Increased Signal Noise Results in Altered Postural Control Behaviour Associated with Parkinson's Disease

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Summary

Underlying processes of postural control and their alterations due to neurological disorders, such as Parkinson's disease (PD), are still not fully understood. In this paper, we investigate the influence of signal noise on postural control behavior and whether changes due to increased noise ratios are comparable to alterations observed in movements of PD patients. By applying predictive neuromusculoskeletal simulations, we detected adaptions of biomechanical sway parameters comparable to observations within our experimental data of PD patients and control participants.

Introduction

Postural control represents a complex process where the body aims to maintain balance by initiating specific muscle reactions controlled by the central nervous system. Neurological disorders, such as Parkinson's disease (PD), can lead to an impaired postural control behavior and postural instability. However, underlying processes of both, physiological as well as impaired postural control due to PD are still not fully understood. In this paper, we investigate whether elements of altered postural control of PD patients can be explained by an increased motor signal noise.

Methods

We used a previously published neuromusculoskeletal model [1] and forward-dynamic simulations within the software framework SCONE [2] and Hyfydy [3]. We applied this model to simulate postural control of unperturbed upright standing. The model consisted of 18 muscles and effectively six degrees of freedom assuming left-right symmetry. Internal signal noise was added to the motor signals that were determined by the model's neural controller for every time step. The muscle activation u was defined as a combination of the ideal muscle activation u' and an additional noise element:

$$u(t) = u'(t) + k_n(t) \cdot R(t)$$

$$k_n(t) = n_c + n_p \cdot u'(t)$$

The amount of noise was defined by k_n and a randomly generated Gaussian-distributed number R. k_n consisted of a constant element $n_c \in [0.00; 0.03]$ as well as a signal-dependent element $n_p \in [0.00; 0.20]$. We gradually increased these signal noise elements n_c and n_p to test our hypothesis that increased motor signal noise leads to PD associated motion behavior.

To evaluate the results, we compared the simulation results with average experimental data from 31 PD patients and 31 age- and sex-matched healthy control participants (HCs).

Results and Discussion

We found that biomechanical sway parameters such as center of pressure (COP) ranges and hip angle ranges of motion (ROMs) increased with higher noise ratios. The detected trends with increasing signal noise showed to be in accordance with trends between HCs and PD patients we observed in experimental data (Figure 1). Also, additional sway parameters were evaluated and represented comparable trends to our study data. Especially n_c showed to affect resulting parameters considerably. Further, we hypothesize that effects of n_p will gain importance in movement tasks demanding higher muscle activations compared to unperturbed upright standing. Even though these findings result in PD-associated movement alterations, it is important to consider that other elements within the postural control circuitry, such as prolonged neural delays, could cause similar changes.

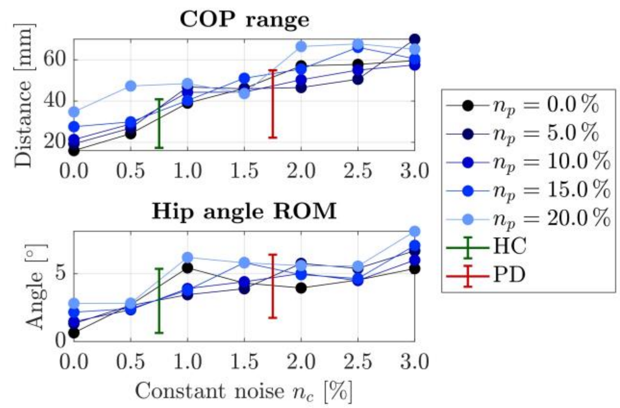

Figure 1: Results of exemplary biomechanical sway parameters depending on signal noise. Experimental data of HCs and PD patients are represented for comparison.

Conclusions

We showed that increasing signal noise results in adaptions of postural control behavior comparable to alteration that can be associated with PD. However, simulations with additional movement tasks are necessary to verify these findings.

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