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Analogy learning in Parkinson's; as easy as a walk on the beach: A proof-of-concept study

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Abstract

Background/Aims: Analogy learning, a motor learning strategy that uses biomechanical metaphors to chunk together explicit rules of a to-be-learned motor skill. This proof-of-concept study aims to establish the feasibility and potential benefits of analogy learning in enhancing stride length regulation in people with Parkinson's.
Methods: Walking performance of thirteen individuals with Parkinson's was analysed using a Codamotion analysis system. An analogy instruction; "following footprints in the sand" was practiced over 8 walking trials. Single- and dual- (motor and cognitive) task conditions were measured before training, immediately after training and 4-weeks post training. Finally, an evaluation form was completed to examine the interventions feasibility.
Findings: Data from 12 individuals (6 females and 6 males, mean age 70, Hoehn and Yahr I-III) were analysed, one person withdrew due to back problems. In the single task condition, statistically and clinically relevant improvements were obtained. A positive trend towards reducing dual task costs after the intervention was demonstrated, supporting the relatively implicit nature of the analogy. Participants reported that the analogy was simple to use and became easier over time.

Conclusions: Analogy learning is a feasible and potentially implicit (i.e. reduced working memory demands) intervention to facilitate walking performance in people with Parkinson's.

Keywords: analogy, implicit motor learning, Parkinson, rehabilitation, gait

1. Introduction

Parkinson's is a neurodegenerative disorder primarily due to dysfunction of the basal ganglia, which manifests mainly as four cardinal symptoms: tremor, rigidity, postural instability and bradykinesia (Jankovic, 2008). Despite optimal medication therapy, many people with Parkinson's still experience gait impairments (Morris et al., 1996). A Parkinson's gait is typically characterized by a reduced velocity and reduced stride length, while cadence (steps per minute) control may be relatively unaffected (Morris et al., 1994). Also a reduced attentional capacity is a common feature in people with Parkinson's (Meireles and Massano, 2012); affecting the ability to perform dual-tasks required for effective daily life (e.g., walking and talking simultaneously) (Rochester et al., 2004). A reduced attentional capacity may lead to an increased risk of falls (Allcock et al., 2009). The consequences of falls, such as reduced confidence, mobility and quality of life (Bloem et al., 2004) greatly affect people's daily life. Therefore there is a need to develop interventions to improve walking performance in people with Parkinson's.

Cognitive strategies such as attentional strategies (self-generated with an internal focus), the use of external cues (auditory, visual or tactile), or self-instruction strategies can be beneficial in improving gait (Keus et al., 2014). In Parkinson's, skills acquired via cognitive strategies will mostly not become automated but will remain under conscious control and may be guided via the use of cues (Keus et al., 2007). From a neurophysiological perspective it is proposed that such consciously acquired, explicit learning strategies may reroute a non-automatic pathway that compensates for the damaged basal ganglia (responsible for internal generation of movements).

While cognitive strategies are frequently recommended to optimise motor learning in people with Parkinson's (Morris, 2000), the attentionally demanding nature of such techniques may impair multi-tasking performance. As cognitive strategies require working memory capacity, their effectiveness may be reduced when working memory processing is already required to perform secondary tasks, due to attentional overload (i.e., when attentional demands exceed working memory capacity) (Lohnes and Earhart, 2011). Indeed, studies using cognitive strategies to support performance in dual task situations reveal equivocal results (Kelly et al., 2012), possibly due to variations in the type (e.g., motor or cognitive) and complexity (cognitive demand) of the dual tasks used. As rehabilitation involves training within a functional context in which multi-task situations frequently occur, it is important that alternative approaches to motor learning are explored.

