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TECHNOLOGY-ASSISTED FEEDBACK FOR MOTOR LEARNING: A BRIEF REVIEW

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ABSTRACT

The motor learning stages of learning Human movement with respect to sport and performance are fairly well understood. However, with the advancements in technologies, there are continued opportunities for leveraging innovations in measuring systems to enhance performance through feedback. While there are countless numbers of technologies that can theoretically be applied to the feedback cycle of motor learning, there has yet to be concurrence on those that benefit and those that do not. In this brief review the stages of motor learning are defined and a subset of technologies that can potentially provide insight and improvement are outlined. Research suggests that there is a balance between use-cases where real-time or post hoc feedbacks are more helpful and appropriate.

Keywords: human performance, biofeedback, kinematic, kinetic, proprioception

INTRODUCTION

Within the realm of athletic performance, medical rehabilitation, and basic improvements to physical activity, there are a wide array of technological advances that can assist facilitating motor function and motor learning. We review a select subset of the technologies that can be used to improve feedback to increase the efficiency of motor learning as well as provide a reference of how these systems can be applied.

Motor learning is the process in which new skills are acquired using motor information, experience, and knowledge. This process is linked to mental and motor abilities and relies on cognitive and physical awareness of a functional movement. The motor learning process can be broken down into three distinct phases; the verbal-cognitive phase, the associative or fixation phase, and the autonomous phase (3,4).

During the verbal-cognitive phase of motor learning, the learner identifies the new skill and begins to understand it. This phase typically lasts between 15 and 30 hours and within this time the learner performs movements unnecessary to the intended skill in attempts to gain specific muscle activation and balance (10). This first stage of motor learning can be applied to an array of areas such as new learning (e.g., children developing a new skill), medical rehabilitation (e.g., recovery from musculoskeletal injury, stroke, etc.), or physical activities (e.g., athletic training) improvements (e.g., receiving coaching or personal trainer guidance).

During the associative or fixation phase of motor learning, the learner begins to integrate multiple elements of movement to more fluidity accomplish the intended skill. This phase typically lasts between 3 and 5 months and within this time the movement skill becomes more refined (10). This second stage of motor learning, like the first stage, can be applied to various tasks such as practicing a new skill (e.g., toddler practicing walking), medical rehabilitation (e.g., repeated or incremental distance walking to improve/regain muscle strength), or for training and/or general physical activities (e.g., running sprints to improve running efficiency and form).

During the autonomous phase of motor learning, the new skill becomes automatic with few errors as the elements of the movement are efficiently integrated. This phase typically lasts for years and potentially never finishes, as in theory movement can always be improved (10). While few errors are expected within simple and complex motor skills in the autonomous phase of motor learning, improved efficiency and performance of these skills can be gained within continued training/practice.

Within these three phases of motor learning, there are two different types of feedback relevant to the individual performing motor tasks: Knowledge of Performance (KP) and Knowledge of Results (KR) (10). These types of feedback vary in specific ways. While both of these concepts relay feedback to the performer, there is a critical difference between the two. Knowledge Performance feedback is intrinsic proprioceptive information that is directly associated with the actual movement (e.g., visual, kinesthetic, auditory, etc.) and allows the individual to critique the quality of the movement. An example of KP is the feeling or sensation felt when an improper foot-placement occurs when kicking a soccer ball. This feeling or sensation sends feedback (i.e., KP) to the performer regarding the quality of their motor task. In contrast to KP, KR is augmented feedback of extrinsic information related to the successfulness of the movement (e.g., time to complete task, quality of task execution, level of success, etc.). An example of KR is the verbal feedback that a coach provides to the player regarding a poorly executed kick (12).

Applying technologies to augment proprioceptive feedback (i.e., KP) as well as external feedback (i.e., KR) can be provided by parents, trainers, medical staff, or others. Technologies can augment sensory feedback within the normal understood spectrum of KP. These feedback areas include video feedback, kinematic feedback, biofeedback, and kinetic feedback (10).

