the participants provided with visual KP after each trial was significantly lower than that of the group with no KP in the 2-day retention test. No significant differences were found between the experimental groups in velocity moment or rifle movement during the pre-trigger period.

Study IV revealed that the participants who received auditory KP during 50% of the trials showed better shooting accuracy during the acquisition phase and in the retention tests relative to the participants receiving no KP.

6.2 The association between shooting accuracy, rifle stability and postural balance

In Study I, the relationships between shooting accuracy and the shooter's behavioural performance were examined on both the intra- and inter-individual levels. The main finding was that postural balance and rifle stability were related to shooting score, but only on the inter-individual level.

The finding that the shooter's behavioural performance was related to shooting accuracy lent support to the first hypothesis of Study I. The present results imply that both good postural balance and the ability to keep the rifle barrel stable are prerequisites for superior shooting performance among inexperienced shooters. This result is in line with earlier empirical findings suggesting that stable posture (Era et al. 1996) and minimal movement of the gun barrel (Mason et al. 1990, Zatsiorsky & Aktov 1990, Konttinen et al. 1998) are connected with shooting accuracy.

Postural balance and rifle stability accounted for 26% of the variance in shooting accuracy in Study I. This low figure implies that other behavioural factors, such as the timing of triggering (Zatsiorski & Aktov 1990, Viitasalo et al. 1999, Konttinen et al. 2000), may influence rifle shooting accuracy among inexperienced shooters. The variance explained in Study I was also low when compared to the results of Mason et al. (1990) and Viitasalo et al. (1999), where postural balance and gun stability accounted for 53% and 75% of the variance in shooting accuracy. Interestingly, the present data also revealed an association between postural balance and rifle stability contrary to findings of the earlier studies (Mason et al. 1990, Viitasalo et al. 1999). One explanation for this discrepancy could be the difference in shooters' skill levels. It can be proposed that elite shooters (see Mason et al. 1990, Ball et al. 2003a) may be able to control postural behaviour and gun stability independently, whereas among novices disturbance in postural balance is more likely to cause an increase in gun movement. Another explanation may be dissimilarity in motor requirements. In pistol shooting (Mason et al. 1990, Ball et al. 2003b), the limb that is holding the pistol is able to move quite independently of the body whereas in rifle shooting the gun is more firmly stabilized against the body. This being the case, in rifle shooting a stronger association between postural balance and gun stability might be expected than in pistol shooting.

The present data failed to show any relationships between shooting accuracy, postural balance and rifle stability on the intra-individual level. Furthermore, the variation in the correlations among the shooters was random, indicating that there were no subgroups of participants for whom the relationship was significant. These results support the second hypothesis of Study I, suggesting that the strength of the relationships differs according to the level on which the data are analysed. The present results, however, are not in line with the results of Ball et al. (2003a), who found a significant intra-individual relationship between body sway and shooting accuracy, or body sway and rifle movement for each shooter. Given that in Ball et al. (2003a) the participants were elite shooters, their behavioural pattern during shooting may have been more consistent compared to the novices in the present study. Differences between novice and elite shooters in behavioural patterns may be reflected in the relationships between the measured variables.

The findings of Study I revealed that postural balance has a special role in the relationship between shooting accuracy and the shooter's behavioural performance among inexperienced shooters. Firstly, postural balance seemed to be related to the shooting accuracy in two ways: directly and indirectly through rifle stability. An increase in body sway could be expected to increase the movement of the rifle barrel which in turn might result in a poor shooting score, whereas good postural balance might facilitate a stable rifle hold, leading to a better shooting score. Secondly, the relationships between shooting accuracy and the behavioural performance variables appeared to depend on the consistency of the shooter's postural sway behaviour. After dividing the shooters into two groups according to variability in postural balance, significant relationships between shooting accuracy and the behavioural performance variables were found only among the group with low postural balance variability. The present findings suggest that if a shooter is able to control his or her posture, the shooting performance overall may be more consistent, and therefore the relationships between the measured variables can be detected. High variability in postural balance in turn may reflect overall inconsistency of the shooting performance, making it difficult to detect any associations between the measured variables.

6.3 The effects of KP on shooting accuracy

In Studies II and IV, the effects of visual and auditory KP, respectively, were evaluated in terms of shooting score. The results of Study II and Study IV are combined in Figure 7. In general, the present results support the findings of previous studies (e. g. Newell & Walter 1981, Newell & Carlton 1987, Boyce 1991, Schmidt & Lee 1999) and the general hypothesis of the present study, suggesting that in tasks with multiple degree of freedom KP feedback is more beneficial for performance and learning than KR alone.

