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Original Article

The effects of practice schedules on the process of motor adaptation

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Abstract

Objectives: Walking is a well-practiced skill but requires adapting steps online to meet external constraints. The objective of this study was to examine the effects of types of practice schedules (i.e., *blocked* versus *random* practice) on the process of adapting and generalizing motor actions. **Methods:** To examine how practice schedules influence the process of adaptation and generalization during walking, 60 young, healthy adults walked to *normal, slow,* and *fast* metronome paces: 30 with *blocked* practice and 30 with *random* practice. Paces were interspersed with 2 carryover trials with no beat. Subsequent paces were a test of generalizing adaptation from the old to the new metronome pace. **Results:** The results showed that participants who received *blocked* practice acclimated more quickly to the metronome beat. Specifically, the *blocked* practice group altered their walking more quickly during the *fast* metronome pace. In contrast, the random practice group matched the metronome beat more quickly during the *slow* pace. Participants who received *blocked* practice demonstrated carryover effects during carryover trials after walking to the metronome. **Conclusions:** These findings extend an understanding of how the process of adaptation unfolds over time with the imposition of timing constraints.

Keywords: Practice, Gait, Metronome, Walking

Introduction

Walking is a well-practiced skill. In the absence of disability, adults maintain consistency in the kinematics and kinetics of their walking patterns from step to step[1]. This consistency is driven by already-learned gait patterns controlled by neurological mechanisms[2]. However, constantly changing environments create demands that require modifying ongoing movements[3]. As individuals run to catch a bus or to cross the street ahead of oncoming traffic, steps are quickened to achieve a goal. Thus, the ability to adapt movements to changes in local conditions is a true hallmark of skilled motor actions[3]. Executing skill in motor actions is the key to adaptive behavior; without skilled motor actions in the face of changing environmental constraints, movements are rote or haphazard and ill-suited for coping with variable conditions.

Skilled motor actions in unimpaired populations are characterized by increases in adaptive behavior, but a widely held belief in the motor learning and control literature is that motor disabilities decrease adaptive behavior[4]. Rehabilitative interventions for those with motor disabilities such as individuals with neurological impairments are built on foundational knowledge gleaned from studies on unimpaired populations. Yet, we still know little about adaptive behavior in unimpaired adults, specifically with regard to limits in adaptive behaviors and even less about possible mechanisms responsible for adaptive (or nonadaptive) behaviors.

With practice comes improvements in motor skill including improved performance and the ability to generalize motor skills from practice to novel situations. For specific, novel tasks, adults show an improved ability to match their steps to the beat of a metronome[5], to alter their steps to descend sloping surfaces[6], or to modify their steps to cross obstacles in their walking path[7]. Basic measures of walking are typically used to understand improvements in skill[1]: velocity (speed),

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cadence (steps per minute), step length (distance between consecutive steps), step width (lateral distance between feet), and double limb support time (time spent with both feet on the ground) as well as the ability to apply that skill in new situations (e.g., when matching steps to a metronome beat, calculating the time elapsed between the sound of the beat and participants' heel contact[5]). Multiple exposures to the same demands result in improved performance. They also demonstrate the ability to retain practiced motor skills over long periods of time. However, less is known about generalization during short periods of time (i.e., generalization right after skill acquisition has occurred).

Along with multiple exposures via massed practice, types of practice schedules are related to the ability to adapt and generalize motor skills. Specifically, *blocked* practice involves presenting the same activity multiple times before shifting to a different activity. In contrast, *random* practice includes presenting activities in a randomized order. Both practice schedules present benefits and challenges over long periods of time. For example, *blocked* practice leads to faster skill acquisition, but a decreased ability to retain and generalize to new situations days after practice[8]. *Random* practice leads to an increased ability to retain and generalize, but is linked with slower skill acquisition[9]. One main contributor thought to result in these differences in skill acquisition, retention, and generalization is contextual interference. With contextual interference, performing variations in the order or similarity of a task within the same practice session creates interference, which leads to decrements during skill acquisition and benefits during retention and generalization[8]. Specifically, *random* practice involves greater amounts of contextual interference than *blocked* practice and consequently results in poor skill acquisition and good retention and generalization[8]. Contextual interference affects long term outcomes of retention and generalization.

The advantages and disadvantages of *blocked* and *random* practice have been discussed in light of long term outcomes[10-12]. However, little information is available on how practice schedules influence both the process of adaptation and generalization in the short term. Researchers have examined the process of adaptation with short time scales during a reaching task[12]. The findings suggest that although the passage of extended periods of time is thought to contribute to motor skill acquisition, shorter periods (i.e., 2 minutes) reveal processes driving motor adaptation.