One such approach that has received recent interest in a variety of movement domains is implicit motor learning (Masters and Poolton, 2012, Masters, 1992). This approach evokes evolutionary heuristics that reflect that much of the way in which humans respond and adapt to the environment occurs implicitly (i.e., without conscious awareness and often without intention). It is unsurprising that evolution has selected advantages of implicit (unconscious) learning, given that learning is a biological imperative, which provided our ancestors a significant survival advantage (Reber, 1992, Claxton and Vincer, 1997). Research has shown that implicit learning is less dependent on individual differences such as age or IQ, is more robust under stress or dual-tasking conditions, and, is more durable over time (Dienes and Berry, 1997). Implicit *motor* learning is therefore a potentially useful strategy for people with Parkinson's, as it strives to minimize the cognitive load in working memory when performing a motor task (Steenbergen et al., 2010). Different strategies to induce implicit motor learning exist including dual-tasking, errorless learning, manipulating feedback, and analogy learning, however, research validating these strategies has mainly been carried out with healthy, unimpaired populations (Masters and Poolton, 2012).

Analogy learning involves repackaging relevant bits of (explicit) information of the to-be-learned skill into one integrated biomechanical analogy or metaphor (Masters and Liao, 2003, Liao and Masters, 2001). Although an analogy is provided as a verbal instruction, it is not presented as an explicit set of rules to guide the execution of the desired movement pattern. Instead, analogies strive to combine explicit information into meaningful chunks of information, which utilise fast, unconscious (working memory independent) processing (Liao and Masters, 2001, Chase and Simon, 1973). For example, the analogy of "reaching your hand into a cookie jar" describes the appropriate wrist snap required to impart backspin on a basketball during the performance of a free-throw, without describing the step by step rules to create the backspin (Lam et al., 2009).

For people with Parkinson's there may be two potential advantages of analogy learning. First, analogies have practical benefits that make them extremely flexible to use in different environments. In comparison, visual cues (e.g., stripes marked on the floor) have to be set out in advance on regularly taken pathways (usually only in the home), and auditory cues require delivery via an earphone, making communication difficult. In analogy learning however, once an appropriate analogy has been found, this can be used anytime and independent of additional material support. Second, the implicit nature of analogy learning may improve the ability of individuals to multitask and perform under more demanding conditions (Liao and Masters, 2001). Research has demonstrated that implicit motor learning techniques free up cognitive resources from step-by-step movement control, and these can be redeployed to other tasks (e.g. Liao and Masters, 2001; Lam et al., 2009).

From both a theoretical and practical perspective, analogy learning seems a promising intervention but its application and feasibility in Parkinson's rehabilitation has yet to be examined. Therefore the following research questions for this proof-of-concept study were established: Can analogy learning facilitate walking performance in people with Parkinson's and is this a feasible intervention in therapeutic practice? We hypothesise that participants will have increased walking velocity and longer strides following exposure to analogy learning, and that attentional costs of dual-tasking will be reduced after training.

2. Methods

2.1. Participants

University of Exeter (Sport and Health Science department) ethical approval was obtained. The study was promoted in collaboration with Parkinson's UK. Interested individuals contacted the first author via phone or e-mail. Participants were included if they self-reported a shuffling gait and were able to walk independently without walking aids for at least 15minutes (with resting breaks). Participants were excluded if they reported other medical problems affecting gait, or were receiving any treatment/rehabilitation to improve walking performance. During the study period participants were asked not to take part in additional physiotherapy programmes. Participants had up to five working days to consider participation and written informed consent was obtained. The study took place at the gait laboratory at the University of Exeter, requiring two visits, spaced 4-weeks apart.

2.2. Procedures and data collection

Pilot testing with the first participant was performed to fine-tune an appropriate analogy (Kleynen et al., 2014), and to determine the duration of the training blocks in the walking protocol. The 'footsteps in sand' analogy was clear and understood immediately by the participant, therefore it was deemed to be appropriate for the study. It was observed by the researchers and confirmed with the participant that the original protocol (four blocks of training) was too long, resulting in tiredness. Therefore the protocol was shortened from four to two training blocks. The initial participant was included in the study, deleting the last two training blocks, as this did not influence the data analysis, or our interpretation of the results.

