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Skill learning from kinesthetic feedback

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ABSTRACT

Background: It is important for a surgeon to perform surgical tasks under appropriate guidance from visual and kinesthetic feedback. However, our knowledge on kinesthetic (muscle) memory and its role in learning motor skills remains elementary.
Objectives: To discover the effect of exclusive kinesthetic training on kinesthetic memory in both performance and learning.
Methods: In Phase 1, a total of twenty participants duplicated five 2 dimensional movements of increasing complexity via passive kinesthetic guidance, without visual or auditory stimuli. Five participants were asked to repeat the task in the Phase 2 over a period of three weeks, for a total of nine sessions.
Results: Subjects accurately recalled movement direction using kinesthetic memory, but recalling movement length was less precise. Over the nine training sessions, error occurrence dropped after the sixth session.
Conclusions: Muscle memory constructs the foundation for kinesthetic training. Knowledge gained helps surgeons learn skills from kinesthetic information in the condition where visual feedback is limited.

1. Introduction

Hand dexterity requires a high level of integration between motion execution and sensory perception. In surgery, skillful performance is constantly regulated by movement schema saved to memory and instantly adjusted via sensory feedback loops, mainly via visual and kinesthetic pathways.[1] Ernst and Banks demonstrated how humans learn skillful movement through vision and kinesthetic feedback loops either separately or by integrating visual and kinesthetic feedback loops over time. Individuals benefit most from visual feedback, but learning can be enhanced further when simultaneous feedback from visual and kinesthetic sensory systems is combined.[2]

Guided Kinesthetic training allows a trainee to attempt to reproduce the movement patterns of an expert.[3] Similarly, kinesthetic memory obtained through guided kinesthetic training helps a trainee to actively learn complex 3D motor skills such as surgical maneuvers by directly performing a movement.[4] For instance, a cholecystectomy procedure is a complex task that can be broken down into smaller simpler surgical tasks, maneuvers and gestures to be more easily remembered in the OR and when offering focused feedback to trainees.[5] During kinesthetic training, kinesthetic memory allows one to memorize and recall which of one's movements and body part positions are necessary to perform a task. Continuous practice of a motion makes it more automatic, thus creating "muscle memory."[6] Moreover, this guided kinesthetic training offers the novice direct information on the position of body parts, improving kinesthetic memory by decreasing the number of errors while completing a task.[7] In this manner, surgical trainees may increase confidence and task performance by tapping into their muscle memory in situations where visual feedback is limited during training.[8]

The purpose of this study is twofold. First, we examined the natural ability of human operators to store movement information in their muscle memory through the kinesthetic feedback loop. Second, we intend to investigate the effectiveness of learning a motor skill purely through kinesthetic feedback. Specifically in Phase 1, we asked a group of participants to perceive movement through a master-slave delivery system through kinesthetic feedback. When the complexity of the task increased with incrementing number of movement steps, we analyzed the accuracy of kinesthetic memory, i.e. the participants' ability to duplicate the

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movement. In a following Phase 2 of the study, participants were required to perform the same task over 9 trials. We explored the learning process of the participants in performing the movement acquired purely from kinesthetic feedback. We hypothesized that: a) increasing complexity of a movement pattern will challenge the human capacity to store in the kinesthetic memory (i.e., accuracy recall will significantly drop to a certain degree when movement complexity increases); b) repeated practice will facilitate skill learning as human operators will develop strategies to optimize memory information storage with practice.

2. Methods

2.1. Environment and participants

The controlled laboratory study was performed in the Surgical Simulation Research Lab at the University of Alberta. A total of twenty volunteer university students (45% female; 95% right-handed. Age range: 18–39 years old, median age = 26 years) participated in the experiment in the first phase. Among them, five participants entered the second phase to complete the nine training sessions over a period of three weeks. The University of Alberta Health Ethics Review Board approved the study's protocol. Information and objectives were explained to the participants prior to obtaining their consent.