The purpose of this study was to examine the effects of types of practice schedules (i.e., *blocked* versus *random* practice) on the process of adapting and generalizing motor actions. A rhythmic walking task was devised in which participants were asked to match their steps to a beat (i.e., an audio metronome). From a theoretical perspective, we take an ecological approach that incorporates traditional and modern views. From a traditional perspective, we examine adaptive behavior via how adults perform motor actions that reflect a match between their physical capabilities and task constraints. We incorporate a modern perspective that considers higher order cognitive contributions responsible for motor actions during adaptation (i.e., contextual interference).

The hypothesis was that the process of adaptation and generalization would differ depending on the type of practice that individuals received: those who received *blocked* practice would change their motor actions more quickly than those receiving *random* practice, specifically at a fast walking pace. Another hypothesis was that the *blocked* group would demonstrate faster generalization to a new beat. The hypothesis in relation to the fast walking pace is based on findings from our previous research[5]. Previous research shows that slow metronome paces are more challenging to meet, possibly due to increased balance constraints (i.e., an increased need to maintain balance on one limb for a longer period of time). In contrast, fast metronome paces are easier to meet, potentially because the fast pace minimizes the need to maintain support on one leg for an extended period of time[5]. However, the belief was that those receiving random practice would demonstrate fewer carryover effects after walking to metronome beats. Previous research has focused on the role of attentional shift[13], cognitive load[14], novel skill acquisition[15], and the degree to which the task is automatized[16]. For example, with less complex and less automatized tasks such as finger rotation[17], individuals demonstrate variability in motor actions, which is consistent with novel skill acquisition. In essence, attempts at adaptive behavior with less complex and less automatized tasks bear similarities to more complex, automatized tasks such as walking. However, tasks that are lower in complexity and automaticity do not allow for an opportunity to examine how individuals alter automatized tasks in the face of complex task constraints.

Methods

Ethics statement

The study and consent procedures were approved by the Boston University Institutional Review board and conformed to the Declaration of Helsinki. Informed written and verbal consent was obtained from all participants before testing began; adult participants provided written consent for themselves.

Participants

A total of 60 college-aged adults (n=30 males, M=21.81 years old, SD=1.53 years) were recruited from Boston University to participate in a one-visit walking task. All subjects were healthy adults and did not have any disorders or injuries that would affect their walking. Participants were excluded if they had a recent history of medical injuries or a serious medical condition that prevented safe participation in the walking task. None of the participants had walked to a metronome beat in the past.

Gait carpet and audio metronome

A pressure-sensitive GAITRite carpet (CIR Systems Inc., Sparta, NJ, USA) was used to collect spatio-temporal data on participants' walking parameters. The GAITRite

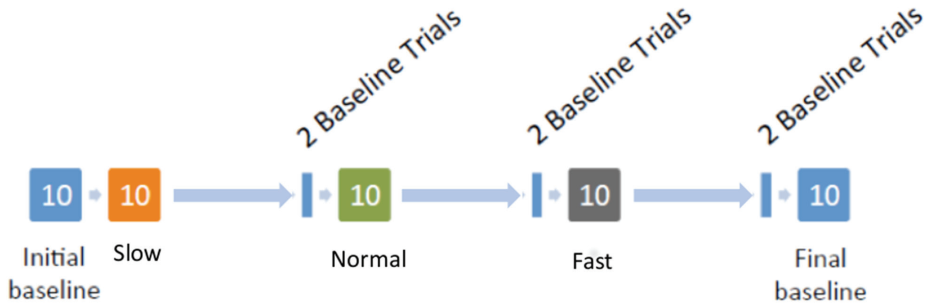

Figure 1. Experimental procedure. The figure shows an example of a session in which a participant in the *blocked* group received the slow metronome pace first. Light blue boxes represent initial and final baseline trials. Orange are *slow* metronome paces, green are *normal* metronome paces, and dark gray are fast metronome paces. After metronome trials at one pace were complete (*blocked* group) or ten metronome trials were complete (*random* group), participants walked for two intermediate trials at their own pace.

system is 4.88 m long and .61 m wide. The GAITRite carpet continuously transfers walking data at a temporal resolution of 120 Hz and a spatial resolution of 1.27 cm to the computer workstation at one end of the carpet through a wired USB connection. GAITRite software installed on the workstation calculates walking parameters for each trial based on the participant's footsteps in real time. The software uses the x and y coordinates of the center of pressure for the heels and balls of the feet on the walkway to calculate spatiotemporal gait parameters, including step length and width, velocity, cadence, single limb support time, and double limb support time.