Demographic data (age, gender, Hoehn and Yahr stage, medication use) were collected during the initial visit. Participants were set up with Codamotion (Charnwood Dynamics, Leicestershire, UK) active markers attached non-collinearly on both feet at the calcaneus, fifth, and first metatarsal. Then a single standing trial (5 sec) and multiple walking trials were performed over different conditions (see Table 1). First a single task (only walking) in the form of a 10 Meter Walking Test (MWT) was performed. This was followed by a motor dual task, in which participants were asked to walk while carrying a tray with empty plastic 'cups' (Bond and Morris, 2000); and a cognitive dual task, that required subtracting in threes (out loud) from a random (to prevent familiarization) three-digit number (Brown et al., 2009). Following these baseline measures, participants were exposed to the analogy instruction (see section 2.3) and practiced this analogy over two training blocks (8 walking trials). Finally both dual task conditions were repeated.

** Table 1 near here**

Every condition contained four walking trials in which participants were asked to walk at a comfortable walking speed. Walking took place over a 10m distance of which the middle 5m was recorded by the two Codamotion CX1 units at 200 Hz, which demonstrates good inter- and intra-rater and inter-session reliability for 3D kinematics (Kiernan et al., 2014). A video camera (Panasonic SDR-S70) continuously recorded walking performance over the entire session, and velocity was manually calculated by timing the walking distance (10 m) using a stopwatch. Stride length was computed using a custom Matlab script (version 2012a, The Mathworks, US). Mean velocity (ms^{-1}) and stride length (m) in the 10MWT (single task) and dual tasks were used to assess walking performance.

At the start of visit two, participants completed an evaluation form and then went through the same set-up procedure as in visit 1. The evaluation form assessed their subjective experiences of the analogy intervention; involving questions targeting adherence, applicability, and perceived improvements (Table 2). Responses were recorded using binary outcome variables "yes/no", scales ranging from 0 – 10, and free comments (partially described in results section and available as a supplementary file). Session two did not involve any training but only the 10MWT and dual-task trials. Visit one lasted for approximately one hour and visit two about 30 minutes.

2.3 The analogy instruction

The analogy instruction was presented to participants pictorially (Figure 1) in association with the following instruction:

"Do you see the footprints in the sand? Now while walking: Pretend that you are following footprints in the sand as you walk"

Participants were instructed to practice at home by incorporating the analogy into their everyday walking, although no specific training exercises were prescribed.

** Figure 1 near here **

2.4 Data analysis

Demographic data were reported descriptively (Mean, Standard Deviation). Individual walking performance was presented by plotting individual delta (change) scores for each time point compared to baseline. A repeated measures ANOVA (Analysis of Variance), comparing each time point (baseline, training block 1, 2 and at 4-weeks) for the single task, was performed to explore group improvements in velocity and stride length. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. Estimated effect sizes (η_p^2) were calculated using partial eta squared and LSD (least significant difference) *post hoc* tests were used to explore effects.

The effects of secondary tasks on walking performance were explored by calculating the DTC (Dual Task Cost) at each time point (pre, post and 4 weeks). The DTCs for velocity and stride length are expressed as a percentage of single task performance using the following formula (Doumas et al., 2008, Kelly et al., 2012):

$$DTC = (\text{dual-task} - \text{single-task}_{(\text{baseline})}) / \text{single-task}_{(\text{baseline})} * 100$$

Reliable differences from zero at each time point were assessed for DTC using one-sample *t*-tests (Doumas et al., 2008).

As this was a proof-of-concept study it was not formally powered for inferential comparisons. Exploratory analyses were undertaken to estimate the mean between group differences (and 95% CI) for outcomes. Velocity increases of $0.05ms^{-1}$ and stride length increases of 0.048m were set as clinically relevant improvements (see discussion; Hass et al., 2014, Brach et al., 2010). Participant's evaluations were reported descriptively. Free comments were used to describe personal experiences of the participants and clarifying examples were quoted.

