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Adaptive Strategies for Speed Change in the Control of Motor Action*

TAEHOON KIM

Department of Psyhology, Kyungnam University; taehoonk@kyungnam.ac.kr

Abstract: This study briefly reviews adaptive strategies of motor action when speed changes. Discussion of adaptive strategies is very important in that people need to adapt themselves in a consistently changing situation. A total of 5 strategies were reviewed: speed-accuracy tradeoffs, simplifying action, rhythm conversion, introduction of an additional coordinative unit, and qualitative change. It is a theoretically meaningful attempt in that findings from various tasks were incorporated into the perspective of adaptive strategies. In addition, it will be very informative in terms of designing customized learning and training programs.

Keywords: adaptive strategy, speed, motion, motor coordination, speed-accuracy tradeoffs

I. Introduction

Everything changes in every second. No one would have ever lived in the environment which is exactly the same to previous ones. Adapting oneself to these changes would be essential to survive or at least to make things more efficient to do (Payne, Bettman & Johnson, 1988). Thus, it is worthwhile to look into the kind of adaptive strategies people apply. It will not just tell us in what situation and how these strategies would be applied but also how human performance had been evolved by cultivating them (Cohen, 1974).

It would be ideal to explore and discuss adaptive strategies in all kinds of human behaviors in this study, but that would be beyond my capability given with diversity of human behaviors and their related factors. In this paper, adaptive strategies in the control of motor action were focused on because the output of human information processing is implemented in motor action, research findings in motor action provided fundamental principles to other fields (Schmidt & Lee, 2011), and it shows how people interact with other people and the surroundings (Wolpert, Ghahramani & Flanagan, 2001).

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People may adapt themselves when environment changes, inner or outer perturbation is introduced, or goal is modified. In the domain of motor action, various factors are associated with adaptive strategies such as movement components, context of movement, change of speed, the level of expertise, and so on. Of special interest are adaptive strategies for speed change among them because speed is one of the core factors which affects how people make movement (Schmidt & Lee, 2011).

Even though a plethora of studies regarding the relationship between motor action and speed change have been conducted, it has not been reviewed in terms of adaptive strategies. It would be interesting to see findings from previous studies in terms of adaptive strategies. Thus, the purpose of this study is to review types of adaptive strategies in the control of motor action: speed-accuracy trade-offs, simplifying action, rhythm conversion, introduction of additional coordinative unit, and qualitative change.

Ⅱ. Types of Adaptive Strategies in Motor Action

1. Speed-accuracy Tradeoffs

"Haste makes waste" describes one of the well-known findings related to speed in motor action, speed-accuracy tradeoffs. It is a common belief that accuracy decreases as speed increases and vice versa. However, different relationship may appear depending on its context such as in temporal relationship (Schmidt, 1969; Newell, Hoshizaki, Clarton & Halbert, 1979).

After a monumental study of speed-accuracy trade-offs by Paul Fitts (Fitts, 1954), how speed is associated with accuracy had been extensively studied. In his study, participants were asked to conduct a reciprocal tapping as the width and the distance of the target varied. As expected, the movement time of tapping increases as the target width decreases and its distance increases. In other words, a decrease of the target width require more accurate performance, resulting in an increase of movement time. In addition, the change of target width and its distance was described as an index of difficulty, which expresses how much information needs to be processed to make a certain movement. Thus, an inverse relationship between the difficult of a movement and the movement speed was identified.

Similar studies with a single-aiming movement were conducted to expand Fitts' findings of speed-accuracy trade-offs. Participants were asked to do rapid single-aiming movements of a stylus. They had to move a stylus from a starting position to target line with different distances within a pre-determined movement time (Schmidt, Zelaznik & Frank, 1978; Schmidt, Zelaznik, Hawkins, Frank & Quinn, 1979). The degree of deviations from the target line was measured and termed as effective target width. Again, as expected, effective target width increased as the target distance increased and movement time decreased.

These findings from Fitts (1954) and Schmidt et al. (1978; 1979) showed typical speed-accuracy trade-offs and furthermore one kind of adaptive strategies for speed change. When accuracy is emphasized, people may sacrifice their performance speed and vice versa.