Video Feedback

The use of analog or digital video is a highly used method of assessing movement of activities and analyzing them in a retrospective manner. That is to say, recording of activities empowers individuals and trainers (i.e., coaches, personal trainers, medical staff, etc.) with a reviewable record of how the activities were performed and allow for attempts at correcting the behavior in a future trial (10) (figure 1). Mirrors can provide a simple and related variant of video analysis that can provide feedback to individuals in real-time. The benefit of mirrors is the fact that they are cost effective and typically are present in fitness centers, hospital rehabilitation centers, and in homes.

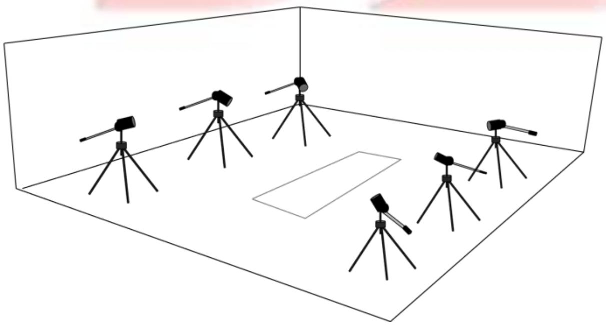

Figure 1. Example of a video recording environment (treadmill in center).

Similar to using mirrors, gaining access to real-time displays of video during the execution of activities can enable improved sensory feedback related to the activity as there will not be a lag-time (i.e., since the movement and senses involved are "fresh", the errors in the activity, theoretically, can be identified easier).

While reviewing videos of movement has been a longstanding practice in athletic training, the review of these movements has often been done using simple observation methods. With software advances, more detailed movement analysis tools can be added to standard digital videos to enable quantified measurements of biomechanical efficiencies and inefficiencies of movements. Software systems such as proprietary MaxTRAQ (8) (Innovision Systems, Inc; Columbiaville, MI) and Dartfish (2) (Dartfish; Fribourg, Switzerland) or open source software like Kinovea (7). These software systems are movement analysis tools that allow users to analyze and characterize biomechanical motions from uploaded videos (figure 2). These tools allow the user to measure distances traveled, angle of joints (static and in motion), mapping of structures with "stick figures", traces of movement, and calculation of center of mass (COM).

Figure 2: Example of video analysis to show proper movement (Dartfish) (9).

These video analysis tools can be very useful as they each have features that allow for description and characterization of specific movements or activities, while also being able to add contextual data to the video. The software also allows for a number of key features such as data refining processes that can be linked to the motions (parameters can be made including time and specific outputs, then data can be run in parallel to the image, below the video). These software systems also typically allow for manually tailoring joints or points of intersection in order to make angle references and motion relationships. Along with these tailored angles and points, distances and specifics between chosen distances can be done. As feedback augmentation, these software programs allow users to analyze the movements more accurately and make modifications in real-time. Completed and tailored video files can also be saved with annotations for later use or continued analysis.

Studies have shown that there are specific delivery schedules, doses, and timing methods that work better than others to achieve best motor learning results from visualized feedback. Furthermore, these studies have shown that these methods have a significant impact on the short- and longer-term effects of the motor learning tasks (6).

Kinematic Feedback

Kinematic feedback in motor learning refers to return of information that is specifically related to the motion, not accounting for the forces and weight distribution that causes them. That is to say, that like the immediate return that video or mirror images can provide, non-augmented, or verbal feedback that a coach, trainer, or instructor would provide on correctness of movements. It has been shown that the schedule, timing, and delivery methods of kinematic feedback can hold weight on the successfulness of the motor learning task. Also, more importantly, it has been shown that in motor learning overall gains in performance can be improved with augmented kinematic feedback (15).

Biofeedback

Biofeedback in motor learning refers to the return of information that is typically not perceived directly by the individual (i.e., blood pressure, heart rate, etc.). While, there have been a limited amount of successful studies showing improvements from implementation of biofeedback for particular tasks, there are intuitive reasons that these measures would be of use during training (10).

In terms of technologies available for relaying biological and physiological information there is a wealth of options. As improvements in monitoring technologies within the medical community, athletics, and in private and commercial industry continue to increase, so do available options for translating to motor learning, specifically in innovations in biofeedback.

