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The learning process of gait retraining using real-time feedback in patients with medial knee osteoarthritis

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ABSTRACT

The objective of this study was to investigate the learning process of knee osteoarthritis (KOA) patients learning to change their foot progression angle (FPA) over a six-week toe-in gait training program.

Sixteen patients with medial KOA completed a six-week toe-in gait training program with real-time biofeedback. Patients walked on an instrumented treadmill while receiving real-time feedback on their foot progression angle (FPA) with reference to a target angle. The FPA difference (difference between target and actual FPA) was analyzed during i) natural walking, ii) walking with feedback, iii) walking without feedback and iv) walking with a dual-task at the start and end of the training program. Self-reported difficulty and abnormality and time spent walking and training were also analyzed.

The FPA difference during natural walking was significantly decreased from median 6.9 to median 3.6° i.e. by 3.3° in week six ($p < 0.001$); adding feedback reduced FPA difference to almost zero. However the dual-task condition increased the FPA difference at week one compared to the feedback condition (median difference: 1.8°, $p = 0.022$), but after training this effect was minimized (median difference: 0.6°, $p = 0.167$). Self-reported abnormality and difficulty decreased from median 5 to 3 and from median 6 to 3 on the NRS respectively ($p < 0.05$).

Patients with medial KOA could reduce the FPA difference during natural walking after the gait retraining program, with some evidence of a reduction in the cognitive demand needed to achieve this. Automation of adaptions might need support from more permanent feedback using wearable technologies.

1. Introduction

People with medial knee osteoarthritis (KOA) often have an increased knee adduction moment (KAM), which is associated with faster progression of the disease [1]. Modifying the foot progression angle (FPA) during gait can reduce the KAM [2–9]. Real-time biofeedback can be used to train gait modifications [3–5,8–10]. There is evidence that patients can learn to walk with gait modifications in the short-term (i.e. within session) and that the gait modifications have beneficial short-term biomechanical effects [2,5,8,9]. There is, however, limited evidence to show whether the modifications can truly be learnt. Similarly, the cognitive demand of walking with a modified gait pattern is unknown, although increases in cognitive demand are expected during the motor learning process [11]. Cognitive loading may be measured using functional near-infrared spectroscopy [12] or electroencephalography [13]. However, both techniques present problems relating to drift when measuring over a long period of time. Use of a concurrent dual-task offers a practical, alternative method of estimating the effect of cognitive demand during walking. Use of a dual-task paradigm has demonstrated the relationship between the cognitive and motor systems [14]. Deterioration of gait performance during walking with a dual-task condition suggests that gait is not completely automatic [15], despite locomotion control by the central pattern generator [16]. The dual-task paradigm represents the many important distractions during walking that are encountered daily, e.g. talking while walking.

In the absence of injury or illness, little conscious effort during normal walking is needed and the gait pattern is easily adapted to changes in the environment and/or terrain. Learning to modify the gait pattern is likely to interrupt the automaticity of normal locomotion and hence require increased cognitive demand. According to the Fitts and

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Posner three stage model of motor learning [11], we would expect that walking with a modified gait pattern would initially cause a steep increase in cognitive demand and that it would be performed with significant errors (1st stage of learning; cognitive phase). With increased practice time, we would expect increasing automaticity and reduced cognitive demand (2nd stage; associative phase) and with sufficient practice time we would expect the task to be performed with little or no cognitive demand (3rd stage; autonomous phase).

We can also consider changes in the motor-learning in terms of fast and slow learning. Fast learning is learning over a short period of time, typically learning within-session. That fast learning occurs during gait retraining has been demonstrated [2,8–10]. Slow learning occurs with repetitive practice over several training sessions with sufficient consolidation time, and leads to gradual, progressive improvements in performance [17]. Slow learning leads to changes in the representation of the learnt activity in the motor-cortex and long-term retention of the learnt skill [18].

The aim of this study was to evaluate the motor learning process during a six-week gait retraining program focused on toe-in gait in patients with medial KOA by assessing the difference in FPA between the target FPA modification and the actual FPA as the primary outcome. Specifically, we aimed to assess changes in the FPA difference as a result of a six-week gait training program during a) normal walking condition and b) a dual task condition, designed to challenge the patients. We hypothesized firstly, that the FPA difference would reduce after the training, indicating slow learning and an increase in automaticity, and secondly that introduction of a dual-task would increase the FPA differences.

