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Movement feedback for gait rehabilitation in individuals with incomplete spinal cord injury and individuals after a stroke

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A non-physiological gait pattern as a consequence of incomplete spinal cord injury or stroke can reduce social participation and cause secondary orthopedic problems, which makes rehabilitation of gait important. As one reason for non-physiological gait is an impaired sensory or proprioceptive function, extrinsic feedback provided by a therapist or a machine is used to promote a conscious normalization of the gait pattern. A own study on individuals with incomplete spinal cord injury and a reduced sagittal knee flexion angle during swing showed that abstract visual feedback of a norm distance value while walking on a treadmill leads to a normalization of this parameter within minutes. The system used for this approach consists of a 3D motion analysis system using passive retroflective markers, a treadmill and a speed-matched database of norm data. Such optical systems are precise, but expensive. They bring about high setup times and restrict therapy to an unnatural environment. Current developments in inertial measuring technology open the way for comparably low-cost gait analysis in a natural environment. Within the project “RehaGait”, a mobile feedback system consisting of 2 shoe-mounted sensors and a tablet PC was developed. Three studies were conducted to generate knowledge to define specifications for such a mobile feedback:

In a *validation study* with 17 able-bodied individuals, the mobile system’s gait event detection latency was estimated in 7 different gait speeds and gait parameter accuracy was calculated using the 3D motion analysis system as gold standard on the treadmill. RMSE and NRMSE were calculated for each gait parameter. The *Audio-visual vs. auditory feedback study* was conducted to test whether purely auditory feedback can compete with audio-visual feedback concerning motor learning with regard to an outdoor use of the system. Two groups with 23 able-bodied individuals trained an artificial gait symmetry movement task on the treadmill. Group AV initially received audio-visual feedback, while group A received only auditory feedback during training. Learning was assessed in retention tests without feedback. In a *mobile feedback proof-of-concept study*, 15 individuals with incomplete spinal cord injury and 11 individuals after stroke trained an individually chosen gait parameter (landing angle, stride length, swing or stance duration) overground under automated verbal feedback by the mobile system, with the aim to normalize this parameter. Training took place on 3 consecutive days; a follow-up analysis took place 2 weeks post training. Each training visit started with a pre-training gait analysis overground. Gait analyses using the treadmill based 3D motion

analysis system were made before and after the training phase. Deviations from a physiological norm were calculated for the mobile system and the 3D system. An end-user satisfaction questionnaire has been filled out by participants.

In the *Audio-visual vs. auditory feedback study*, groups AV and A performed similarly in the first retention test after training, however, AV showed a higher performance in the second retention test on the second day, according to visual inspection, respectively. There was a trend for influence of the factor “group” (ANOVA, $p = 0.0637$). In the *mobile feedback proof-of-concept study* changes in the trained parameter over the pre-training gait analyses ($p < 0.0001$, Friedman’s Test) were found. Post-hoc tests revealed a normalization from visit 1 to visit 2, and from visit 1 to visit 3 ($p < 0.001$, respectively, paired Wilcoxon Test). Gait analyses using the 3D system revealed an increase in average norm distance of hip- knee and ankle angle joint trajectories when individuals were asked to walk with the pattern they learned, relative to the following gait analysis when asked to walk as usual ($p < 0.0001$, paired Wilcoxon Test). Individuals reported self-perceived therapeutic effects and general positive attitude towards feedback design.

The mobile system was validated successfully. A feedback latency < 200 ms provides a real-time experience, the good match of gait parameters with the gold standard shows good measuring accuracy. High RMSE for lifting angles can be explained by detection time differences of final contact events. Although audio-visual feedback seemed to have an advantage in medium-term learning, auditory feedback was implemented in the mobile system due to safety reasons. To foster understandability, a verbalized feedback was chosen. The normalization observed in the *mobile feedback proof-of-concept study* in the training parameter and the positive results in the questionnaire suggest a general feasibility of mobile feedback therapy in individuals after incomplete spinal cord injury or stroke. While increases in norm distance during reproduction of the trained pattern observed with the 3D system may point to trick movements in proximal joints, a lack of familiar walking aids on the treadmill and changed kinetics may have posed an additional challenge.

Mobile overground feedback therapy is a feasible approach to normalize a selected gait parameter in individuals with non-physiological gait after incomplete Spinal cord injury and stroke. Future studies should monitor multiple joints and capture long-term motor learning.