Metronome

An audio metronome (Boss DB-90, 8x6x2 in) was placed within a standard distance away from the GAITRite system to project a loud, audible beat for participants. The metronome pace was used during the main trials as an external constraint for participants to adjust their cadence. The tempo ranged from 30-250 beats per minute (bpm) with an accuracy of ±0.1%. Researchers used the rotary dial on the metronome to change the speed of the cadence. The audio metronome was synchronized with the time at which the foot contacted the ground. To do this, we used a computerized video coding system to time stamp the first time that the metronome beat sounded at the beginning of each trial. A customized algorithm was written to insert times for subsequent metronome beats. We then imported the gait carpet data with time signatures for each step and synchronized each time stamps for the metronome beat to each step on the carpet. With this information, we included another measure to test how much participants deviated from the metronome pace: a metronome difference score (heel contact time – metronome beat time), which was an absolute error score.

Procedure

Participants were tested in the Motor Development Laboratory at Boston University. After participants provided informed consent, their height and weight were measured using a tape measure and Tanita digital scale respectively.

Participants were instructed to start walking on the gait carpet at the experimenter's instruction. Specifically, the experimenter said, "Walk along the carpet so that your heel touches the ground when you hear the metronome beat." The participants walked barefoot across the entire length of the GAITRite carpet for 5 conditions, with 10 trials for each condition. The conditions were: initial *baseline, slow, fast, normal*, and final baseline. The initial and final baseline conditions were used to obtain participants' self-selected walking patterns before and after metronome conditions. During baseline trials, participants walked at a self-selected pace on flat ground to no metronome beat. The participants' cadence at the initial baseline was obtained by averaging their cadence across the ten trials. Metronome paces (in beats per minute) were then calculated based on the participant's individual cadence (steps per minute) during the initial baseline trials. A *slow* pace was 75% of initial baseline, a *normal* pace was 100% of initial baseline and a *fast* pace was 125% of initial baseline. During the metronome conditions, participants were asked to walk to the beat of the normal, slow, and fast metronome paces. The experimenter started playing the metronome beat while the participants stood at the beginning of the carpet. They were told to begin walking when they were ready. In between the metronome paces, participants walked at a self-selected pace to no metronome beat during two intermediate trials. Thus, participants walked for a total of 56 trials (Figure 1).

A block randomization technique was used to assign participants[18] to one of the two groups for the present study, which determined the order of metronome paces that they encountered during the trials. Participants that were assigned to the *blocked* group encountered metronome trials that were grouped in order by the *normal, slow* and *fast* paces. The *random* group encountered metronome trials that randomly varied in pace: either *normal, slow* or *fast*. Metronome pace conditions were counterbalanced for participants in the *blocked* group.

Table 1. Baseline comparisons. Standard errors are shown in parentheses.

		Blocked	Random
Initial Baseline	Velocity	128.52 (0.85)	128.13 (0.99)
	Cadence	113.88 (0.44)	113.06 (0.56)
	Step Length	67.64 (0.28)	68.02 (0.28)
	Double Limb Support Time	221.37 (2.29)	221.72 (2.17)
	Step Width	9.07 (0.20)*	9.22 (0.21)*
Final Baseline	Velocity	127.89 (0.64)	125.34 (0.67)
	Cadence	114.00 (0.36)	111.99 (0.41)
	Step Length	67.35 (0.22)	67.06 (0.21)
	Double Limb Support Time	220.68 (1.90)	229.88 (1.88)
	Step Width	8.69 (0.18)*	8.90 (0.21)
*p<0.01			

