Learning to Tie Well with Others: Bimanual vs. Intermanual Coordination during Shoe-tying

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A shoe-tying paradigm was developed to examine mode effects and motor learning functions when people are asked to handle a familiar object (e.g., tying a shoe) using an unfamiliar coordination mode (e.g., tying a shoe with another person). Dyads first tied a shoe apparatus using their own two hands ("bimanual") for 10 trials and then tied the shoe as a dyad, each person using one hand ("intermanual") for 20 trials. Finally, participants tied the shoe bimanually for another 10 trials. Previous research has indicated that intermanual is faster than bimanual, but those experiments examined novel tasks performed by novices. For this familiar task, results revealed that participants were significantly slower in the intermanual mode compared to either set of bimanual trials, and participants were significantly faster in the second set of bimanual trials than the first. Unlike mode effects for novel tasks with novice participants, the intermanual mode was slowest, though intermanual performance may have enhanced subsequent bimanual performance. Previous research on motor learning suggests an exponential function describes acquisition of a novel skill, whereas a power law describes persistent motor learning. Analyses revealed that dyads exhibited a power law function over both the first set of bimanual trials and the intermanual trials. That finding suggests that participants were not learning a new coordination skill in the intermanual mode but may have transferred persistent, bimanual shoe-tying skill to the novel mode. Theoretical and practical implications of acquisition of a novel coordination mode for a familiar task are described.

INTRODUCTION

People coordinate their hand movements individually (e.g., pouring a cup of coffee) and with other people (e.g., handing someone a cup of coffee) on a daily basis. Manipulating objects with the hands provides a channel of sensation and perception that specifies one's relationship with the objects and people around them. Interestingly, when people handle unfamiliar objects, their manual coordination patterns are more varied compared to handling a familiar object (Gibson, 1962). The current study is a twist on that observation; instead of manipulating object familiarity, we sought to manipulate the manual coordination pattern with which a familiar object is handled. The current study was conducted in the context of a well-known manual coordination skill, tying one's shoelaces.

In this study, we asked participants to complete this familiar task on their own with two hands ("bimanual") or with another person, each handling one shoelace ("intermanual"). This paradigm poses an interesting question, What happens when people must learn a new coordination mode (i.e., intermanual) for a familiar task (i.e., tying one's shoelaces)? The answer to this question has practical implications. The results of this research may, for instance, inform new strategies to facilitate relearning simple manual coordination tasks, such as tying a shoe, after one loses the use of a hand (e.g., due to paralysis, amputation, or after a stroke).

The shoe-tying paradigm provides a model environment for addressing various research questions. Previous research has shown that participants are faster in a laparoscopic cutting task when performing intermanually compared to bimanually (Zheng, Swanström, & Mackenzie, 2007). Additionally, research in the context of teleoperations revealed intermanual performance was faster than unimanual and bimanual when learning to drive a mechanical "rover" (Gorman & Crites, 2013). These differences in performance when completing the same task with different coordination modes (i.e., "mode effects") have been observed, however, with novice participants performing a novel task. Shoe-tying allows us to examine mode effects using a familiar task. Hence, examining manual coordination in the shoe-tying context allows us to extend the empirical literature by introducing a familiar task at which (we assume) most participants are highly-experienced. Gorman and Crites (2013) found that mode effects, wherein intermanual is faster than other manual coordination modes, disappear with practice. We similarly expect that the intermanual speed advantage observed in novel interpersonal tasks will be absent when a highly familiar bimanual task, such as shoe-tying, is examined.