Common clinical use technologies such as electromyography (EMG), electroencephalographs (EEG), electrocardiographs (ECG), and others have been translated and morphed into biofeedback systems for use in research, physical training, and rehabilitation (11).

EMGs are surface mounted electrodes that are systematically placed on various areas of the body, over target muscle groups (e.g., biceps, calves, etc.) that are used to relay electrical signals describing muscle initiation and power. These systems can be used in a real-time or retrospective view to analyze early or late muscle activation, unbalanced coordination of muscle operations (i.e., left leg initiates more than right), or for diagnosing gait abnormalities or asymmetry (11).

EEGs are surface mounted electrodes placed systematically on an individual's scalp and are used to measure activity in various areas of the brain. Clinically, EEGs are used to determine a number of issues, most commonly used for detection of seizure disorders, brain tumors, or cerebral damage (11). However, these systems can be used for enabling real-time biofeedback by being instrumented during activities (e.g., cognitive to muscle reaction times).

ECGs consist of surface mounted electrodes that are placed across the torso and potentially on the wrists, and/or legs with the goal of measuring electrical activity of the heart. This measurement is one of the higher resolution forms of obtaining the heart rate, as it records a wave spectrum that makes up the entire interbeat interval, creating the QRS complex (11). These measures can have a significant impact on training as it would be able to measure a retrospective record of physiological status given different context as well as can be used for real-time biofeedback.

Mature and multi-element sensor systems such as the Hidalgo Equivital™ (EQ02) (figure 3) or Zephyr BioHarness™ (figure 4) physiological status monitors (PSM) are being utilized for more scenarios to provide real-time biofeedback during activities. These sensor systems collected data that included heart rate (HR), respiration rate (RR), skin temperature (Tsk), sweat rate, ECG waveforms, body position, and tri-axial (3D) accelerometry data (i.e., lateral, vertical and longitudinal) using micro electro-mechanical systems (MEMS) based accelerometer ± 3 g. Also available with these PSMs is the availability to collect core temperature (Tc) by using a Respironics Jonah Core temperature telemetry pill, an FDA 510K certified ingestible thermometer (figure 5). With this array of information, information can be gleaned that is useful for a complex set of parameters.

Figure 3. Hidalgo Ltd. Equivital™ EQ-02

Figure 4. Zephyr BioHarness™

Figure 5. Respironics, Jonah ™ Core Temperature Pill

Another innovative sensor technique for presenting biofeedback is the use of force sensing technologies to assess the weight displacement, velocity, and mass of stepping. This information can be gained by using high resolution laboratory equipment such as force plate sensing treadmills, platforms or low resolution insole inserts (figure 6). These methods can provide information related to gait or gait asymmetry, allowing for correction and adjustment, typically for locomotive activities (i.e., running, walking, etc.).

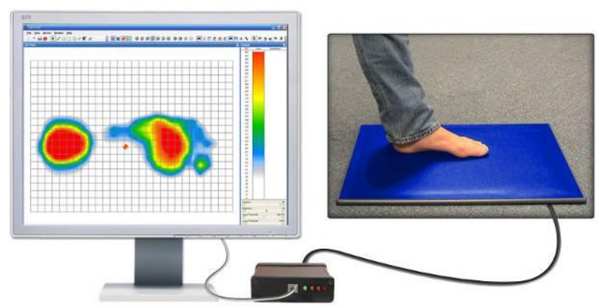

Figure 6. Example of force sensing plate

Kinetic Feedback

Kinetic feedback in motor learning is the relay of information related specifically to the forces and weight distribution that cause kinematic movement. As this information is typically complex, it is often reviewed retrospectively. However, given advances in technologies and computational power of certain software programs, this information can also be given as real- and near-real-time feedback. As previously discussed, some video analysis software tools can allow for estimating movement forces; while innovative technologies in force and pressure sensing can also provide near- or real-time kinetic feedback to users. Furthermore, during the movement real-time kinetic feedback can be provided to individuals from being outfitted with tailor-made tension bands on key areas of the body to relay information of tension/force. Similar to research on kinematic feedback, it has been shown that the schedule, timing, and delivery methods of kinetic feedback holds weight on the percentage of errors observed during movement activities (14).