Statistical analyses

SPSS 16.0 software was used to conduct analyses with data presented as means for all trials in each condition for each participant and standard errors around those means. Paired t-tests were used to examine participants' recalibration to their normal walking patterns. The ability to meet the metronome paces was tested with repeated measures (RM) analysis of variance (ANOVAs): a mixed between-within design with group as the between subjects factor and condition (*slow, normal*, and *fast*) and trials as the two within subjects factors. A 2 group x 2 condition (baseline, trials) RM ANOVA was conducted to examine carryover comparisons; for carryover comparisons, the between subjects factor was group and the within subjects factor was carryover trials. Changes after the slow and fast paces were compared to the initial baseline condition. The cadence for the two carryover trials were averaged and compared to the initial baseline cadence. Post hoc analyses for RM ANOVAs consisted of pairwise comparisons. To reduce experiment-wise errors because of the multiple tests that were conducted, the Tukey procedure was used for all tests. Levene's test was used to test for homogeneity of variance and the Shapiro-Wilk's test was used to test for normality. Neither assumption was violated. Cohen's *d* is listed after each p-value as a measure of effect sizes for follow up pairwise comparisons[19]. Interpreting effect size is based on the absolute value of Cohen's *d*. Absolute values of Cohen's *d* are interpreted as small, medium, or large: absolute values of Cohen's $d \geq 0.2$= small effects, ≥ 0.5= medium effects, and ≥ 0.8= large effects.

Results

Baseline comparisons

Comparisons of the initial and final baseline conditions determined if participants returned to their normal walking patterns after walking to the metronome. No differences in velocity, cadence, step length, or double limb support time were found (all *ps*>.05, *ds* ranging from .17 to 2), Table 1. However, participants of both groups did decrease their step width from the initial to the final baseline ($F(1,58)=10.58$, $p=.002$, $d=.25$). Figure 2 shows the cadence values from the initial baseline condition for each participant by group.

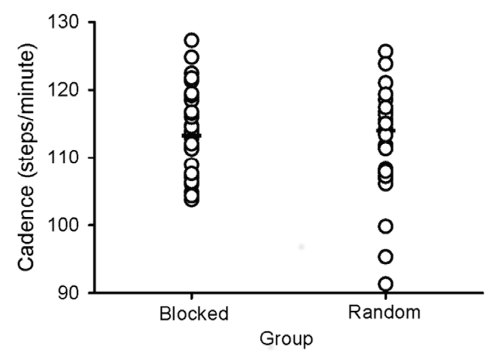

Figure 2. Mean initial baseline cadences. Cadence in steps per minute is plotted for each group. Each circle represents one participant's average cadence at the initial baseline. Horizontal bars within each group represent group averages.

Gait parameters during the metronome

Participants' spatio-temporal patterns as they walked to the metronome were examined. Participants had the shortest step length ($F(2,116)=35.64$, $p<.001$) and slowest velocity ($F(2,116)=522.58$, $p<.001$) at the *slow* pace (*ps*<.001, *ds* ranging from -.67 to 2.33), Table 2. Double limb support time was longest ($F(2,116)=926.10$, $p<.001$) at the *slow* pace and shortest at the fast pace (*ps*<.001, *ds* ranging from 2.00 to 2.80). No difference for step width was found (all *ps*>.05, *ds* ranging from .2 to .3).

Table 2. Gait parameters during the metronome. Standard errors are shown in parentheses.

		Blocked	Random
Slow Metronome	Velocity	97.22 (2.17)*	99.02 (2.22)
	Cadence	92.08 (1.56)	92.92 (1.52)
	Step Length	63.15 (0.47)*	63.62 (0.51)
	Double Limb Support Time	313.19 (7.27)*	308.20 (7.39)
	Step Width	9.16 (0.21)	9.25 (0.22)
Normal Metronome	Velocity	128.46 (0.94)*	128.69 (1.15)
	Cadence	114.63 (0.51)	114.54 (0.62)
	Step Length	67.22 (0.37)*	67.32 (0.43)
	Double Limb Support Time	220.88 (2.31)	221.52 (2.85)
	Step Width	9.00 (0.18)	9.27 (0.21)
Fast Metronome	Velocity	149.10 (1.99)*	145.61 (2.07)
	Cadence	131.99 (1.45)	129.98 (1.61)
	Step Length	67.72 (0.50)*	67.33 (0.54)
	Double Limb Support Time	180.28 (3.83)*	184.81 (4.33)
	Step Width	9.03 (0.19)	9.23 (0.19)