However, the relationship between speed and accuracy does not always appear in this manner. When a primary focus is on the spatial accuracy, this relationship holds, but different relationship appeared when the focus is on the temporal accuracy. Temporal accuracy is important in the tasks requiring anticipation and timing such as baseball batting, hitting a ball in tennis, and other tasks with swing manipulandum. For example, in a baseball batting, a batter would miss a ball if he were not temporally accurate in terms of a contact time. Schmidt (1969) conducted an experiment which was similar to a baseball batting. Participants were asked to move a slide along a trackway to hit a target rapidly coming toward the trackway. Temporal accuracy was measured by calculating error in timing regarding the target arrival. Interestingly, temporal accuracy was higher with slower movement time and higher movement speed. Similar results were shown for temporal consistency of movement in the study of Newell et al. (1979).

Thus, when speed changes, people would apply different kinds of adaptive strategies depending on the requirement of the tasks. When the focus is on the spatial accuracy, people would sacrifice speed to increase accuracy and vice versa. However, both speed and accuracy would increase at the same time when the focus is on temporal accuracy, thus making us do faster for more precise output.

2. Simplifying Action

People make a lot of different actions everyday, most of which seem very easy to do such as walking, grasping, shaking hands, etc. However, making these actions are more complicated than it looks. For example, when shaking hands with other person, there are infinite number of possibilities in terms of the direction, height, grip pressure, etc. Bernstein (1967) described this problem as degrees of freedom, meaning that there are infinite number of cases of combining movement components for a single action.

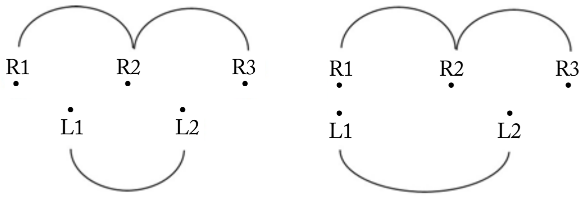
To solve this degrees of freedom problem, patterning of harmonizing movement components should be generated by coupling them spatially and temporally (Turvey, 1990). Also, different kinds of constraints such as anatomical and/or spatial were applied to reduce the number of possibilities by reciprocal inhibition of its associated movement components (Haken, Kelso & Bunz, 1985).

An easier way to make a pattern is to freeze other components except core ones. For example, in the tennis swing, core components would be arms and legs at the beginning stage. A swing made by beginners looks very awkward because they freeze all the components except arms and legs: they do not turn their waist to convert vertical forces from lower body to rotational forces for upper body, they do not bend their elbow and/or wrist when making a swing, etc. This is more apparent especially when they try to make swing faster. As they become more advanced, they start to unfreeze other parts, making their swing more natural (Jagacinski & Flach, 2003).

This type of freezing can be observed with those in a rehab after suffering from damage by injury or disease (Todorov & Jordan, 2002). For example, their walking looks like ones made by those without knees and ankles. In other words, parts of their legs do not bend because they would not be able to process those high number of possibilities. As they learn more and more, other parts would become unfreezed.

This can be interpreted one of adaptive strategies with regard to speed change and the level of expertise. Initially, their skill level is not high enough to use all of the related components, so that only core parts are utilized and increase of skill level gradually unfreeze other parts. Especially when performing faster, this kind of freezing occurs more often. It is very efficient to use this strategy given with limited capacity of human information process. Parts of movement become automated as the level of expertise goes up, providing more room to process operation of other movement components.

A similar pattern was observed in a polyrhythmic tapping. A polyrhythm is a rhythm where two rhythmic components has non-integer relations e.g., 3:2, 4:3, and 5:2 (Jagacinski, Marshburn, Klapp & Jones, 1988). It is relatively difficult to conduct compared to a simple rhythm such as 1:1, and 2:1 because it is hard to find a reference timing point when dividing timing interval of polyrhythm as seen in Figure 1A. For example, in 3:2 polyrhythmic tapping, each left-handed tapping needs to be placed between previous and successive right-handed tappings.