The shoe-tying paradigm also allows us to test a hypothesis based on theories of motor learning. The motor learning literature traditionally suggests that a power law is the general motor learning function (A. Newell & Rosenbloom, 1981). This is due largely to seminal works early in the field of motor learning (e.g., Crossman, 1959; Snoddy, 1926). However, reanalyzing learning (trial series) data on an individual-by-individual basis has revealed that an exponential function is a better fit for trial-to-trial fluctuations in performance that are present early on when learning a new motor skill (Stratton, Liu, Hong, Mayer-Kress, & K. M. Newell, 2007). Fluctuations described by an exponential function are also present in the warm-up decrement following a retention interval separating performances of a novel skill (K. M. Newell et al., 2001; cf. Adams, 1987). Whereas exponential functions describe transitory changes early in learning a new motor skill, a power law tends to describe persistent motor learning (Stratton et al., 2007). Hence, if people are acquiring a new motor coordination skill when they learn to tie with a partner, then we expect to observe an exponential learning function. On the other hand, if they are not acquiring a new skill, but transferring persistent, bimanual shoe-tying skill to a novel coordination mode, then we expect to see a power law learning function.

The Current Study

In this study, we asked dyads to tie a shoe-like apparatus during three sets of experimental trials. First, participants completed the task as they typically would, bimanually. Next, participants completed the task as a dyad, intermanually, with each person handling one shoelace. Finally, each individual completed the task once more bimanually. The purpose of the first set of bimanual trials was to provide a baseline against which intermanual performance may be compared. The purpose of the second set of bimanual trials following intermanual performance was to further explore motor learning in the context of transfer from the intermanual to bimanual coordination mode (e.g., Gorman & Crites, 2013; Nozaki, Kurtzer, & Scott, 2006).

METHOD

Participants

Seventy-two undergraduates (36 dyads) from Texas Tech participated for partial course credit. Participants' mean age was M = 18.60 (SD = 1.09), and 75.3% were female. The preponderance of female participants was unplanned. Three of the dyads were all male, 21 were all female, and 12 were mixed gender. Four of the dyads reported knowing each other (i.e., classmates) prior to participation. All participants were required to be and self-reported being right-handed; participants' self-reported handedness was corroborated using the Edinburgh Handedness Inventory (Oldfield, 1971). All participants reported being familiar with tying a shoe, and 85.1% reported tying a shoe daily or weekly.

Experimental Design

Participants first used the bimanual coordination mode to complete 10 trials (B1). Next, the participants used the intermanual coordination mode to complete 20 trials as a dyad (Inter). Finally, participants completed another 10 trials using the bimanual coordination mode (B2). Members of dyads participated in the bimanual conditions separately. A within-subjects variable, Coordination Mode, indexes the first, second, and third blocks of trials. All dyads participated in the same Coordination Mode order: B1→ Inter → B2. The number of trials in each block was determined by the number of trials required to reach a performance asymptote during pilot testing. Verbal communication between dyad members and shoe-tying strategy (an organismic variable) were also factors in this study; however, we do not report the analysis of these factors in this paper.

Apparatus

A black shoe-like apparatus (referred to hereafter as the shoe) was secured on top of a black cardboard box. We used this apparatus instead of a real shoe so as not to bias participants with a particular shoe type (e.g., men's vs. women's). A grey lace was used to tie the shoe, and small black pushpins were used to set the laces in their starting position for each trial. Small white squares located to the left and right of the shoe were used as home keys. The home keys marked the starting position and ending position for each trial. Figure 1 shows the study apparatus.

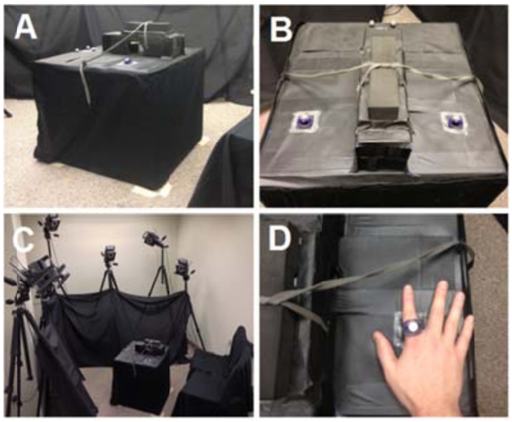

Figure 1. Apparatus used in the current study: (A) Side-view of the shoe; (B) Top-down view of the shoe with markers on the home keys; (C) Motion capture room; and (D) A demonstration of a participant hand wearing a marker at the starting position on a home key.