*$p<0.01$

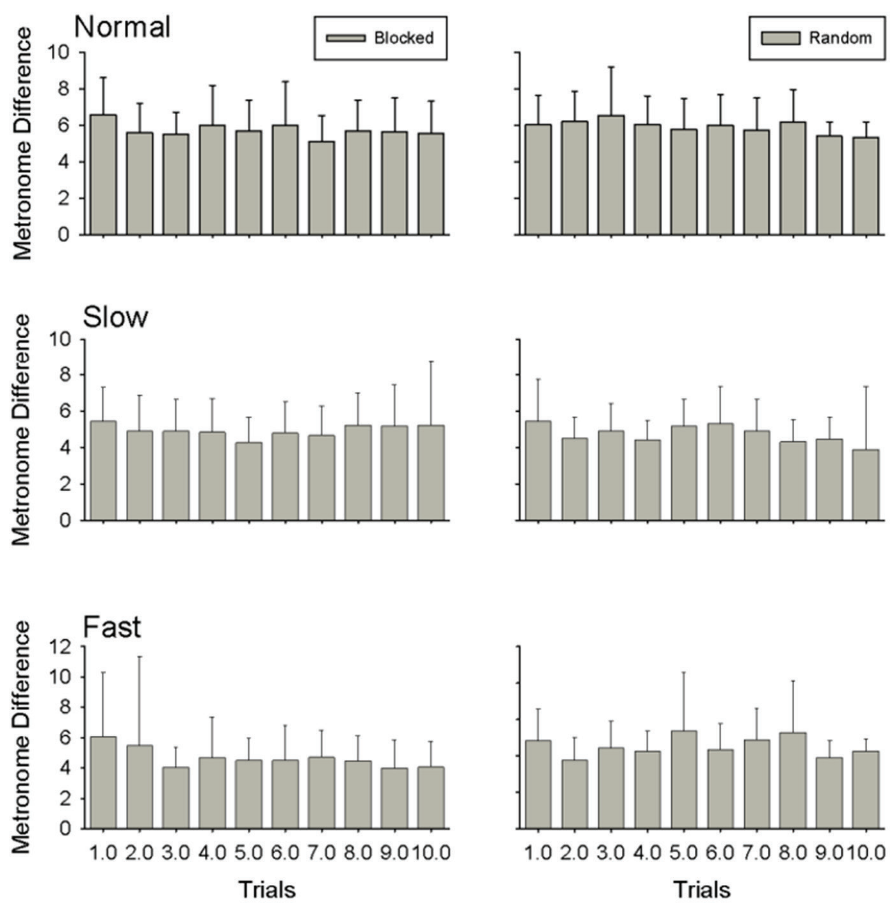

Figure 3. Mean metronome difference scores. Group averages are plotted for the metronome index (heel contact time – metronome beat time) in milliseconds for the *blocked* group and the *random* group. Bars represent standard errors. Asterisks depict results from the three-way interaction among group, metronome, and trial

Meeting the metronome pace

There was a main effect for condition ($F(2,116)=55.06$, $p<.001$); participants' steps deviated more from the metronome during the *normal* pace ($M=5.55$, $SE=0.32$) compared to the *slow* ($M=4.84$, $SE=0.31$) and *fast* ($M=4.59$, $SE=0.38$) paces ($ps<.001$, $d=.45$). A main effect for trial was found ($F(9,522)=4.61$, $p<.001$); it took participants three trials to minimize deviating from the metronome ($ps<.001$, $d=.70$).

The findings also revealed interactions. A trial x group interaction was found ($F(9,522)=3.00$, $p=.002$). Participants in the *blocked* group acclimated to the metronome more quickly than those in the *random* group ($F(18,1044)=2.04$, $p=.006$); by the third trial, the *blocked* groups' steps did not significantly deviate from the metronome ($M=4.82$, $SE=0.26$), but the *random* groups' steps deviated until trial nine ($ps<.001$, $ds=5.00$ and .90 respectively, $M=4.59$, $SE=0.18$). A three-way interaction ($F(18,1044)=2.04$, $p=.006$) demonstrated that participants who received *blocked* practice did best at the fast pace; they matched the metronome by trial three ($M=4.05$, $SE=0.24$). However, those who received *random* practice did the best at the *slow* pace, but took nine trials ($M=4.48$, $SE=0.22$) to consistently decrease their metronome difference score to match the metronome pace ($ps<.001$, $ds=2.00$ and .90 respectively, Figure 3).

Carryover effects

The results showed a main effect for condition ($F(1,58)=8.22$, $p=.006$) and an interaction between condition and group ($F(1,58)=12.58$, $p=.001$), Table 3. During the two trials after the slow metronome pace, participants' cadence was slower than their initial baseline cadence (all $ps<.001$, ds ranging from .33 to .48). Specifically, the interaction showed that those who received *blocked* practice had lower cadences after walking to the *slow*, *normal*, and *fast* paces compared to their cadences at baseline (all $ps<.001$, $d=.57$). In contrast, those who received *random* practice had lower cadences after walking to the *slow* pace compared to the initial baseline, but returned to their normal cadence after walking to the *normal* and *fast* paces ($p<.001$, $d=.43$).

