The Savings in Motor Adaptation: Implications on Sports Training

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Abstract. Motor learning, consisting of skill learning and motor adaptation, is one of the most important topics in sports training. However, motor adaptation, investigating how human make quick adjustments in the face of altered conditions, has been largely ignored in coaching. Here in this paper, we reviewed the savings effect in visuomotor rotation, which is the most typical paradigm in motor adaptation, and discussed the implications on sports training. Savings, referring to faster relearning effect, is regarded as an indicator of motor memory and learning transfer. In laboratory studies, researchers find that in many cases, motor adaptation could not be transferred directly across limbs or directions. However, researchers found that by performing an irrelevant task at the to-be transferred condition could eliminate the learning specificity and even achieve complete transfer. The irrelevant task may enhance the control of the new effector or help people get familiar with the new environment. Then, we explored which is necessary for the savings, forming an explicit strategy or experiencing similar errors. By using novel techniques to dissociate the two factors, we conclude that experiencing salient errors is critical for savings to occur. Inspired by these findings, we suggest that in order to increase the extent of learning transfer, some warming-up exercises could be introduced in the to-be transferred condition. Moreover, magnifying the errors between athletes’ and standard movement by taking videos or using VR and AR techniques may be helpful to motor learning.

1. Introduction

Motor learning, which refers to improvement in the performance of motor behavior through practice, is one of the most important topics in sports training. Motor learning includes not only learning new motor skills, but also compensating for natural and artificial perturbations of the sensorimotor system for the learned skills. The former is called motor skill learning while the latter is called motor adaptation.

Motor adaptation is very commonly experienced in both sports and in our daily life. For example, we have to adjust our ways to hit the ball when we play tennis in wind and we naturally adjust our grip force when we drink a cup of coffee as the decreases of the cup’s weight. For laboratory studies, perturbation paradigm is most commonly used to study motor adaptation. Specifically, an experimentally-manipulated perturbation is imposed to alter the relationship between a movement and its resulting sensory feedback. When the perturbation is firstly applied, subjects experienced large movement errors. By adjusting their motor outputs in subsequent trials, they gradually reduce the errors and make their performance return to its initial baseline levels.

Among the perturbation paradigm, adaptation to visuomotor rotation is one of the most typical task. Visuomotor rotation is a screen-cursor transformation that introduces a systematic directional bias around the hand. It is like the way we control our computer mouse, but the direction mapping between the hand and cursor movement is changed. For example, participants have to move 30° clockwise (CW) to hit the target if a 30° counterclockwise (CCW) rotation is imposed. Participants will learn a new visuomotor mapping through the task.

As easily controlled in laboratory and universally experienced in people's life, motor adaptation has served as a cornerstone in understanding motor learning. However, researchers in the field of sports training focus more on the motor skill learning, while ignoring the significance of motor
adaptation. Here in this paper, taking visuomotor rotation as an example, we review some key experimental results in motor adaptation and discuss the implications on sports training.

2. The Savings in Motor Adaptation and its Implications on Sports Training

2.1. The Savings in Motor Adaptation

The saving effect refers to the phenomenon in which people show faster relearning of a previously forgotten memory, compared with the rate of initial learning. Savings is a universal metric for all learning systems, including semantic, perceptual, and motor systems. In the domain of motor adaptation, if participants have learned how to adapt to a 30° CCW rotation, after we bring their performance back to baseline, they will still show faster learning rate when they readapt to the same perturbation even after a year. Here, we first ask whether participants could learn faster in a similar context compared to initial learning. That is, whether learning of visuomotor rotation could be transferred to other situations. Then, we ask what is saved on earth during the initial learning and whether there is boundary conditions for the savings. We will answer these two questions in the following sections.

2.1.1. Eliminating Learning Specificity across Limbs and Directions

Transfer of motor learning across the limbs has been widely studied in the field of sports training. In motor adaptation, previous research indicates that the extent to which learning of visuomotor rotation is transferred across the arms is typically very limited [1]. For example, learning a visuomotor rotation of a particular direction and size using right hand cannot accelerate the learning rate of the same perturbation using left hand. That is to say, it seems that the task is totally new for one arm of the participants even though they have already experienced the task using the other arm. One recent research sought to explore new training methods to enhance the extent of interlimb transfer [2]. They found reinforcing the initial learning was not beneficial for the extent of transfer. In contrast, repeatedly performing a simple task without learning new visuomotor mappings with one arm while adapting to a visuomotor rotation with the other could lead to complete interlimb transfer. The finding suggests that the limited interlimb transfer may result from the absence of motor instances associated with the to-be transferred arm.

In another study, we found that the savings of visuomotor rotation is not only effector specific, but also direction specific [3]. That is, participants learned visuomotor rotation in one direction could not accelerate the learning rate of the same perturbation in directions 135° away from the training direction. Surprisingly, the direction specificity could be eliminated if the participants were trained with an irrelevant visuomotor task (here we use visuomotor gain, in which the movement distance between hand and cursor has been changed) at the to-be transferred direction. However, the complete transfer could be weakened if the directional error signals were removed during the new mapping learning. Besides, learning with directional errors but without a new mapping at the to-be transferred directions could only lead to partial transfer. Moreover, control experiment showed that tasks which could activate similar muscle, but with neither directional errors, nor new mapping learning had no influence on the transfer at all. These findings suggest that exposing to a new visuomotor mapping and original error signals are essential for the complete transfer of visuomotor rotation across directions. We speculate that learning an irrelevant task may induce meta-learning mechanism, as both tasks involve learning of a novel visuomotor mapping. In this way, participants could infer that the novel rotation mapping is also applicable to far directions. Plus, experiencing original error signals may help our brain quickly recognize rotation errors at the new directions and adapt to the rotation perturbation with a faster relearning rate.

