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BILATERAL TRANSFER IN LEARNING: IMPLICATIONS FOR SPORT SKILLS

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1. INTRODUCTION

Methods to facilitate the learning of motor skills have been studied extensively by researchers in psychology and physical education. A major topic in this research is the concept of transfer, specifically inter-task, intra-task and bilateral transfer of skills (Magill, 1998). Bilateral transfer is the focus of this paper. Bilateral transfer of learning or training is the phenomenon of practising a novel task with one limb which then typically facilitates subsequent learning and performance by the opposite, untrained limb in the same task (Ammons, 1958). The terms cross-education (Parlow and Kinsbourne, 1989), intermanual transfer and bimanual skill transfer (Hicks *et al.*, 1982) are also used to define bilateral transfer.

Evidence for bilateral transfer dates to the late nineteenth and early twentieth century, but this type of research was quite popular from the 1930s through the 1950s. Although research interest the topic of bilateral transfer has not been as popular more recently, a reasonable amount of experimental data has accumulated over the past 50 years or so, addressing topics such as distribution of practicep, overload, response selection, and fatigue. Some research has addressed the underlying reasons or mechanisms for bilateral transfer and variation in the magnitude of transfer between limbs in learning and control of motor skills.

2. SIGNIFICANCE OF BILATERAL TRANSFER

Implications of bilateral transfer in the learning of sport skills are apparent in several contexts including the following:

(1) Bilateral transfer may result in the conservation of practice time;

(2) Practice of a skill on both sides of the body may lead to a more thorough understanding of the skill;

(3) The mechanism of bilateral transfer may shed light on whether and/or how transfer occurs in learning the complex movements

that characterize most sport skills, and whether and/or how transfer can be enhanced by practice and training;

(4) Understanding bilateral transfer in the learning of sport skills would enhance the effectiveness of teaching sport specific skills.

Overall,the study of the bilateral transfer may offer valuable insights into the understanding of skilled performance.

3. BILATERAL TRANSFER IN A VARIETY OF TASKS

Simple observation highlights the relevance of bilateral transfer. In the performance of both simple and complex motor tasks, most individuals express clear preference for one hand over the other, and about 90% of the human population uses the right hand for most skill activities (Hicks and Kinsbourne, 1976). A novel task practiced with one hand typically facilitates subsequent performance of the opposite, untrained hand in the same task. The same is suggested for transfer between the lower extremities. A question of interest is the following: Does bilateral transfer occur in the acquisition of more complex sport skills?

Early examples of research into the phenomenon of bilateral transfer include the following. Bryant (1892) noted transfer of tapping between two hands among the children during the development of voluntary motor ability. Woodworth (1899) studied bilateral asymmetry in manual aiming, and showed distinct superiority of the right over the left hand in accuracy. Swift (1903) was apparently the first to conduct an experiment on transfer with a ball skill. Subjects learned to toss two balls with a single hand (right), and then learned the same skill with the other (left) hand more quickly after mastering this skill with preferred hand (right). Subsequent research has generally focused on relatively discrete tasks including mirror drawing, tracing and writing; dart throwing; rotary and linear pursuit; pursuit tracking; inverted-reversed printing; one-hand typing and typewriting; rapid finger tapping; finger aiming and lifting; and a pegboard test (Ammons, 1958; Elliott *et al.*,1993). More complex movements studied in the context of bilateral transfer have included dance movements, knee extension, the basketball lay-up, the javelin throw and shotput, target throwing at target, and an anticipatory timing task (Ning, 2001; Teixeira, 2000).

4. WHY BILATERAL TRANSFER OCCURS?

It is apparent that much of the above literature on bilateral transfer is based upon discrete motor tasks, with relatively little applied to more complex tasks, including sport-specific skills. Clearly, many issues still need consideration, and among these is the explanation of the basis and/or underlying mechanisms of bilateral transfer: why transfer occurs, how it occurs, and the direction of transfer, among others. Two hypotheses, cognitive hypothesis and neuromuscular activation hypothesis, of why bilateral transfer occurs and threee models of how it occurs have been proposed.