3. Results

In total 13 people with Parkinson's (Hoehn and Yahr I-III) were included in the study (7 females, 6 males) with a mean (SD) of 70 (7) years. One participant withdrew during the study due to back problems, leaving 12 participants to be included in the subsequent analysis.

3.1. Effect of analogy on single task walking

Figure 2 demonstrates walking performance of each individual. Most participants showed an initial drop in velocity, with a simultaneous increase in stride length. At 4-weeks, most participants achieved improvements for both velocity and stride length (See supplementary video data for a 3D stick figure demonstration of one of the participants).

Figure 2 near here

As a group, for velocity, statistically significant results between the conditions were obtained ($F_{(1.47, 16.18)}$ = 5.32, p = 0.02, η_p^2= 0.33). LSD pairwise comparisons demonstrated that compared to baseline (0.89 ± 0.14ms^{-1}), velocity significantly decreased at training block 1 (0.80 ± 0.16ms^{-1}, p = 0.04), and increased at 4-weeks (0.99 ± 0.15ms^{-1}, p = 0.046). Velocity at 4-weeks was also significantly greater than at block 1 (p = 0.01). For stride length no significant main effect was obtained ($F_{(1.17, 12.86)}$ = 1.08, p > 0.5, η_p^2 = 0.09). Group performance in the single task conditions, including confidence intervals are demonstrated in figure 3.

Two participants (6 and 11) reported experiencing a “bad day” during visit two, resulting in increased festination and impaired walking (dotted lines, Figure 2). Post hoc sensitivity analysis, excluding these two participants resulted in highly significant outcomes and large effect sizes in the predicted direction for both velocity ($F_{(3, 27)}$ = 14.73, p < 0.001, η_p = 0.62) and stride length ($F_{(1.41,12,68)}$ = 7.51, p = 0.01, η_p = 0.46).

** Figure 3 near here **

3.2. Effect of analogy on dual tasking while walking

The proportional dual task costs (DTCs) are presented in figure 4. At baseline, the dual task costs for *velocity* were reliably different from zero in the motor- ($t_{(12)}$ = -2.43, p < 0.05) and cognitive- ($t_{(12)}$ = -2.43, p < 0.05) dual task conditions. For *stride length,* only the cognitive dual task cost ($t_{(12)}$ = -2.72, p < 0.05) at baseline was reliably different from zero. Post training, the mean costs were not reliably different from zero for either performance measure. At 4-weeks post training, dual-task performance was actually better than baseline single task performance (though not significantly so).

** Figure 4 near here**

3.3. Participant Evaluation

Participant responses are reported in Table 2. People reported having to think a lot while using the analogy but also reflected that it became easier over time *“at first yes and then it becomes second nature”* (Participant 5). However others reported, *“It’s so simple that it doesn’t matter”* (Participant 11). One participant reported that the analogy intervention didn’t bring any improvements and commented with *“I don’t feel any difference”* (Participant 3), whereas others reported gaining focus, control and stability as well as feelings of confidence.

Some participants pointed out that they would only use the analogy incidentally, only when situations when walking deteriorated, whereas others stated using the analogy daily. Only four participants had used cues previously and with varying degrees of success. Participant 4 had used marching as a strategy, *“but this was very mechanical. I prefer walking while following the footprints because it is more natural.”*

** Table 2 near here**

4. Discussion

This is the first proof-of-concept study exploring analogy learning in people with Parkinson's and aimed to investigate the feasibility and potential benefits of this intervention on walking performance.