(A) Ideal time interval (B) Simplified time interval

Figure 1 Time interval of 3:2 polyrhythmic tapping

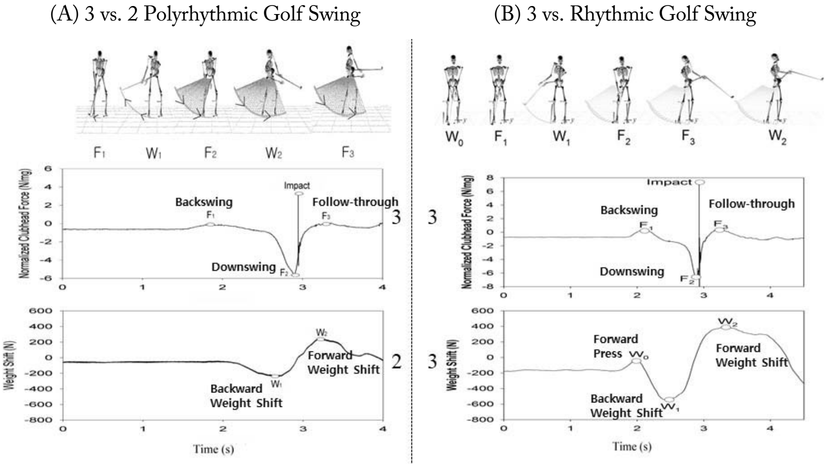
However, as people continuously do this tapping with higher speed, phase drift occurs very often, so that one of the left-handed tap moves to either prior or after right-handed tap (Summers, 2002). One of the strategies making this polyrhythmic tapping much easier is to have the first right-handed tap and the first left-handed tap co-occur as seen in Figure 1B (Summers, Rosenbaum, Burns & Ford, 1993; Summers, Todd & Kim, 1993). An application of this strategy change a polyrhythm to a simple rhythm: after tapping the first right- and left-handed taps simultaneously, the rest of rhythm becomes a simple 2:1 rhythm.

3. Rhythm conversion

A large part of human movement is conducted based on rhythm, such as breathing, walking, swimming, and so on. To implement a certain rhythmic movement, a part of the rhythm is allocated on each component of movement and needs to be harmoniously integrated into a whole rhythm (Zehr, 2005). For example, walking, one of the movement most often conducted can be described as 1:1 rhythmic movement. When people walk, rhythmic allocation is made on their arm and leg, which are integrated into make 1:1 rhythmic movement.

All of the rhythms are not equal in terms of difficulty. For example, among simple rhythms, 1:1 is easiest compared to 2:1 or 3:1, and as explained above, a simple rhythm is much easier to perform compared to a polyrhythm.

Interestingly, even in the same rhythm, the timing between two rhythmic components changes. One of the representative examples for this kind of rhythm conversion appears in the case of in-phase vs. anti-phase. When conducting a simple 1:1 rhythmic tapping, two taps occur simultaneously or alternate each other. The former is called in-phase and the latter anti-phase. Both of them are easier to perform because they are simple rhythms. However, as speed increases, performance of the anti-phase suddenly become unstabilized and collapsed into an in-phase timing interval (e.g., Schöner & Kelso, 1988). As noted above, 2 timing interval should be maintained to conduct an anti-phase 1:1 tapping. This is capable when performance speed is moderate, but once speed goes up a certain level, maintaining 2 intervals becomes almost impossible. Thus, an anti-phase rhythm eventually converges into an in-phase rhythm.


(A) 3 vs. 2 Polyrhythmic Golf Swing

(B) 3 vs. Rhythmic Golf Swing

Figure 2 Two rhythmic movement of golf swing (Adapted from Kim, Jagacinski & Lavender, 2010)

Another type of rhythm conversion is a change from polyrhythm to simple rhythm. A golf swing can be described as 3:2 polyrhythmic movement where 3 events from upper body and 2 events from lower body are integrated: 3 events from upper body are a backswing, a downswing, and a follow-through and 2 events from lower body are a backward weight shift and a forward weight shift as seen in Figure 2A.

When making a series of golf shot, this kind of polyrhythm were shown (Kim, Jagacinski & Lavender, 2010). The authors of this study compared the performances of younger and older golfers and found an interesting difference in terms of rhythm conversion. More number of older golfers showed another event from their lower body, indicated as a forward-press in Figure 2B. By having a forward-press, a 3:2 polyrhythmic movement suddenly becomes a 3:3 simple rhythmic movement. Interestingly, the swing speed was not different between two groups. However, the flexibility of older golfers was much lower than that of younger golfers. To maintain their swing speed, they adaptively reduce cognitive load with a change of rhythm by introducing another event in the lower body.

4. Introduction of an Additional Coordinative Unit

Another interesting phenomenon was observed in a bimanual tapping. Most of the studies for bimanual coordination have shown that two hands were integrated into one single stream (Summers, 2002 for a review). As seen in Figure 3A, there is no need to maintain two different streams. This integrated tapping was more prevalent for beginners as well as for experts.