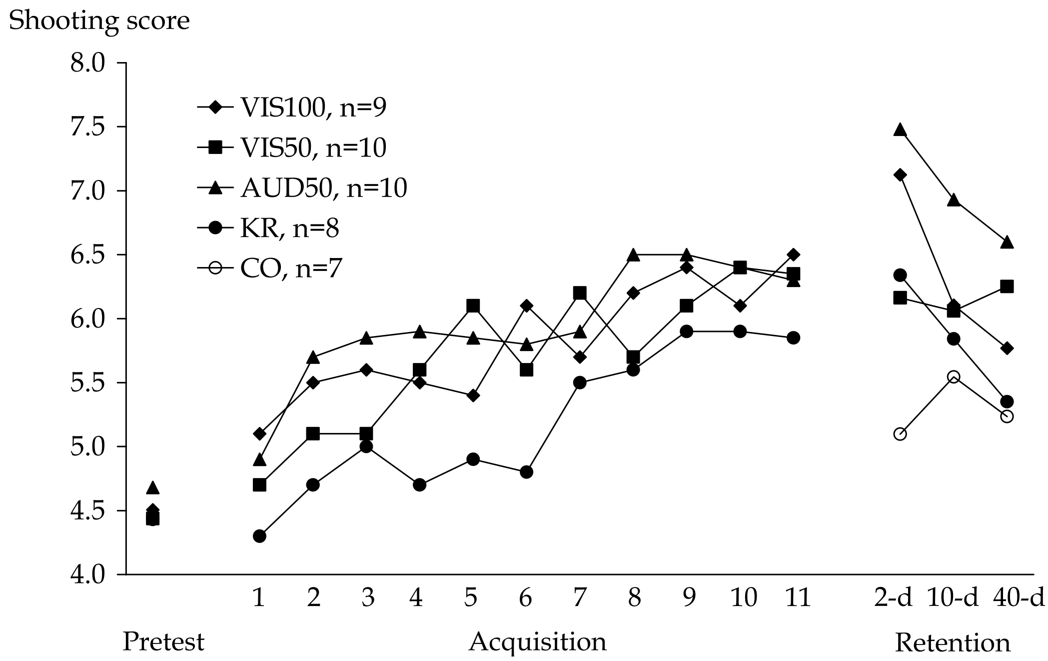

FIGURE 7 Mean shooting scores (points) for the VIS100, VIS50, AUD50, KR, and CO groups during the pre-test, acquisition phase, and the 2-day, the 10-day and the 40-day retention tests. Since some participants in the KR, VIS50, and VIS100 groups were absent from the 40-day retention test, the means of the 40-day retention test for those groups were 6, 9, and 8, respectively.

The present results showed that providing participants with the KP feedback resulted in a relatively permanent improvement in shooting performance. The findings concerning the retention data supported the hypothesis of Studies II and IV that participants with KP during acquisition would show greater improvement in shooting accuracy relative to those receiving KR-only during the training period. The group provided with concurrent auditory KP in 50% of the shooting trials outperformed the group with KR in shooting accuracy in all three retention tests (Figure 7, Retention). Additionally, the group with visual KP after every trial performed better than the KR group in the 2-day retention test. This effect, however, was transient, disappearing in the subsequent retention test. It could be suggested that the motivational or energizing effects of feedback might have affected the performance of the participants receiving visual KP after each trial in the 2-day retention test, but that these effects were no longer present 10 days after the acquisition phase.

The findings of Study IV indicate that learning with auditory feedback seemed to transfer effectively to conditions where the shooters had to perform without any extrinsic KP or KR. The present results were in line with previous research on augmented auditory feedback and sport performance indicating the effectiveness of augmented auditory feedback within the contexts of sport behaviours (Gauthier 1985, Takeuchi 1993, Jagacinski et al. 1997). It is proposed that in Study IV auditory feedback promoted a shooter's self-initiated error detection and correction abilities by directing his attention to the critical components of psychomotor regulation. Additionally, the concurrent auditory KP may have provided information about how the movement pattern should be altered to improve rifle stability. This may not have been the case with visual KP, where the link between feedback and the correction that should be made was not obvious: the visualized aiming trajectory did not give exact information on how to correct the movement.

Importantly, it seems that the concurrent auditory feedback did not cause any sensory overload effect during practice. This may be due to the nature of the task performance conditions, where the environment during shooting was relatively unchanging, and the attentional demands of the task were minimized. It should be also noted, that during precision shooting performance, audition is not as involved as vision. In shooting, vision is needed in the aiming process to recognize the target and the position of the sight in relation to the centre of the target. Delivering visual feedback concurrently during the aiming phase might disturb the performance by overloading the visual channel, whereas use of auditory feedback might be beneficial for performance.