Cognitive Hypothesis:

The cognitive hypothesis postulates that the common elements of a task to be performed by two limbs underlie the transfer phenomenon (Ammons, 1958). The hypothesis is based on the theory of identical elements proposed by Thorndike (1914). The essence of the identical elements theory is that in order for transfer of learning between skills and/or movement contexts to occur, the elements underlying the two skills or situations must be identical. A more recently developed view of transfer (Bransford *et al.*,1979), transfer-appropriate processing, proposes that the learning of any movement skill is enhanced if the nature of the processing activities involved in the practice of that skill is similar to the type of processing that underlies the performance of the same skill in a different context or in a different movement pattern from the one practiced. In contrast to the identical elements theory, advocates of transfer-appropriate processing suggest that is the similarity of the cognitive processing that determines whether transfer occurs (Ross, 1997). According to the transfer-appropriate processing framework, practicing a variety of structurally dissimilar skills that require the same types of cognitive processing needed to perform other related movement skills, should promote positive transfer (Lee, 1988).

The cognitive hypothesis suggests that bilateral transfer is a result of central information processing and does not entail peripheral neuromuscular transmissions. The role of mental imagery in bilateral transfer from the right to the left hand was investigated in a rotary pursuit task to address the issue of central processing (Kohl and Roenker, 1980, 1983). A sample of 60 right-handed males were randomly assigned to one of three groups: right hand mental imagery group in which the subjects created an mental image of himself holding the stylus in the right hand and performing the rotary pursuit; right hand physical rehearsal group in which the subjects physically practiced the pursuit task; and a control group without neither mental imagery nor physical practice. Results of left hand performance in rotary pursuit tracking of all subjects showed that mental imagery and physical rehearsal significantly facilitated bilateral transfer, i.e., transfer from the right to the left hands. The physical and mental imagery practice groups performed similarly and both performed better than the control group. The results suggest a cognitive basis for bilateral transfer.

Other studies suggested that bilateral transfer occurred in contralateral hand among subjects who only observed the other hand performing a task.

Moreover, the amount of bilateral transfer shown by the subjects who observed the task was as much as that which occurred among the subjects who physicall practiced the task. It has also been suggested that the knowledge architecture of a task needs to be first established and then gradually modified and refined as a skill is acquired (Glencross, 1992). Thus the initial stages of learning require the recognition and elaboration of the relevant declarative knowledge and the development of a knowledge structure. The role of initial instruction, demonstration and observation is critical in this process. The cognitive hypothesis thus involves a cognitive representation of the observed behavior that provides a standard of correctness and guides the subsequent action so that observation (e.g., verbal self-instruction) can lead to bilateral transfer in learning.

Neuromuscular Activation Hypothesis

Neuromuscular involvement in bilateral transfer has also been hypothesized. It has been proposed that some bilateral transfer of skill is mediated by inter-hemispheric transfer of the motor components of the task (Hicks, 1983). "Motor overflow at a submotor level" provides the nonpracticing limb with the kinesthetic sensation of moving without any overt movement. An overflow of impulses to the contralateral limb apparently occurs during practice. It was also suggested that involuntary movement (motor overflow) accompanying the intended movement might be related to the transfer of training. During the performance of rapid finger-sequencing by one hand (active hand), unintended movement (i.e., motor overflow) was observed in the passive hand (Edwards and Elliott, 1987).

A role for task efficiency in the occurrence of motor overflow has also been proposed. Within the framework of schema theory (Schmidt, 1999), this information can be used for error detection and correction, and can be integrated into the development of a generalized motor program for control of the movement. In essence, neural activity as evidenced by EMG readings in the nonpracticing limb facilitates the transfer of task-specific motor components between limbs and covertly promotes the development of a motor program to control the performance of the nonpracticing limb (Hicks, 1983). In a study of unilateral isometric training of the quadriceps, a large increase (576 to 793 Newtons). The contralateral (control) leg also increased (though not significantly) in isometric force (606 to 662 Newtons), suggesting a bilateral transfer of training effects (Rutherford and Jones, 1986).

Overview of Hypotheses

Bilateral transfer does occur and evidence for both neuromuscular activation and cognitive explanations has been reported. This would suggest that bilateral transfer is the result of both cognitive and motor factors. Two implications for the learning of sport skills follow. First, learning a sport skill has a cognitive base. Second, sport skills are controlled by a generalised motor program that represents the specific actions without including muscle information. Skill refinement including specific neuromuscular involvement follows with training.