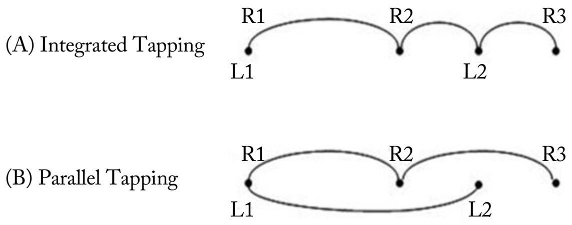


Figure 3 Integrated vs. parallel timing of polyrhythmic tapping (Adapted from Jagacinski, Kim & Lavender, 2009)

However, a couple of exceptions have been observed especially when the tapping speed was very high (Jagacinski, Rizzi, Kim, Lavender, Speller & Klapp, 2016; Krampe, Kliegl, Mayr, Engbert & Vorberg, 2000). In those studies, those with higher level of expertise (e.g., concert level pianists) were asked to perform polyrhythmic tapping at different speeds. Interestingly, an integrated tapping was more prevalent at lower speed, but at higher speed more number of participants showed an independent tapping (Figure 3B).

An additional work load would be needed when incorporating two different streams if two streams were maintained. Then, the question becomes why at higher speed an independent tapping is more prevalent even though a cognitive work load seems larger. Note that only experts were able to do tapping at this high speed. In other words, incorporating two-handed tapping at very high speed might not be possible because it becomes too fast to maintain in a single stream. Thus, performing each tapping independently with a certain type of time keeper would make things easier (Krampe et al., 2000).

This tendency appeared in another study with experts' performing high speed polyrhythm (Kim & Jeong, 2019). The authors tested the effect of speed and rhythmic complexity on bimanual tapping task. A quicker performance may be needed at the same speed if rhythmic complexity increases because more number of events should occur during the same time period, Thus, the event rate was suggested as a key factor for an appearance of independent tapping, in which speed and complexity are incorporated.

5. Qualitative Changes

Sometimes qualitatively different motor action emerges as speed increases. It seems to happen when maintaining a current motor action wastes energy consumption. An amount of oxygen people consume can be an indicator for how much energy they are using. Alexander (1992) conducted an interesting study where the amount of oxygen consumption was measured when participants were walking on a treadmill. As speed increases, more amount of oxygen consumption was measured. The level of energy cost was shown in Figure 4. Of special interest is the point of change from walking to running.

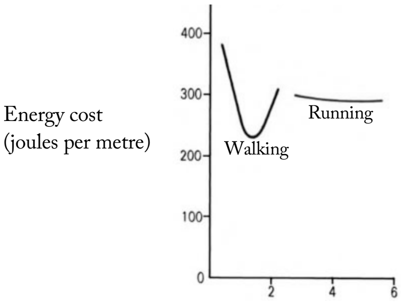


Figure 4 Energy used per meter travelled as a function of speed (Adapted from Alexander, 1992)

As seen in Figure 4, energy cost decreases as speed of walking increases and after a certain point, it rapidly increases. It is intriguing that at a point when energy cost of walking is higher (around 2.5 meters per second), the mode of movement changes from walking to running. This adaptive strategy might be very important in terms of energy savings in the human evolution (Bramble & Lieberman, 2004).

Ⅲ. Discussion

The present study briefly reviewed different types of adaptive strategies for speed change in the control of motor action. This attempt is very meaningful in that how people change their motor action when context and/or situation vary and findings from various tasks were integrated into adaptive strategies. Also, it brings a discussion of speed-related changes beyond speed-accuracy tradeoffs.

Not all of the adaptive strategies were covered here and it is hoped that this brief review would be a starting point for deeper discussion. For example, further discussion of other aspects as well as speed change in adaptive strategies will be very informative in terms of providing how humans interpret and apply a constantly changing context and/or environment.

It is clear that adaptive strategies do not just apply to the domain of motor action. Rather, almost all aspects of human behaviors need to be addressed in terms of adaptive strategies and in many cases they are linked together. The vibration of vocal cords for the production of human voice is one example. To generate appropriate vibration, the movement of vocal cords need to be adaptively adjusted.

One of the implications in this review is that those strategies mentioned above could be applied to the development of learning and training programs. A demand for customized program gets higher, but most of the programs are not described or designed in consideration of factors affecting trainee's performance.

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