With respect to performance effects, the participants provided with auditory KP performed better during the acquisition phase than did the group with KR only (see Figure 7, Acquisition). This result supports earlier studies that have demonstrated the strong performance-enhancing effects of concurrent feedback (see Swinnen et al. 1997). Although visual KP benefited performance more than KR only, this difference did not reach the level of statistical significance. During the acquisition phase, the participants receiving KR-only showed the poorest performance in all sessions when compared to the three KP groups. In the experimental groups, with the exception of the group with visual KP on the 50% of trials, the shooting score improved from the last training session to the 2-day retention test. This may indicate that in these groups at least some of the learning advantages from the feedback intervention were latent. In other words, the intervention helped the participants to build an efficient shooting strategy that did not become visible until the augmented feedback was withdrawn.

6.3.1 The effects of KP frequency on shooting accuracy

The results of the present study indicate that reduced frequency of auditory KP was more effective in facilitating shooting performance than either high or reduced frequency of visual KP (see Figure 7, Retention). These results were not, then, in line with the second hypothesis of Study II, or with the previous empirical findings concerning feedback frequency (Schmidt et al. 1990, Yao et al. 1994, Guadagnoli et al. 1996, Swinnen et al. 1997, Wulf et al. 1998, Wulf & Shea 2002) supporting the view that the frequent feedback may advance learning of more complex skills. However, because in the present study the visual and auditory groups differed not only in feedback frequency but also in the timing of feedback, the findings cannot be attributed to feedback frequency alone, but to the interaction between feedback frequency and the timing of feedback. Furthermore, a limitation of the present study is that the data do not provide us with any insights into the different frequencies of auditory KP, thus limiting the discussion concerning feedback frequency to the groups with visual KP.

The present results indicate that the high frequency of visual KP was more effective when compared to the reduced frequency of visual KP or condition without KP, when measured in the 2-day retention test. Thus far, the present results supported the second hypothesis of Study II, and the previous findings (Schmidt et al. 1990, Yao et al. 1994, Guadagnoli et al. 1996, Wulf et al. 1998) suggesting that frequent feedback might be more effective in learning a complex task, especially for novices (see, Wulf & Shea 2002). Moreover, no dependence on feedback was shown in high the frequency group, supporting the proposal of Wulf and Shea (2002) that, as different components have to be coordinated to produce skilled performance, augmented feedback in complex tasks is generally not as prescriptive as in simple tasks. Therefore, a learner has to also rely on intrinsic feedback sources, which is thought to reduce dependence on feedback. In Study II, however, the superiority of the high KP frequency group was temporary and disappeared in the subsequent retention tests. Interestingly, the retention performance of the participants with reduced frequency of visual KP differed from that of all the other experimental groups: they were able to maintain their shooting score at almost the same level across all the retention tests, whereas shooting score in other feedback groups showed a decline after the 2-day retention test. This result may lend some support to the guidance hypothesis (Salmoni et al. 1984), indicating that the participants with visual KP after 50% of the trials were able to construct a somewhat more permanent pattern of performance under the combination of trials with and without KP.

Concerning auditory feedback, it remains uncertain whether a higher or lower frequency of KP would have resulted in a more efficient shooting performance than the present 50% protocol applied here. As previous studies have shown, high frequency of concurrent feedback in particular has a strong effect on performance when presented during practice, but often results in clear decrements when the feedback is withdrawn in retention or transfer tests (Vander Linden et al. 1993, Winstein et al. 1996, Schmidt & Wulf 1997, Park et al. 2000). As the concurrent KP was delivered after 50% of the trials in the present study, it can be suggested that it did not block the processing of other important types of information (intrinsic) but enhanced learning. The no-feedback trials may have caused the participant to engage in additional important cognitive processes such as those related to error detection (Winstein & Schmidt 1990). It can be speculated whether a higher (e.g. 75%) relative frequency would have interfered with the skill learning by blocking important information-processing activities, or, whether a lower relative frequency of KP (e.g. 25%) would had helped the shooters to encode the task-related kinesthetic and proprioceptive information even more effectively than the 50% schedule.

6.3.2 The effects of KP timing on shooting accuracy

In the present study KP was delivered in two ways regarding the timing of feedback: concurrently with the performance, and terminally after completing the performance. As far as the shooting scores of the groups with the same feedback frequency are conceived, the present results indicate that concurrent auditory feedback seemed to be more effective than terminal visual feedback (see Figure 7, Retention). The present findings are in line with those of previous studies, which have revealed that the performance and learning of a complex task, such as dance routines (Clarkson et al. 1986), cycling (McLean & Lafortune 1988, Sanderson & Cavanagh 1990, Broker et al. 1993), and swimming (Chollet et al. 1988) is enhanced when concurrent feedback is provided. It can be suggested that concurrent auditory feedback in the present study enabled the shooters to make feedback-based corrections in performance. Unlike rapid movements that cannot be modified once they are initiated, the aiming phase in precision shooting lasts long enough to make feedback-based corrections. Moreover, the precision shooting task is performed in closed, stable and predictable environment and it tends to be structured in advance. This presumably frees attentional processes for the detection of errors (see Schmidt & Wulf 1997). Real time information about the movement of the aiming point may also facilitate on-line control through the establishment of a direct link between the desired outcomes and the participant's intrinsic information (see Swinnen et al. 1997).