4.1. Walking performance: single task

For people with Parkinson's, clinically important differences in walking velocity range from 0.05 to 0.22ms^{-1} (Hass et al., 2014). For older people meaningful changes in *step* length are estimated in a range from 0.24 to 0.61m (Brach et al., 2010). Strides were used rather than steps, therefore we proposed a conservative threshold of 0.48m for *stride* length and 0.05ms^{-1} for velocity. In line with the hypothesis that analogy learning would increase walking velocity and stride length, statistically and clinically (i.e. exceeding the meaningful threshold) significant improvements for velocity were obtained. The findings for stride length failed to reach statistically significance, but they revealed clinically relevant improvements (n = 7) and demonstrated positive trends in the predicted direction (i.e. increased stride length following intervention; Figure 2).

In interpreting these results it is important to recognise that the current study was designed to establish *'proof of concept'* that analogies have potential clinical benefits for this population and was not powered to confirm statistical significance. Additionally, it is important to note that we included the data of two participants who reported having a "bad" day at the 4-week follow-up in the statistical analysis and it was evident from the sensitivity analysis that they negatively influenced the overall result. Despite these concerns, the magnitude of performance improvements found in this brief intervention is similar to those obtained in studies using cues to facilitate walking (Baker et al., 2007).

The current study observed most performance improvement in velocity during visit 2 (4-weeks later) rather than directly at visit 1. This is in contrast with other analogy studies, which have tended to find immediate improvements after training (Masters and Liao, 2003, Liao and Masters, 2001). While it is evident that participants were able to make some initial improvements in stride length, we suggest that participants require time to fully assimilate the analogy and slow down initially in order to focus on their stride lengthening. Once stride regulation has been internalised, they are able to increase velocity and maintain their new stride length (Figures 2 and 3).

An alternative explanation may be related to differences in training dose, with some previous analogy learning using up to 300 repetitions (Liao and Masters, 2001). However, as we worked with patients rather than young healthy individuals, similar amounts of repetitions within one session were not feasible for safety reasons (as determined via pilot testing, section 2.2). One clear difference between analogy learning for sport (where most of the research has been applied) and for therapy is that safety is *the* critical factor in therapy, whereas the rate of skill acquisition is prioritised in sport. The nature of the different study populations may also contribute to the different findings. Whereas the existing literature involved younger, healthy people, our study comprised older people with a neurodegenerative disorder who are known to take longer to learn motor skills (Ren et al., 2013).

4.2. Walking performance: dual tasks

At baseline, interference effects were obtained for both dual task conditions, indicating that the task difficulty was appropriate (Figure 4). However, at immediate and 4-week post test conditions there was no significant cost of dual-tasking, suggesting that participants were now able to free up resources from the walking task to complete the secondary tasks. The reduction in the dual task cost (DTC) of walking in the motor dual task (carrying glasses on a tray), importantly demonstrate the functional transferability of analogy learning to a daily life task.

Additionally, the DTC data for the cognitive dual task condition reflect a positive trend towards the analogy exhibiting the implicit characteristic of robust performance under secondary task loading (Dienes and Berry, 1997). However, the current study cannot claim that the improvements in walking performance are due solely to the intervention, as performance could also have improved due to the multiple exposures to the same testing conditions. The dual tasks demonstrated a relatively large 95% CI at 4-weeks (Figure 4) which may be explained by the large variability in performance within the group (two influential data points; section 3.1) and small sample size of the study. Future research should include a control group (receiving an explicit, cognitive intervention) to determine if analogies provide *relative* benefits in multitasking performance over other techniques.

4.3. Feasibility of the analogy intervention

Generally participants were positive about the analogy intervention, finding it relatively easy to use and perceiving noticeable improvements in their gait. Most participants perceived the walking on the beach analogy positively. Although one participant reported experiencing no improvements in walking (Table 2), walking performance at 4 weeks revealed positive changes in the objective measures of interest. This discrepancy between objective measurement, self-report and subjective perceptions highlights the need for mixed-methods evaluations using a range of data collection methods to fully understand the impact of interventions from the perspective of the patient and the clinician. Whilst all 12 participants reported that they would continue to use the analogy, there were differences in terms of whether they responded with "daily / frequently" or on a more "situation dependent" basis that appeared to be related to the degree of gait impairment they experienced. This finding reveals an important additional benefit of analogies – they can be easily tailored to the specific needs of the individual.