4. HOW BILATERAL TRANSFER OCCURS?

It is generally that the direction of bilateral transfer is asymmetric, i.e., a greater amount of transfer occurs from one limb to the other. It is not clear, however, whether this asymmetry favours initial preferred or non-preferred limb practice, or whether transfer of learning is greater from the non-preferred to the preferred side, or vice versa. Taylor and Heilman (1980) showed that initial training with the non-preferred hand led to greater transfer to the preferred hand than the opposite practice and transfer schedule did while Parker-Taillon and Kerr (1989) proposed that initial practice with the preferred hand would provide better quality feedback with regard to response specifications and sensory consequences and thus transfer of learning should be greater from the preferred to the non-preferred hand. Three models of inter-hemispheric interaction have been proposed to explain the asymmetry of bilateral transfer.

Access Model:

Based on observations that the right hand benefited more than the left from opposite-hand training, an access (callosal) model has been suggested (Parker-Taillon and Kerr, 1989). The model links the direction of greater transfer with hemispheric specialisation for some tasks, specifically of the left hemisphere which controls movements of the right hand. The corpus callosum participates in such higher order "control" functions as the support of bilateral representation of language, functional inter-hemispheric inhibition, and the maintenance of hemispheric differences in arousal (Clarke and Zaidel, 1994). Further, callosal regions that connect primary and secondary sensory and motor areas are characterised by a large proportion of fast-conducting, large-diameter fibres, while regions connecting the association areas and prefrontal areas have a high density of slow-conducting, lightly myelinated and thin fibres (Aboitiz, 1992). These observations suggest that the fast-conducting fibres connecting sensory and motor areas contribute to fuse the two hemi-representations in each hemisphere. According to the access model, lateral transfer should favour the right hand (in right-handed subjects) because of direct access to skills learned by the left hand in the left hemisphere, and same hand training would be superior to opposite-hand training for the non-preferred but not for the preferred hand.

Proficiency Model:

Several studies of opposite hand training have shown that the left hand benefited more than the right hand in mirror-drawing, rotor pursuit and fast tapping. A preproprammed, nonsequential model of motor control associated with right hemisphere function was proposed (Parlow and Kinsbourne, 1989). The greater proficiency of the right hand for most unimanual skills was due either to left hemispheric specialisation and/or greater practice. This proficiency model argues that the more proficient hand (hemisphere) learns more elements during training and/or forms a better standard that then can be used to the advantage of the untrained hand. Although each hemisphere may be capable of performing a component of a given processing task, the stage of processing required to complete the operation is functionally localised to one hemisphere.

The proficiency model generates a contrasting prediction as does the access model, i.e., the left hand should benefit more than the right from opposite-hand training. The proficiency model proposes that same hand training is superior to opposite-hand training for the preferred hand, but not for the non-preferred hand.

Cross-activation Model:

The cross-activation model presents an alternative view. Accordingly, under certain conditions (as when the preferred hand is trained), dual "engrams" are formed - one in each hemisphere, and under other conditions (as when the non-preferred hand is trained), a single "engram" might be formed (Parlow and Kinsbourne, 1989). To explain why the former would facilitate the transfer of skill between limbs, it is speculated that activation of the dominant hemisphere leads to maintaining the opposing hemisphere in a state of readiness to respond. In this state, the nondominant hemisphere learns about the task in parallel fashion, forming an independent internal representation (engram) and interpreting the information obtained from the preferred hand in its own way. The cross-activation model assumes coupling of hemispheric proficiency in the sense that the dominant hemisphere is usually more efficient, which is reflected in better performance by the hand that it controls. Evidence for cross-activation comes from clinical studies of the corpus callosum. This brain structure apparently plays a role in bimanual motor co-ordination although other pathways (probably ipsilateral and/or subcortical) may provide compensation in cases in which the corpus callosum is absent. Clinical data also suggest that the corpus callosum may be important for inter-hemispheric transfer of tactuo-motor learning when a spatial component is involved (Sauerwein and Lassonde, 1994).