6.4 The effects of visual KP on the shooter's behavioural performance

6.4.1 The effects of visual KP on rifle stability

In Study II, the effects of augmented visual KP on rifle stability were evaluated in terms of the horizontal and vertical deviations in the movement of the rifle barrel. Furthermore, Study III investigated the effects of augmented visual KP on rifle stability preceding the pull on the trigger.

Training with visual KP after each trial supported rifle stability as compared to the situation in the non-training control group. However, the participants with KP after each trial did not show better rifle stability compared to the participants with KP after 50% of the trials or with KR only. This finding did not support the hypothesis of Study II and Study III that visualized information on rifle barrel movement would have positive effects on rifle stability. Although visual KP provided information on the aiming trajectory of the rifle barrel, the link between the feedback and the correction that should be made, however, was not obvious. The visualized aiming trajectory did not give exact information on how to correct the movement pattern, and therefore the shooter continued to have to decide how to change his performance in the subsequent trials. That being the case, the participants might have benefited from additional instructions on how to interpret the feedback and how to modify their performance after each single trial.

The present results indicate that increased rifle stability did not directly lead to better shooting accuracy. The experimental groups did not differ from each other in the rifle stability variables, although in shooting accuracy the participants with visual KP after each trial outperformed the other visual groups. One explanation for this could be that the amount of feedback was not enough to have an effect on of rifle stability. Furthermore, despite a fixed rifle position and accurate aiming, an undesirable jerking movement during the pull on the trigger could have resulted in a lower shooting score. In this study, the effects of augmented auditory KP on rifle stability were not examined. Therefore, it remains uncertain whether the improvement in the shooting accuracy of the participants with auditory KP on 50% of the trials was accompanied by improved rifle stability.

6.4.2 The effects of visual KP on postural balance

In study III, the effects of augmented visual KP on the shooter's behavioural performance were assessed in terms of the maximal amplitude of sway and the moment of velocity. The results revealed that visual KP after each trial was associated with postural balance when compared to the no-KP condition. The effect was seen in an improvement in the maximal amplitude of sway two days after completing the training period. Thus the present results were, at least partly, in line with the hypothesis of Study III, indicating that there were some tendencies towards better control of postural balance among the participants receiving KP after each trial. Although visual KP guided the shooter to concentrate on taking up a fixed rifle position, it seemed that some effects of KP were seen in the capability to stabilize body movement as a whole during shooting. An attempt to minimize the movement of the rifle may have led to more comprehensive control of the shooter's whole body as indicated by the reduction in sway amplitude. On the other hand, the participant's response to feedback may have been to stabilize the rifle by controlling the whole body instead of just the rifle. As Study I revealed, postural balance seems to affect the shooting score in two ways. Therefore, it can be suggested that improved postural balance might have promoted shooting performance and learning among the participants with visual KP after each trial both directly and indirectly via rifle stability.

6.5 Methodological observations

6.5.1 Participants

Some of the participants were unable to participate in every practice session or every test because of their military duties. Therefore, some participants were dropped from the statistical analyses, starting with those who were absent from the post test and the retention tests, and those whose non-attendance in the training sessions was highest. The number of participants was therefore somewhat low in certain groups. This should be noted in interpreting the results and assessing the practical significance of the present study.

The participants accomplished the acquisition phase during normal military training. During this phase, the training conditions varied from classroom studies to outdoor combat training. The acquisition phase included strenuous phases during which the participants carried out combat training outdoors for several days at a time. However, the conditions were same for all the participants during the study. Furthermore, the participants were highly motivated and showed high concentration during their training sessions.

6.5.2 Methods and study design

Shooting accuracy and rifle stability measurements

Shooting accuracy and rifle stability were measured with an optoelectronic shooting training system. The system was originally designed for the analysis of elite shooting performance; however, the performance of both inexperienced and expert shooters has been measured and analysed with this system. It has been suggested that the optoelectronic shooting training system used in the present study has construct validity and supports technical analysis of the movement of the rifle barrel (Mononen et al. 2003). Further, it has been proposed that with an optoelectronic shooting training system it is possible to detect the differences between shooters with different levels of skills (Mononen et al. 2003).