4.4. Future implications and conclusion

From a clinical perspective, this study demonstrated that the application of analogy learning is feasible to facilitate improvements in walking performance in people with Parkinson's. Although the process of developing meaningful analogies might take time and require some creativity (Kleynen et al., 2014), once an appropriate analogy is found to correct a specific movement pattern, the concept is relatively easy to apply. In effect, the analogy used in the current study perhaps manages to provide some of the benefits of external and internal cues without their associated problems (Nieuwboer, 2008): There is no need for the additional technology or information required for external cues, while potential problems with having to self generate internal cues (increased cognitive load and an internal focus) are also potentially reduced. While these preliminary results must be interpreted with caution, we conclude that analogies may improve walking performance in people with Parkinson's. Not only were these benefits found during a simple walking test, but improvements were also found under cognitive (counting backwards) and motor (carrying a tray) dual task conditions Future studies including control groups and appropriate sample sizes are needed to establish clinical effectiveness of analogy interventions.

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5. Key points

- Analogy learning is a feasible learning strategy to facilitate walking performance in people with Parkinson's.
- The study brings implications for the delivery of instructions to facilitate walking performance in Parkinson's.
- Future studies, involving control groups and appropriate sample sizes, should establish the clinical effectiveness of analogy learning.
- Future studies could explore the use of different analogies on walking in Parkinson's.

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Table captions

Table 1. Overview of walking trials in sessions 1 and 2

Conditions session 1	Conditions session 2
• Single task	• Single task
• Motor dual task	• Motor dual task
• Cognitive dual task	• Cognitive dual task
• Training Block 1	
• Training Block 2	
• Motor dual task	
• Cognitive dual task	

Table 2. Responses (n = 12) from the evaluation form, at 4-weeks.

Question	Response	
	Mean ± SD (range)	Agreed (n)
1. How often did you practice the analogy at home? (days/week)	6 ± 1 (3)	-
2. Is it difficult to use the analogy? (0 not – 10 very difficult)	3 ± 2 (4)	-
3. Does it become easier to use the analogy the more you practice / use the analogy?	-	9
4. Do you need to think a lot when using the analogy? (0 not – 10 very hard)	4 ± 2 (7)	-
5. Is the analogy difficult to visualise? (0 not – 10 very difficult)	3 ± 2 (7)	-
6. Do you enjoy going to the beach / walking through sand?	-	10
7. Did the analogy bring any improvements?	-	11
8. Will you use the analogy in the future?	-	12
9. Have you used different analogies before or are you using other analogies at the moment?	-	4

Figure captions

Figure 1.
Picture of footprints in the sand (Source: 4ever.eu, 2012)