Discussion

An example of a training (or initially research) protocol for improving sprint performance in response cues, could likely include a force plate sensing treadmill (or insoles), complete digital video camera recording of all available angles, mirrored walls or video display of real-time movement, and individuals would be instrumented with a variety of individual body-worn sensor systems (PSM system, EMG, EEG). The important factor that each of these elements would have to include is a real-time or near-real-time observable component to ensure learner feedback can delivered timely. As references suggest, the scheduling, weight, and delivery method of these feedbacks is critical, some method training (refinement) would have to occur to ensure maximal efficiency for each task or by individual.

Although some evidence suggests that enabling an individual with certain feedback can actually hinder the time for motor learning, overall it seems that feedback of a variety of modalities works best (10). Furthermore, it seems that there is a balance that must be achieved with the timing, amount, and scheduling of feedback to achieve the most desired training results. Also there has been recent work to suggest that a level of full attention on the learner with high frequency of feedback provides the most influential results in motor learning (13). This along with the individual investigative research conducted on each of the areas of feedback and the individual variability of learners, an argument could be made to suggest a fully-engaged and technology-enhanced feedback design could be significant benefit. That is to say, by instrumenting individuals during athletic training, rehabilitation, or for learning complex tasks with all available means of feedback delivery could help increase the efficiency of learning.

References

1. Adams, J.A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior*, 3, 111-150.

2. Dartfish (2009). Dartfish website. Accessed July 20, 2013, from http://www.dartfish.com

3. Fitts, P. M. (1964). Perceptual-motor skill learning. In *Categories of human learning*, eds. A. W. Melton. New York, NY: Academic Press.

4. Fitts, P. M., & Posner, M. I. (1967). *Human performance.* Belmont, CA: Brooks / Cole.

5. Hidalgo. (2013). Equivital™ TnR. Accessed July 22, 2013, from http://www.equivital.co.uk/products/tnr

6. Ikegami, T., Hirashima, M., Osu, R., Nosaki, D. (2012). Intermittent visual feedback can boost motor learning of rhythmic movement: evidence for error feedback beyond cycles. *The*

Journal of Neuroscience, 32(2), 653-657.

7. Kinovea (2013). Kinovea website. Accessed July 20, 2013, from http://www.kinovea.org/
8. MaxTRAQ (2013). Innovision Systems, Inc. Accessed July 20, 2013, from http://www.innovision-systems.com/Products/MaxTraq.html
9. Muha, M. (2008). More on dartfish video analysis at Fall Technique Clinic. Accessed July 20, 2013, from http://www.nordicskiracer.com/news.asp?NewsID=3002
10. Schmidt, R.A. & Lee, T.D. (2011). *Motor control: a behavioral emphasis* (5th ed.). Champaign IL: Human Kinetics.
11. Springhouse. (1994). *Illustrated guide to diagnostic tests: student version.* Springhouse, PA: Springhouse Corp.
12. Winstein, C.J. (1991). Knowledge of results and motor learning – implications for physical therapy. *Physical Therapy*, 71(2), 140-149.
13. Wulf, G., Chiviacowsky, S., Schiller, E., & Gentilini-Avila, L.T. (2010). Frequent external-focus feedback enhances motor learning. *Frontiers in Psychology*, 1(190). Doi: 10.3389/fpsyg.2010.00190
14. Vander Linden, D.W., Cauraugh, J.H. & Greene, T.A. (1993). The effects of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. *Physical Therapy*, 73, 79-87. http://physther.org/content/73/2/79.full.pdf
15. Young, D.E. & Schmidt, R.A. (1992). Augmented kinematic feedback for motor learning. *Journal of Motor Behavior*, 24(3), 261-273. http://hp-research.com/sites/default/files/publications/Young%20%26%20Schmidt%20(JMB,%201992).pdf
16. Zephyr (2012). BioHarness™ 3: Remote Physiological Monitor, Zephyr Technology Corp. Accessed July 22, 2013, from http://www.zephyr-technology.com/products/bioharness-3/