Numerous missed shots were observed especially in the pre-test and during the early phase of acquisition, which reduced the number of trials that could be analysed. However, missed shots will always be a characteristic of novice shooters; therefore reducing the difficulty of the task may not be appropriate, especially when a complex task is in question.

Postural balance measurements

Postural balance was measured by using a 50 Hz sampling frequency with a 12-byte ADC. Ball (1999) has suggested that the measurement resolution and error due to quantisation using 12-byte ADC may be a limitation on the measure, especially in elite shooters, who show minimal movement of the COP during performance. In the present study, however, the participants were not competitive shooters, and there was much more movement of the COP in their performance compared to elite shooters. With respect to sampling frequency, it has been reported that over 90% of power in COP movement during quiet stance exists below 2 Hz (Soames & Atha 1982). Given that shooting in the standing position is very similar to a quiet standing situation, a 50 Hz sampling frequency should be adequate in the present study.

The variables used in the present study have commonly been used in postural balance studies in shooters. In addition to displacement data (Aalto et al. 1990, Era et al. 1996, Konttinen et al. 1999, Viitasalo et al. 1999), velocity information (Viitasalo et al. 1998, Konttinen et al. 1999) has been used in earlier shooting studies. Sway velocity has been shown to be sensitive in differentiating shooters with different skill levels (Konttinen et al. 1999). Furthermore, Takala et al. (1997) showed high reproducibility in velocity measures. Velocity moment on the other hand has been used in number of shooting studies (Era et al. 1996, Viitasalo et al. 1998, Viitasalo et al. 2001), and it has provided comprehensive information about postural balance by indicating the mean area covered by the movement of the COP during each second.

Study design

The primary aim of this study was to examine the effects of visual KP on shooting performance and learning. In order to clarify the influence of feedback modality on motor skill learning, the protocol was extended with auditory KP. Although the auditory KP was included as extra condition, it turned out to bring an interesting aspect to the whole study. Because the number of participants was limited, some compromises had to be made. The present data, therefore, do not provide us with any information concerning the optimal frequency of auditory feedback, enabling the discussion of feedback frequency to concern only the groups with visual KP. Moreover, the mechanism of auditory KP remains unknown, as no analysis on the effects of auditory KP on shooters' behavioural performance was performed.

The training procedure was designed to be reasonably effective for beginners. However, the total time spent on feedback training was only 5.5 hours. As achieving expertise in complex skills requires at least 10 years of practice (Ericsson & Charness 1994), the present feedback training period was extremely short. Although the feedback training procedure had a positive effect on the essential features of shooting performance among the novice shooters, the period was not probably long enough to discriminate between the effects of different augmented feedback procedures. It can be suggested that had the training period been longer, the participants might have learnt to use the KP feedback more effectively (see Abernethy et al. 1994): as a shooter becomes more skilled, he or she may be more capable of perceiving and interpreting the essential features of feedback, and linking this information to the subsequent trial.

6.6 Practical remarks

From the practical viewpoint, the most interesting finding was that auditory feedback clearly facilitated learning. Optoelectronic shooting training systems have commonly been used in shooting practice to inform the shooter about the performance outcome, i.e. shooting score, and in the technical analysis of shooting performance (see Mason et al. 1990, Konttinen et al. 1998, Viitasalo et al. 1999, Mononen et al. 2003). With respect to feedback, the visualized aiming trajectory has been used in some extent during shooting training, whereas the auditory mode has rarely been used in training situations. The findings of the present study support the view that auditory feedback describing gun stability could be used to advance skill learning in the training of inexperienced shooters. Therefore, the use of a shooting training system among inexperienced shooters should be encouraged.

6.7 Recommendations for the future studies

The results of the present study support the view that concurrent auditory KP on rifle stability benefits the learning of shooting performance in inexperienced shooters. In future studies it may therefore be of value to investigate in more detail different concurrent feedback conditions. Different concurrent feedback frequencies as well as different combinations of terminal and concurrent feedback conditions may help to clarify what the optimal feedback procedure is for learning a complex motor skill. Additionally, it would also be important to examine the effects of KP on shooters with different skill levels in order to expand knowledge on the effects of level of skill on the use of KP.

7 CONCLUSIONS

On the basis of the results of this study the following conclusions can be drawn:
1. Augmented KP advanced shooting accuracy among inexperienced shooters when compared to the no-KP condition.
2. When provided terminally, high frequency of visual KP appeared to improve shooting accuracy when compared to reduced frequency of visual KP or to the no-KP condition.
3. Concurrent auditory KP based on the on-target trajectory of the alignment of the rifle after 50% of trials is beneficial for the learning of precision shooting. It is postulated that the auditory feedback provided concurrently with the aiming promotes a shooter's self-initiated error detection and correction abilities by directing his attention to the critical components of psychomotor regulation. Concurrent auditory KP also provides the shooter with information about how the pattern of movement should be altered to improve rifle stability, which is a vital determinant of superior shooting performance.
4. Terminal visual KP had minor effects on shooters' behavioural performance. Therefore, the mechanisms underlying significant improvement in the shooting score remain unknown.