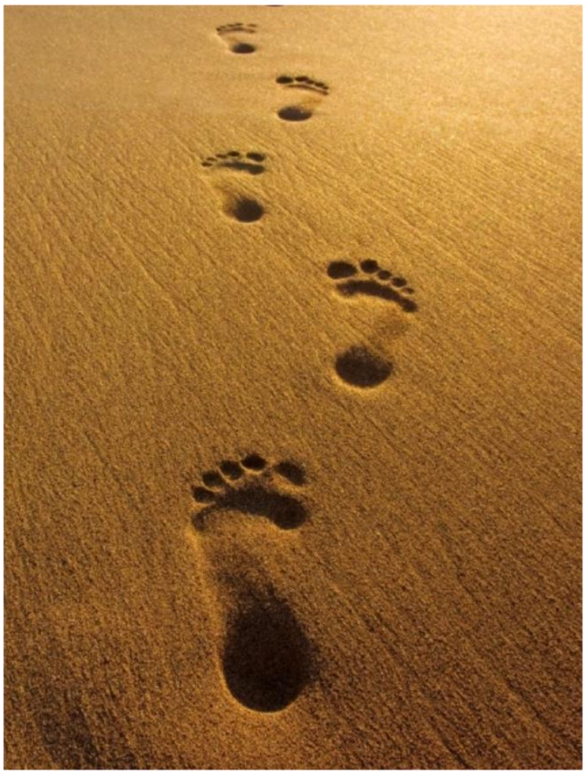

Figure 2.
Individual walking performance in the single task condition for velocity (left) and stride length (right). Data is presented as change (delta) scores of each time point (block 1, block 2 and 4-week retention) compared to baseline. Horizontal dashed lines indicate the meaningful threshold for clinically relevant improvements.

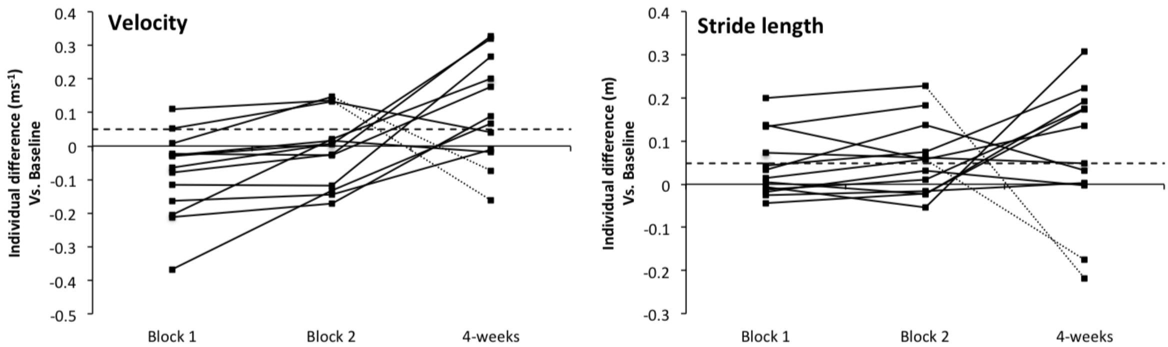

Figure 3.
Mean (± 95% C.I.) group performance in the single task condition for velocity (left) and stride length (right). Data is presented as change (delta) scores of each time point compared to baseline. Dashed lines indicate the meaningful threshold for clinically relevant improvements.

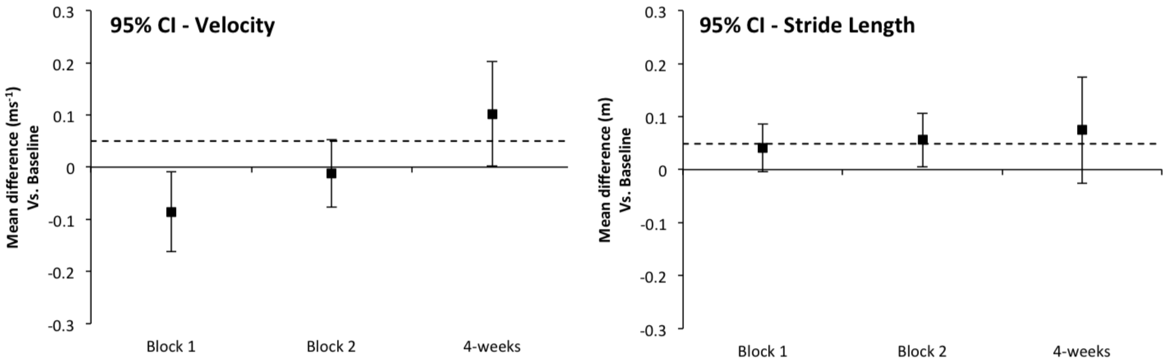

Figure 4.
Mean (± 95% C.I.) dual task cost (DTC) for velocity (a) and stride length (b) for the motor and cognitive secondary task conditions.