Table 3. Carryover effects. Standard errors are shown in parentheses.

	Blocked	Random
Initial Baseline	113.88 (1.16)	113.06 (1.69)
After Slow	109.64 (1.53)	110.42 (1.99)
After Normal	113.41 (1.46)	113.73 (1.39)
After Fast	116.87 (1.30)	111.50 (1.75)
**p*<0.01		

Discussion

Effects of practice schedules

During the process of adaptation, participants in our study who received *blocked* practice modified their steps to match the metronome more quickly than those who received *random* practice due to the lack of contextual interference; no other beat interfered with the process of modifying walking patterns during the current metronome beat. Three participants in the *random* group had lower baseline cadences than the rest of the group. However, this did not affect their ability to alter their steps according to the metronome beat. Few studies have examined the effects of practice schedules on imposed task constraints[20]. The results from this study support the findings of the current study; *blocked* practice yields faster adaptation to external constraints compared to *random* practice. These findings may facilitate a better understanding of how the process of adaptation affects adults' ability to alter motor actions.

However, specific types of practice are not always needed to observe improvements in the process of performing motor actions[20]. In our study, we found that both groups decreased their step width from the initial to the final baseline conditions. Narrowing step width is indicative of improved walking patterns. Although this is not a group specifically in need of improving walking patterns, practice overall may have shifted their own walking patterns to be slightly improved.

Effects of practice and metronome pace

The findings from this study showed that the blocked practice group adapted more quickly during the fast metronome pace (i.e., by trial 3/3rd exposure). In contrast, the *random* practice group matched the metronome beat better during the slow pace (i.e., by the 9th exposure). The *blocked* practice group received the same metronome beat within conditions. Therefore, that group needed little time to adapt from one trial to the next, which may have facilitated performance during the fast pace. Instead, due to contextual interference, the *random* practice group possibly benefited from longer periods of time elapsing between steps to reassess the modification of walking patterns (i.e., adapting more quickly performance at the *slow* pace). Some researchers posit that contextual interference could either improve or result in decrements when learning[21]. This study suggests that contextual interference in the *random* group led to slower changes in the process of adaptation, but only at particular metronome paces (i.e., *normal* and *fast* paces). This study demonstrates that the type of task demand (e.g., metronome pace) may lead to different outcomes when contextual interference is introduced, particularly during short periods of time after skill acquisition. However, contextual interference could result in faster adaptation in situations that involve simple tasks with low attentional demands[22]. The benefits of contextual interference become more apparent with increased practice[23,24]. In addition, since participants who received random practice had to adapt to a new pace after each trial, the task may have served as a dual task (i.e., walking and listening to the beat). Studies have shown that dual task demands increase cognitive load for individuals[25]. We plan to test this hypothesis empirically with future studies. The results also add to our current knowledge of adapting to timing constraints[26] by highlighting how a timing constraint could yield insight into the interface between practice schedules and the process of adapting motor actions during short periods after skill acquisition.

The healthy adult walkers in our study had the motor wherewithal to modify their walking in accordance with the task. Specifically, those in the *random* group benefitted from walking to the *slow* pace, which requires maintaining balance on one leg for a longer period of time prior to the next beat being played. Sophisticated walking skills, for these individuals, led to improved performance. This is different, however, in populations who are still improving motor skills such as children[5,25,27,28] or those who have impaired walking patterns[29,30]. Therefore, the presence of intact walking and balance abilities translates to a better ability to alter the process of adapting motor actions even in the face of a difficult task.

Carryover effects

Participants who received *blocked* practice demonstrated carryover effects. This finding suggests that *blocked* practice facilitated maintaining particular gait patterns even beyond the imposition of the external timing constraint. Although *blocked* practice leads to faster changes in the process of adaptation, it also limits generalization[8]. Since follow up analyses showed that the *random* practice group demonstrated no carryover effects after their second and third set of metronome trials, they became accustomed to facing new metronome paces from trial to trial. Thus, these findings extend our understanding of how practice influences the process of adaptation with the imposition of timing constraints.

Future directions

One of the future directions for this research includes comparing the influence of practice schedules on long and short term adaptation. Another future direction for this work includes comparing the ability to adapt to external constraints between unimpaired adults and those who possess biomechanical difficulties that impact their walking ability (e.g., adults with obesity). Findings from the current study serve as the beginning of foundational information needed in rehabilitation research to compare motor abilities in impaired and unimpaired populations.

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