YHTEENVETO

Ulkoisen palautteen vaikutus motoriseen oppimiseen ammunnassa: Harjoittelututkimus kokemattomilla kivääriampujilla

Johdanto. Suorituksesta saatavalla palautteella on tärkeä merkitys motoristen taitojen oppimisessa. Suorituksesta saatujen omien näkö, kuulo- ja tuntoaistimusten lisäksi oppijan ulkopuolelta tulevan lisäpalautteen (augmented feedback) on todettu edistävän motoristen taitojen oppimista. Ulkoinen palaute voi olla joko tietoa suorituksen lopputuloksesta (knowledge of results, KR) tai tietoa lopputulokseen johtaneista liikemalleista (knowledge of performance, KP).

Aiempien oppimistutkimusten perusteella uskottiin pitkään, että oppiminen on sitä tehokkaampaa, mitä enemmän ja mitä tarkempaa tietoa oppija saa suorituksesta. Palautteen vaikutukset ovat kuitenkin osoittautuneet monimutkaisemmiksi, varsinkin kompleksisen motorisen taidon oppimisessa. Ulkoisen palautteen vaikutuksia on tutkittu perinteisesti yksinkertaisten motoristen taitojen yhteydessä. Valtaosassa tutkimuksista on käytetty KR-palautetta. Näiden tutkimusten tulokset ovat osoittaneet, että tieto suorituksen lopputuloksesta on yleensä riittävän tehokas tapa tukea yksinkertaisten motoristen taitojen oppimista. Viime aikoina on siirrytty tutkimaan myös ulkoisen palautteen vaikutuksia monimutkaisempien käytännön taitojen oppimiseen. Tutkimusten mukaan tieto suorituksen liikemalleista edistää tehokkaammin monimutkaisen motorisen taidon oppimista kuin pelkkä tieto suorituksen lopputuloksesta.

Tämän tutkimuksen lähtökohtana oli selvittää ulkoisen palautteen vaikutusta motorisen taitosuorituksen oppimiseen. Tutkimuksen tavoitteena oli selvittää, millaisia vaikutuksia KP-palautteella on monimutkaisen motorisen taidon oppimisprosessin alkuvaiheessa. Tutkimustehtäväksi valittiin tarkkuusammunta, jossa KR- ja KP-palautteet ovat selkeästi erotettavissa toisistaan. KR tarkoittaa ampumatulosta, joka on mitattavissa osuman etäisyytenä taulun keskipisteestä. KP kuvaa puolestaan ampumasuorituksen aikaisia liikemalleja. Tässä tutkimuksessa KP-palautetta annettiin kehon tasapainon hallinnasta ja aseen vakaudesta. Kokemattomien ampujien ammuntasuoritusta tutkittiin neljässä eri osatutkimuksessa. Osatutkimusten tutkimusongelmat olivat seuraavat:

1. Ovatko ampumatarkkuus, kehon tasapainon hallinta ja aseen piipun vakaus yhteydessä toisiinsa?
2. Millä tavoin ulkoinen KP-palaute vaikuttaa ampumatarkkuuteen?
3. Millä tavoin ulkoinen KP-palaute vaikuttaa ampujan kehon tasapainon hallintaan ja aseen piipun vakauteen?

Tutkimuksen kohderyhmä ja menetelmät. Tutkimuksen koehenkilöinä oli 58 varusmiestä, jotka satunnaistettiin viiteen ryhmään. Kaikki harjoittelevat ryhmät saivat KR-palautetta jokaisen laukauksen jälkeen, mutta erosivat KP -palautteen suhteen seuraavasti:

– Ryhmä 1 sai visuaalista KP-palautetta jokaisen laukauksen jälkeen (palautefrekvenssi 100 %)
– Ryhmä 2 sai visuaalista KP-palautetta joka toisen laukaussarjan jälkeen (palautefrekvenssi 50 %).
– Ryhmä 3 sai auditiivista KP-palautetta joka toisen laukaussarjan aikana (palautefrekvenssi 50 %)
– Ryhmä 4 ei saanut lainkaan KP-palautetta (palautefrekvenssi 0 %)

Ryhmä 5 toimi kontrolliryhmänä ja osallistui vain ammuntatesteihin.