An eight-camera Vicon MX-T10 motion capture system captured participants' hand-movements (100 Hz) as they tied the shoe. Data were collected from reflective markers attached to rubber rings, which participants wore on their index fingers.

Measures

A predetermined volume of the motion capture space was used to start and stop motion capture analysis for each trial. The exact location of the start/stop volume was determined during pilot testing and was located just above the home keys on each side of the shoe. The start/stop volume was used to identify the onset and offset of movement duration for each trial, such that movement onset occurred when the first hand entered the volume, on its way to the shoe, and offset occurred when the last hand exited the volume, on its way back to its home key. Trial time was measured as offset minus onset in seconds. Trial times in the bimanual coordination mode were averaged across participants for comparison with the intermanual trials. Variability was measured as generalized variance across hands; however, specific measures of variability are not addressed in this paper.

Additional measures that were collected for this study included: communication data from digital voice recorders: dexterity (Grooved Pegboard test; Trites, 1989); post-test survey; and anthropometric data (hand spans) on each hand. However, we do not report the analyses of these measures in this paper.

Procedure

Informed consent was obtained prior to the start of the experiment. Participants were then shown the shoe and given a general overview of the two coordination modes in which they would be tying the shoe. For both coordination modes, participants were instructed to “tie the shoe as quickly as possible” and to “tie the shoe similar to the way you would normally tie a shoe”. All participants were instructed to place the marker rings on their index fingers and to put their hands as flat as possible on the box with the markers centered on the home keys. To ensure that the starting knot position was identical for every trial, the initial fold-over tie was completed and locked into place on the shoe. Participants were asked to not double-knot the lace.

Participants were randomly assigned as either Participant One (P1) or Participant Two (P2). P1 completed the B1 trials while P2 completed the Grooved Pegboard test and the demographics survey. Individual instructions were given to each participant for their current task. Participants then switched roles. When they were finished, P1 and P2 completed the intermanual trials as a dyad. For the Inter condition, P1 was instructed to sit on the right side of the shoe and to tie the shoe with his or her right-hand, and P2 was instructed to sit on the left side of the shoe and to tie the shoe with his or her left-hand. Participants were asked to put their free hand either behind their back or underneath their leg. The main emphasis was that their free hand should not interfere with the task in any way. Upon completing the Inter condition, the dyad was again separated. P1 completed the B2 trials first while P2’s hand span measurements were recorded. Participants then switched roles, and P2 completed the B2 trials while P1’s hand span measurements and post-test survey were completed. After P2 completed their post-test survey, both participants were debriefed and thanked for their time. Each experimental session lasted approximately 75 minutes.

RESULTS

Dyads’ trial times were analyzed in two ways to address (1) whether mode effects were present for Inter compared to Bi for this familiar task, and (2) what does the learning function look like when people perform a new coordination mode to accomplish a familiar task?

Mode Effects

Repeated contrasts were first analyzed between each level of trial to determine whether dyads reached asymptotic levels of performance in each coordination mode. Two contrasts were significant for B1 (Trial 1 vs. Trial 2; Trial 7 vs. Trial 8), one contrast was significant for Inter (Trial 1 vs. Trial 2), and one contrast was significant for B2 (Trial 3 vs. Trial 4); indicating that trial time did not continue to significantly decrease beyond Trial 8, Trial 2, and Trial 4, respectively (Figure 2).

Because performance asymptote occurred prior to the last trial, and because participants were instructed to “tie the shoe as quickly as possible for every trial” in each coordination mode, the minimum trial time (MinTT) was obtained for each dyad across all trials for each level of Coordination Mode. MinTT measures the highest level of performance achieved at each level of Coordination Mode.