5. WHAT IS TRANFERRED BETWEEN THE LIMBS?

In general, bilateral transfer of learning is task-specific, and the main control components for proficient performance and control of action are transferred between the limbs. The main control components are both cognitive (or perceptual) and motor. Bilateral transfer may occur in different ways. There may be a transfer of all relevant components for proficient performance, or a transfer of only more generalizable, effector independent, control components. Transfer may be partial with a decline in performance of one or more components in the transfer task, or complete. Examples of transferable components in motor behaviour are anticipatory timing and force control (Teixeira, 2000).

Bilateral transfer occurs in both directions during the learning of a skill, i.e., from the preferred to the non-preferred limb and from the non-preferred to the preferred limb. This was shown for performance errors, velocity and acceleration in learning overarm throwing (Ning, 2001). However, performance errors (perceptual component) transferred more so from the non-preferred to the preferred hand, while velocity and acceleration (motor components) transferred more from the preferred to the non-preferred hand in this experiment with the overhand throw.

It is speculated that directional effects in the transfer of training between hands may be linked to brain organization, and specifically to hemispheric specialization of function. Hemispheric specialization of function indicates that the left hemisphere is specialized for speech and phonetic analysis, motor functions, and certain forms of emotion, while the right hemisphere is specialized for some visuo-spatial functions, components of attention, and other forms of emotion (Hoptman and Davidson, 1994). The right hemisphere may also have a special role to in preparing spatial aspects of aiming movements, while the left hemisphere is more important for movement execution (Elliott *et al.*, 1993).

The amount and direction of bilateral transfer of learning in motor skills are apparently dependent on the main components, or on a combined pattern of perceptual and motor components involved in a given task. There is variation, however, in the transfer of measures that are predominantly cognitive or perceptual in contrast to measures that are predominantly neuromuscular (kinetic or kinematic).

6. POTENTIAL IMPLICATIONS FOR SPORT SKILLS

- Bilateral transfer is asymmetric. Hence, sport skills which require both limbs to be involved, as some ball games, the preferred limb should learn and practice a complex sport skill to a reasonable degree of proficiency before practice for transfer to the non-preferred limb. For example, a basketball player may practice dribbling first with the right (preferred) hand; then after an amount of practice with the right hand, the player begins to practice dribbling with the left hand. Thus, the right hand not only has a greater amount of practice, but practice with the right hand will enhance the more efficient learning of by the left hand because bilateral transfer occurs between the two hands during learning.

- Alternative practice is optimal for the acquisition of bilateral tasks in contrast to practicing the task with the preferred or the non-preferred hand. The efficiency of an alternative schedule can be attributed to the involvement of both hemispheres and limbs in the practice. It is also suggested that alternative schedules should be used in learning of bilateral motor tasks in order to optimize the learning process.

- Both motor and cognitive elements could be transferred between limbs. The rationale and principles of bilateral transfer suggest that when the preferred limb is not able to perform because of injury, practice with the non-preferred limb may help to retain and perhaps enhance the athletic ability of the preferred limb. It is also possible than practice with the non-preferred may have a facilitatory in overcoming the deficits of the injured preferred limb. For example, in some sports (e.g., tennis, badminton) or events/activities within a sport (e.g., throwing), practice or special exercises with the non-preferred hand may help to avoid decrease in the capacity of the preferred arm and/or may maintain the capacity of the preferred hand. This may have relevance during the treatment and recovery phase of injured limbs.

- During training or the course of a season, performances of athletes occasionally stagnate and even decrease. This is commonly referred to as a "plateau" and "slump". This is likely due to inhibiting or restraining factors (both cognitive and motor). According to the rationale of bilateral transfer, practice with the non-preferred (non-dominant) limb may transfer to the preferred (dominant) limb which has been inhibited/restrained. When the effects of bilateral transfer are accumulated, the inhibiting/restraining factors on thepreferred/dominant limb may be relaxed or alleviated, so that the "plateau" or "slump" is overcome.

There are probably other implications and applications of the principles of bilateral transfer to sport skills, but these need to be elucidated in the contexts of specific age groups and sports. Unfortunately, a good deal of motor learning research is based in the laboratory and on adults so that application of these principles to the playing field or gymnasium, and to young athletes, many of whom are learning sport-specific skills, needs care.

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