Exploratory Locomotor Actions Revealed by Experimental Pain

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Summary

Our wearable system links knee kinematics to painful stimuli to study motor adaptation. Through exploration of knee joint motion most participants solved the movement-pain relationship when tasked, but few did spontaneously.

Introduction

Adapting our motor actions to new environmental and internal challenges is fundamental to life. Locomotor control is no exception as it allows for navigation and foraging but often requires adjustments to accommodate changing terrain, disease, injury or pain. Indeed, pain is a strong driver of motor adaptation [1]. This study builds on our previously developed experimental pain model [2] by enabling participants to modulate the perceptions of pain based on knee kinematics, in real-time. Our primary objectives were to 1) demonstrate real-time modulation of pain intensity by knee kinematics and 2) gain insight into the solvability of spontaneous and goal-directed locomotor adaptation to movement-evoked pain.

Methods

Nine healthy adults participated in the study (age=24±2 years, female=5). We collected lower body kinematics – focusing on knee flexion angle (KFA) – and knee pain intensity (numerical rating scale 0="no pain", 10="worst pain imaginable") while participants walked with and without experimental knee pain with an upper limit of 5/10 pain.

Stimulation magnitude was linearly mapped to KFA with no pain at ≥0° KFA and 5/10 pain if the KFA was below the mean min KFA during baseline walking. A 10Hz sinewave was passed to a constant current electrical stimulator connected to surface electrodes placed over the infrapatellar fat pad of the dominant limb's knee. Lower body kinematics were tracked with inertial measurement units (IMU; MPU9250) on the pelvis, shank, thigh, and foot and wired to a portable I/O unit running custom LabVIEW software (200 Hz) to compute KFA and modulate stimulation magnitude. IMU orientations were mapped to limb segments with a functional calibration.

Participants experienced three walking conditions starting with baseline walking (BASE) without pain (4 min). Next, experimental pain was mapped to knee angle (NAÏVE) without instruction (2 min) to evaluate spontaneous locomotor adaptation. This was followed by the same condition but with the explicit task of minimizing their perception of pain (GOAL) to examine the solvability of the movement-evoked pain condition. Participants were not informed of the pain and knee angle mapping at any point. We quantified adaptation by a mean KFA change >3SD from BASE [3] and a reduction in pain intensity at the end of the walk compared to the start (5/10). Less similar kinematics in the experimental pain conditions compared to BASE suggest exploratory or adaptive movement, quantified using normalized, windowed dynamic time warping (DTW; larger values=less similar).

Results and Discussion

Our system modulated pain based on KFA (Fig 1). Only one participant spontaneously adapted (NAÏVE) without prompting. Compared to the BASE mean KFA (-18.9°±3.4), participants did not adapt (paired t-test; t=-0.64, p=0.54) in the NAÏVE (-18.6°±3.4) and pain remained high (4.1±1.2) by the end of the bout. When tasked with solving the movement-pain condition (GOAL), all but one participant modified their KFA >3SD (t=-4.9, p=0.001) with a group mean of -10.0°±6.3 and lower pain by the end of the condition (0.4±0.4). These results align with previous locomotor adaptation to metabolic cost [3]. It is plausible that higher pain intensity is needed to induce spontaneous adaptation. With respect to BASE, the GOAL condition (DTW: 98.7±14.0) had significantly higher DTW (W=1.0, p=0.009) than NAÏVE (DTW: 82.5±6.7), indicating less similarity, again highlighting the limited spontaneous adaptation but that the movement-pain condition was readily solvable without explicit knowledge of the solution.

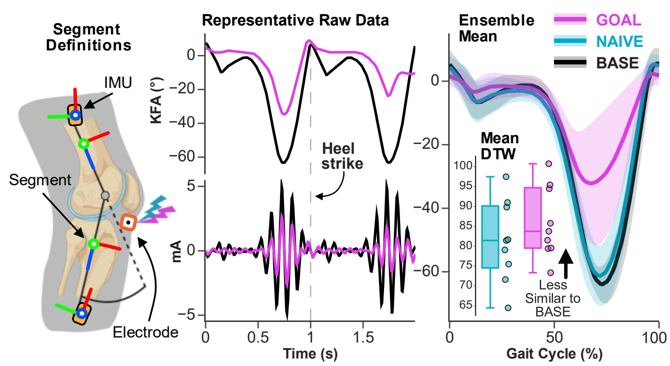

Figure 1: Experimental setup, raw data showing real-time modulation of pain, locomotor adaptation with GOAL.

Conclusions

Our wearable, real-time movement-evoked pain system produced marked motor adaptation and highlights the solvability of movement-pain relationships when a goal-oriented framework is implemented.

Acknowledgments

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References

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