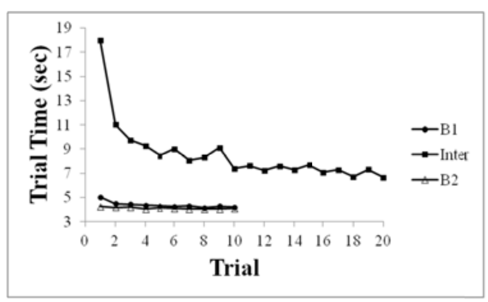

Figure 2. Mean trial times and performance asymptote for B1, Inter, and B2.

A one-way ANOVA was conducted to examine the effect of Coordination Mode on MinTT, F (2, 36.35) = 43.30, $p < .001$, $\eta^2 = .55$ (Figure 3). Post hoc contrasts revealed that Inter was significantly slower than both B1 and B2, and B2 was significantly faster than B1 (all p's < .001).

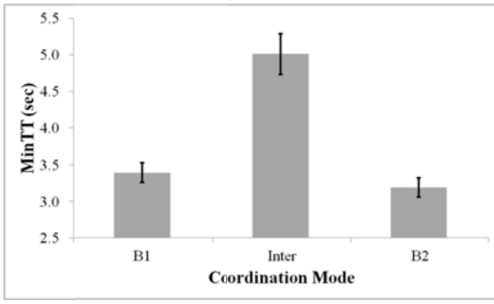

Figure 3. Mean minimum trial time as a function of Coordination Mode. Error bars indicate standard error of the mean.

Learning Functions from Individual Data

To assess how people learn a new coordination mode for a familiar task, we fit exponential and power functions to each dyad's trial series in each coordination mode (e.g., Figure 4). We did not average across dyads in each coordination mode prior to fitting the learning functions, as recommended by numerous papers in the motor learning literature (K. M. Newell et al., 2001; K. M. Newell et al., 2006; Stratton et al., 2007); however, the data were averaged across participants within each dyad in the B1 and B2 conditions. The amount of variance explained (R^2) was calculated for exponential and power law fits for each dyad at each level of Coordination Mode.

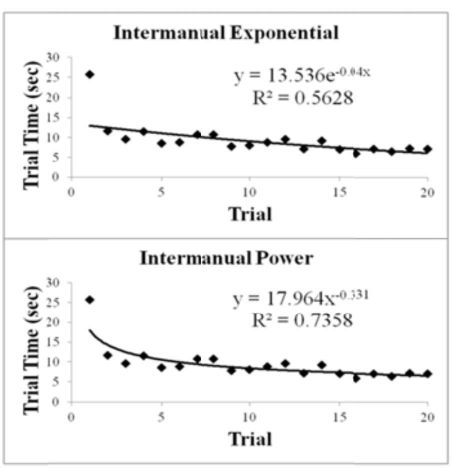

Figure 4. Exponential vs. power fits for one dyad during the Inter condition.

The R^2 values were analyzed using a 3 (Coordination Mode) × 2 (Learning Function) within-subjects ANOVA. The interaction was significant, F (2, 70) = 13.00, $p < .001$, $\eta^2 = .27$. A follow-up simple effects analysis revealed a simple effect of Learning Function for B1, F (1, 35) = 13.86, p = .001, $\eta^2 = .28$, and Inter, F (1, 35) = 34.79, $p < .001$, $\eta^2 = .50$, trials but not for B2 trials, F (1, 35) = .09, p = .761, $\eta^2 < .01$. As shown in Figure 5, the trial-by-trial B1 and Inter data were better fit by a power law learning function.