Tutkimusryhmät harjoittelivat kolme kertaa viikossa neljän viikon ajan. Koehenkilöt ampuivat jokaisen harjoituksen aikana neljä 10 laukauksen sarjaa. Harjoituskerran kesto oli keskimäärin 30 minuuttia ja harjoitteluun käytetty kokonaisaika oli noin 5,5 tuntia. Harjoituskertoja oli yhteensä 11. Harjoittelujakson aikana koehenkilöt saivat ulkoista palautetta ammuntasuorituksestaan. Mittaukset toteutettiin ennen harjoittelujaksoa sekä 2, 10, ja 40 päivää harjoittelujakson loppumisen jälkeen ilman ulkoista palautetta.

Harjoittelujakson aikainen ulkoinen palaute koostui sekä osumatiedosta (KR) että aseen piipun liikeratainformaatiosta tähtäyksen aikana (KP). KR-palaute näytettiin osumana taulupinnalla tietokoneen monitorissa laukauksen jälkeen. KP-palaute jakaantui visuaaliseen ja auditiiviseen palautteeseen. Visuaalinen KP kuvasi, miten tähtäyspiste liikkui suorituksen aikana suhteessa ampumatauluun. Liikerata oli nähtävissä tähtäyspisteen liikeratatietona tietokoneen monitorissa välittömästi laukauksen jälkeen. Auditiivinen KP ilmaisi ampujalle tähtäyspisteen etäisyyden taulun keskipisteestä: mitä korkeampi ääni oli, sitä lähempänä tähtäyspiste oli taulun keskipistettä. Palaute annettiin koehenkilölle kuulokkeiden kautta suorituksen aikana. Ulkoisen palautteen vaikutuksia ampumasuorituksen oppimiseen arvioitiin ampumatuloksen sekä kehon tasapainon hallintaa ja aseen piipun vakautta kuvaavien muuttujien avulla.

Tulokset. Ensimmäisessä osatutkimuksessa selvitettiin ampumatuloksen, kehon tasapainon hallinnan ja aseen piipun vakauden välisiä yksilöiden sisäisiä ja yksilöiden välisiä yhteyksiä ennen harjoittelujakson alkamista. Tulokset osoittavat, että henkilöiden välisessä tarkastelussa ampumatulos, kehon tasapainon hallinta ja aseen piipun vakaus olivat yhteydessä toisiinsa. Aseen vakautta ja kehon tasapainon hallintaa kuvaavat muuttujat selittivät ampumatulosta kohtalaisesti. Sen sijaan tarkasteltaessa yksittäisen ampujan laukausten välisiä yhteyksiä näiden muuttujien väliset yhteydet olivat vähäisiä. Kehon tasapaino näytti vaikuttavan ampumatulokseen sekä suoraan että aseen vakauden kautta. Kyseiset yhteydet olivat voimakkaampia niillä koehenkilöillä, joilla kehon huojunnan vaihtelu oli vähäistä ammunnan aikana, kuin henkilöillä, joiden kehon huojunnan vaihtelu oli suurta.

Toisessa osatutkimuksessa selvitettiin suorituksen jälkeen annettavan visuaalisen KP-palautteen vaikutusta ampumatulokseen ja aseen vakauteen tähtäysvaiheen aikana. Tulokset osoittavat, että kaksi päivää harjoittelun jälkeen visuaalista KP-palautetta jokaisen laukauksen jälkeen saaneiden koehenkilöiden ampumatulos oli parempi kuin niiden koehenkilöiden, jotka saivat joko visuaalista KP-palautetta 50 %:ssa laukauksista tai pelkkää KR-palautetta. Ryhmien välisiä eroja ei ollut havaittavissa enää 10 päivää harjoittelujakson loppumisen jälkeen. Aseen vakaudessa ei ollut eroja harjoittelevien ryhmien välillä.

Kolmannessa osatutkimuksessa tutkittiin suorituksen jälkeen annettavan visuaalisen KP-palautteen vaikutusta sekä kehon tasapainon hallintaan että liipaisuvaiheen aikaiseen aseen vakauteen. Tulokset osoittivat, että kaksi päivää harjoittelun jälkeen visuaalista KP-palautetta jokaisen laukauksen jälkeen saaneiden koehenkilöiden tasapainon hallinnassa oli havaittavissa kehittymistä verrattuna niihin koehenkilöihin, jotka saivat pelkkää KR-palautetta. Visuaalisella KP-palautteella ei ollut vaikutusta aseen liipaisuvaiheen aikaiseen vakauteen.

Neljännessä osatutkimuksessa selvitettiin suorituksen aikana annettavan auditiivisen KP-palautteen vaikutusta ampumatulokseen. Niiden koehenkilöiden ampumatarkkuus, jotka saivat auditiivista KP-palautetta 50 %:ssa laukauksista, oli parempi sekä harjoittelun aikana että seurantamittauksissa verrattuna pelkkää KR-palautetta saaneisiin koehenkilöihin.