2.2. Apparatus

A master-slave delivery system was used to transfer movement between two persons (Fig. 1). In this study, the participants' vision was blocked, and could only feel the movement from the slave-end by placing their hand in the style. The trainer for all of the trials was one of the researchers (DP) and was the only person who performed the movement at the master-end. By following the shallow groove engraved on the wooden plate, the experimenter ensured that the same movement pattern was delivered consistently over the trials. In this study, five movement patterns were chosen randomly with increasing movement complexity (Fig. 2). Each pattern was comprised of movements with three lengths (short: 5 cm, medium: 10 cm, and long: 15 cm) and different movement directions (N, S, E, W, NE, NW, SE, SW). Participants had a chance to inspect the experiment apparatus and were informed with basic

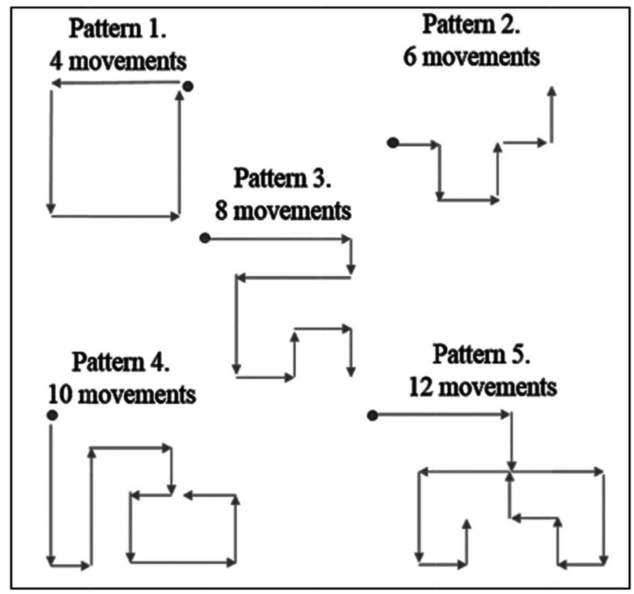

Fig. 2. The five movement patterns used for this experiment. The arrows show the direction of the movement (lines), while the red dot indicates the starting point of the pattern.

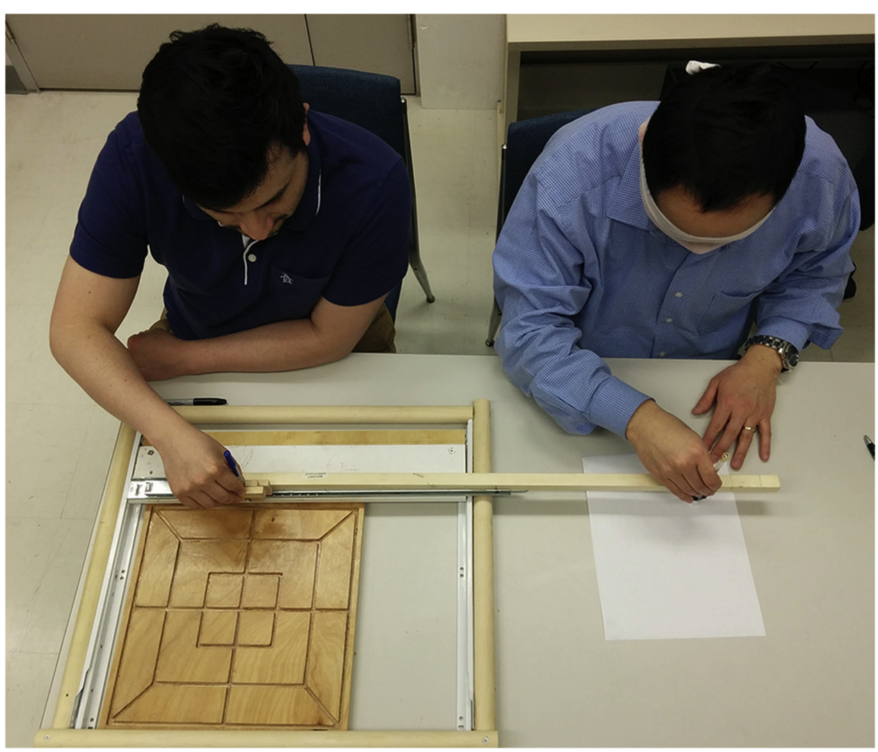

Fig. 1. Kinesthetic guidance device allows feedback translate between the master and trainee. Note that trainee's vision is blocked. The participants experienced the movement of the trainer by grasping the guide.