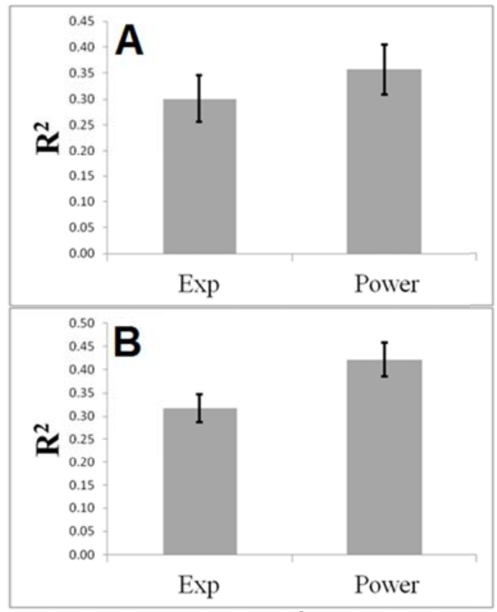

Figure 5. Average model fit (R^2) for exponential vs. power law functions for individual data: (A) the first set of bimanual trials; (B) the intermanual trials. Error bars indicate standard error of the mean.

DISCUSSION

The significant effect of coordination mode for minimum trial time suggests that dyads were never able to match their baseline level of bimanual performance when completing the task in the intermanual coordination mode. This may be due to participants' high level of familiarity with shoe tying. Gorman and Crites (2013) found that mode effects, wherein intermanual is faster than bimanual, can be significantly altered (or disappear) with practice. In the current study, participants performed 10 bimanual trials followed by 20 intermanual trials, and it remains to be seen whether dyads' intermanual performance would eventually equal their baseline bimanual performance, if given enough practice in the intermanual coordination mode.

Interestingly, we observed that minimum trial time in the second set of bimanual trials was significantly faster than minimum trial time in the first set of bimanual trials. One possible explanation for the increase in bimanual speed is that participants' skill in tying our "shoe" was still developing, and the increase in performance from the first set of bimanual trials to the second set of bimanual trials was merely a practice effect. However, in the context of our "shoe", participants appear to have achieved asymptotic performance during the first set of bimanual trials. In this light, the data begins to suggest that something about participating in the intermanual trials may have enhanced, rather than interfered with, performance in the subsequent bimanual trials (e.g., working with a faster partner may have compelled slower individuals to speed up during the second set of bimanual trials).

The results of the analysis of the learning functions revealed that a power law better fit the individual data compared to an exponential fit. Previous research suggests that when acquiring a new motor coordination skill, the learning function will most likely be an exponential function, as opposed to a power law function, because the trial-to-trial fluctuations observed early on when acquiring a new skill are better fit by an exponential curve (Stratton et al., 2007). A power law function is traditionally associated with well-honed, persistent skills, such that transitory, trial-by-trial fluctuations have already vanished (K. M. Newell et al., 2001). Given the familiarity of the task (i.e., tying a shoe), it is not surprising that the initial set of bimanual trials was better fit by a power law function, as participants warmed up to the task. However, the power law function was also a better fit for the intermanual coordination mode, which begins to suggest that people were not acquiring a novel motor skill when they performed the new coordination mode. Because we obtained a better power law fit for the intermanual trials, we think participants may have been transferring their bimanual skill in shoe-tying to the novel intermanual coordination mode. In the case that one must actually relearn a familiar bimanual task intermanually (e.g., after loss of limb function), they may be able to transfer their past bimanual experience rather than having to learn an entirely new coordination skill.

Caution needs to be exhibited in using only variance explained to assess the learning function; model fit should be accompanied by motor analysis to better understand subtle changes in motor skill (K. M. Newell et al., 2001; Stratton et al., 2007). In the future, we plan to more closely scrutinize hand movement data in the shoe-tying task to investigate subtle changes in motor learning and transfer when transitioning from one coordination mode to another.

Finally, the shoe-tying paradigm allows us to investigate coordination modes in a unique fashion. To date, mode effects have been studied in the context of novel tasks performed by novice participants (e.g., Gorman & Crites, 2013; Zheng et al., 2007). To our knowledge, this study is the first to examine mode effects and performance of new coordination modes in the context of a familiar, everyday task. Future research should continue to examine mode effects for novel coordination modes for other familiar tasks (e.g., acquisition of unimanual skill of a familiar bimanual task).

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