2. Method

Sixteen patients with medial KOA (61.2 ± 5.8years, 12 female), completed a six week gait retraining program (one session per week) in the Virtual Reality lab at the VUmc. Patients were recruited from a previous study in this lab [9], with inclusion criteria being medial KOA, aged between 50 and 75, and at minimum a 10% reduction in the first peak KAM between normal walking and modified walking conditions in our previous study. Further inclusion and exclusion criteria are given in [9]. Ethical approval for this study was granted by the Medical Ethics Committee of the VU Medical Centrum, Amsterdam, Netherlands in September 2015. Patients provided written consent to participate in the study. Demographics of the included patients are presented in Table 1. Reflective markers positioned over the patient's lower limbs and trunk were used to calculate the FPA and KAM in real-time [19] during walking on an instrumented treadmill. Marker position data were recorded at 100 Hz, using a 10 camera Vicon motion-capture system. Ground reaction force data were recorded at 1000 Hz using two ForceLink force plates embedded in the treadmill [9]. Patients walked at self-selected comfortable walking speed.

Feedback on the participant's FPA was presented on a 180° screen in front of the treadmill, in the form of two arrows. Targets for FPA were determined based on a previous study [9], with a mean (SD) target angle across the group of 3.0 (2.5) degrees in-toeing. The targets were set specifically for each patient with a mean (SD) target change of 7.3° (4.5) towards in-toeing. Targets were presented as stationary arrows, which changed colour according to the FPA difference, Fig. 1.

Table 1
Characteristics of patients completing the training program.

	Mean (standard deviation)
Age	61.1 (5.7)
Gender	12F 4 M
Height	1.72 (0.08)
Weight	76.0 (12.2)
BMI	25.5 (2.9)
KL score	I: 10, II: 1, III: 4, IV: 1

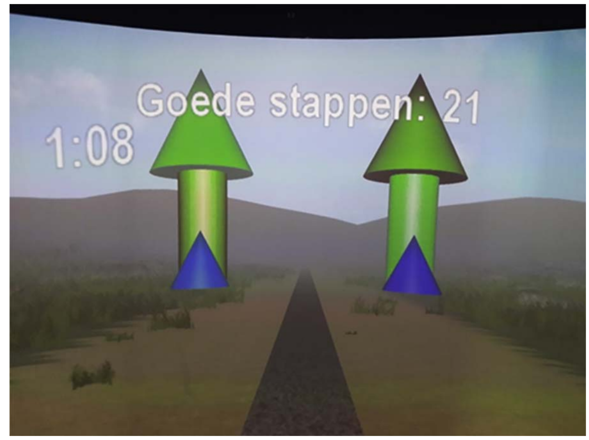

Fig. 1. Real-time feedback as seen by the patient while walking on the treadmill. The blue arrows represent the current position of the feet, with the larger arrows in the background representing the target angle. The difference between the actual and target angle is given by the colour of the large arrows (green is on target, orange is ≥2° and ≤5° either side of the target, red is > 5° either side of the target). The patient aims to align their actual foot progression arrow with the target arrow of the left and right foot separately resulting in green arrows when the actual and target angles are the same. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Faded feedback protocol used during the training program.

	Training time (min)	Feedback time (% of total time)
Week 1	9 (3 × 3 mins)	100
Week 2	12 (3 × 4 mins)	100
Week 3	15 (3 × 5 mins)	100
Week 4	18 (3 × 6 mins)	75
Week 5	21 (3 × 7 mins)	50
Week 6	12 (3 × 4 mins)	25

Training time increased from week 1 to week 5, while feedback time reduced after the third week, according to a faded feedback protocol [3,4,20], as shown in Table 2. This is considered to reduce reliance on feedback and improve retention of the learnt skill [21,22]. Due to additional measurements and time constraints, the total walking time in week six was reduced (unrelated to the faded feedback protocol).

During week one and week six we assessed the FPA difference during four conditions which were always performed in the same order: i) natural walking (no feedback), ii) walking with feedback on the FPA, iii) walking without feedback and iv) walking with a dual-task but without feedback on the FPA.

For the dual task, patients performed the Visual Stroop test [23] whilst walking on the treadmill. Words were displayed on the screen in front of the patient at 2 s intervals. For example if the word "green" appeared on the screen in a red font the response should be "Red". Patients were asked to maintain their modified FPA during the Stroop test, but were not told to prioritize either task.

Between sessions we asked participants to practice using the gait modification and to complete a weekly log book, to estimate a) time spent walking daily, b) time spent consciously using the modification daily (from 1 (not at all) to 4 (all of the time)), c) difficulty of walking with the modification (from 1 (no difficulty) to 10 (extreme difficulty)) and d) the abnormality of the modification (from 1 (completely normal) to 10 (completely abnormal)).

2.1. Data analysis

We post-processed the gait data using BodyMech (www.bodymech.nl), an in-house Matlab based biomechanics software used to calculate