Pohdinta ja johtopäätökset. Tutkimuksen keskeisin tulos on se, että suorituksen liikemalleja ilmentävällä palautteella on mahdollista tukea aloittelevien ampujien oppimisprosessia. Tulokset osoittavat myös, että kehon tasapainon hallintaa ja aseen vakautta kuvaavat muuttujat liittyivät olennaisesti ampumasuoritukseen kokemattomilla ampujilla.

Osatutkimusten 2 ja 4 tulokset osoittavat, että ammuntatuloksen lisäksi joko visuaalista tai auditiivista KP-palautetta saaneiden koehenkilöiden ampumatarkkuus oli parempi kuin pelkästään tuloksesta palautetta saaneiden koehenkilöiden. Jokaisen laukauksen jälkeen annettuna visuaalinen palaute aseen piipun liikeradasta edisti tehokkaammin ampumasuorituksen oppimista kuin joka toisen laukaussarjan jälkeen annettu vastaavanlainen palaute tai pelkkä tieto osumasta. Tämä havainto viittaa siihen, että monimutkaista motorista taitoa harjoiteltaessa aloittelija hyötyy suorituksen liikemalleja kuvaavasta lisäpalautteesta, erityisesti silloin kun palaute annetaan jokaisen suorituksen jälkeen. Suorituksen aikana annettu auditiivinen palaute aseen piipun liikkeestä edisti ampumatuloksen kehittymistä enemmän sekä harjoittelun aikana että sen jälkeen kuin pelkkä palaute ampumatuloksesta. Joka toisen laukaussarjan aikana annettu auditiivinen palaute edisti ammuntasuorituksen oppimista enemmän kuin kaikki tutkimuksen muut palautejärjestelyt. Voidaan esittää, että suorituksen aikana annettava auditiivinen palaute kehittää oppijan kykyä tunnistaa ja korjata virheitä ohjaamalla hänen huomionsa psykomotorisen säätelyn kannalta olennaisiin tekijöihin. Suorituksen aikaisen auditiivisen palautteen voidaan olettaa kertovan oppijalle myös, miten liikemalleja tulisi muuttaa aseen vakauden parantamiseksi.

Tutkimus antaa samalla viitteitä siitä, että ulkoisella palautteella on ampujan tasapainon hallintaa ja aseen vakautta edistäviä vaikutuksia. Osatutkimus 3 osoitti, että jokaisen suorituksen jälkeen annetulla visuaalisella palautteella, joka koski aseen tähtäyksen liikerataa, pystyttiin tukemaan suorituksen aikaista tasapainon hallintaa.

Osatutkimuksissa 2 ja 3 havaittiin, että ei ainoastaan aseen piipun liikerataa koskeva visuaalinen palaute jokaisen laukauksen jälkeen vaan myös pelkkä tieto osumasta edisti aseen vakauden kehittymistä. Suorituksen aikaisista liikemalleista kertovan ulkoisen palautteen voidaan siis esittää vaikuttavan myönteisesti aloittelevien ampujien suoritustekniikkaan.

Tutkimus vahvistaa käsitystä siitä, että monimutkaista motorista taitoa harjoiteltaessa suorituksen liikemalleista annettu palaute edistää oppimista enemmän kuin pelkkä tieto suorituksen lopputuloksesta. Tutkimus osoittaa myös, että oppimisen alkuvaiheessa suorituksen jälkeen annettava palaute edistää taidon oppimista parhaiten, kun se annetaan mahdollisimman monen suorituksen yhteydessä. Suorituksen aikana annettu palaute näytti edistävän tehokkaasti oppimista silloin, kun sitä annettiin vain osalle suorituksista. Tutkimuksen tulokset tukevat myös käsitystä siitä, että ulkoisen palautteen vaikutukset ovat monen tekijän yhteistulos. Palautteen tyyppi, määrä ja ajoitus yhdessä tehtävän vaikeustason sekä oppijan taitotason kanssa ohjaavat oppimistilanteessa valitsemaan optimaalisen palautejärjestelyn.

Jatkotutkimuksissa olisi syytä tarkastella yksityiskohtaisemmin etenkin suorituksen aikana annettavan palautteen vaikutusta motoriseen oppimiseen. Eri frekvensseillä annettavien palautteiden vaikutusten tutkiminen, samoin kuin suorituksen eri vaiheissa annettavien palautteiden yhdistäminen toisivat myös uutta tietoa ulkoisen palautteen hyödyntämisestä monimutkaisten motoristen taitojen oppimisessa.

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