2.1.2. What is Saved during Initial Learning

As mentioned above, the saving effect can be regarded as an indicator of motor memory and learning transfer. In the following study, we dig into it and explore what is learned and saved during initial learning. In other words, we want to figure out what is the most essential element for the savings to
occur. Different researchers have different opinions on this question. One theory suggests that reinforcing the adapted action repeatedly is essential for the savings \[4\]. However, more evidences indicate that reinforcing the learned movement may not be necessary. For example, some researchers found that participants showed savings with only a few trials of practice for initial learning, so that the solution action has not yet been reinforced \[5\]. Another theory suggests that forming an explicit strategy during initial learning seems to be the sole source of savings in visuomotor rotation \[6\]. Here, the explicit strategy refers to aiming to a direction deviated from the target. For example, for a 30° CCW rotation perturbation, some participants will form a strategy that aiming to the 20° CW to the target instead of the target itself. For the discrepancy between the two (10°) is the magnitude of implicit learning, which the participants do not realize their hands have been drifted to more clockwise directions than their aiming direction. In the framework of this account, faster relearning results from quickly recall of the explicit aiming strategy. They used aiming report paradigm, in which the aiming direction was asked to verbally report by the participants before each movement, to separate the explicit strategy and implicit learning. They found the amount of explicit strategy was larger for relearning than initial learning, while that for implicit learning remained the same. The third theory emphasizes the importance of experiencing similar errors between initial learning and relearning \[7\]. They propose that the consistent environment increases the participants’ sensitivity to this kind of error and savings occurs because the errors are revisited and the brain recognizes the errors it experienced before. They found evidence that although the perturbations of the two learning were opposite, as long as the participants experienced the errors of the same direction and with similar size, they could show savings.

The last two theories: explicit strategy account and error-sensitivity account are the two most prevailing accounts for the savings in motor adaptation. However, they cannot be easily teased apart as most studies introduced a large-sized perturbation abruptly for both initial learning and relearning. As a result, the participants could saw similar errors and form an aiming strategy at the same time. Thus, it is challenging to find out which is the true reason for the savings to occur. Lately, we employed a novel paradigm to dissociate between the two accounts \[8\]. Specifically, in one condition, during initial learning, a cursor move synchronously with the hand but always offset 30° CCW to the target no matter where the hand movement direction is. As the errors the participants saw were fixed, this group was called Error-clamp Group. The participants were fully informed that they could not control the movement direction of the cursor and were instructed to ignore the cursor feedback and move their hands directly to the target. Thus, the participants saw the errors similar to what they would experience in the 30° CCW visuomotor rotation, but they could not form an explicit aiming strategy through this task. We found that compared to the Control Group who learned the 30° CCW visuomotor rotation twice, Error-clamp Group could also show savings as they learned 30° CCW rotation as fast as they have learned it before. Therefore, it seems that forming an explicit strategy is not necessary for the savings. In another condition, we introduced the perturbation gradually enough to make sure that the participant could not clearly notice any stable errors, which was called Gradual Group. Meanwhile, they could not form an explicit aiming strategy as they have not experienced noticeable errors. As expected, Gradual Group did not show savings. However, when a circle of number landmarks were surrounded by the target and the participants were asked to verbally report their aiming directions, even though the perturbation was gradually introduced, they could still show savings. We assume that the number landmarks make small errors more salient and regular to the participants. Based on these evidences, we postulate that salient errors instead of explicit strategy is critical for the savings to occur in the field of motor adaptation.

2.2. Implications on Sports Training

Motor adaptation is as important as motor skill learning in motor learning. As reviewed above, savings is an effective indicator to measure not only motor memory, but also learning transfer. In the following section, we will talk about how to put the theories we get from the laboratory into practice.
2.2.1. Warming-up before Relearning
It is not uncommon that motor learning cannot be transferred naturally across limbs or contexts. According to the studies mentioned above [2,3], it may help if the athletes are led to do warming-up exercises using an easy task before learning by a new effector or under a new condition. For example, training an athlete how to adapt to the changes when shooting a basketball using the right arm cannot be transferred to the left hand directly. At this time, coaches may ask the athletes to do some simple tasks using left hand before transferring of the basketball shooting adaptation. Warming-up exercises such as mirror drawing using left hands may enhance the control of athletes’ left hands, which may increase the extent of inter-limb transfer.

2.2.2. Magnifying Errors before Transfer
For transfer between similar tasks, such as smashing in badminton and spiking in volleyball, coaches could guide the athletes to discover and summarize the systematic errors by themselves, apart from emphasizing the specific skills of how to achieve the goal. Besides, coaches could make videos for athletes’ movement, highlighting and magnifying the errors during their action execution. If condition permits, it is better to make the athletes learn in a virtual reality (VR) or augmented reality (AR) environment to compare their movements with the standard ones from every angle, making the errors more salient.

3. Conclusion
Taking visuomotor rotation as an example, we reviewed some key experiments of the savings in motor adaptation from two aspects: how to eliminate learning specificity and what has been saved on earth during motor learning. Inspired by these findings from laboratory, we suggest that coaches could introduce warming-up exercises under the to-be transferred conditions before learning transfer. Moreover, magnifying the errors by taking videos or using VR and AR technologies instead of emphasizing the motor skill itself may be more beneficial for motor learning transfer.

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References
