Activity Plan

Design of a closed-loop wearable assistive device to prevent loss of balance

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Introduction

The current research activity is carried out in the framework of the PRIN 2022 project "**REBALANCE - REinforcing BALANCE with a neurally-driven wearable assistive device**".

The project aims to reduce falls and related healthcare and social costs in older adults [Haagsma et al, 2020]. To tackle this pressing problem, two top-end Italian universities (UNIBO and UNIPD) will collaborate to develop an innovative, low-cost, neurally-driven, wearable assistive device (WAD) to prevent loss of balance (LoB), a prodromal sign of an incipient fall, in ecological environments. In this project, the WAD will be deployed as a rehabilitative tool in conjunction with an active balance board to reinforce balance control based on individual cerebral, muscular, and kinematic responses.

Knowledge Gaps

This project will contribute to fill two main knowledge gaps:

1) BIOMECHANIC STABILIZATION STRATEGIES. Two main strategies emerge in response to balance perturbations in healthy adults: ankle and/or hip strategy [Baston et al, 2014]. Older adults show larger kyphosis, more posterior hip position, and tend to lean forward. Antero-posterior limits of stability are decreased, and this translates into an over-reliance on the hip joint during an upright stance [Berg et al, 2009]. Older subjects have more rigid hip joints and demonstrate minimal hip angle change during Achilles tendon vibration during postural perturbations [Abrahamova et al, 2009] and respond to perturbation demands on a treadmill by modulating EMG amplitude instead of EMG onset timing. This suggests that hip joint control may be important for stabilizing posture in older subjects; older subjects likely compensate for LoB by stiffening instead of using a hip strategy. The role of the hip joint in postural stabilization in older adults is still disputed: we will understand if reducing stiffness and increasing hip modular control can improve balance and reduce the number of LoB during unexpected perturbations. This knowledge may pave the way for innovative hip wearable assistive devices.

2) REHABILITATION PARADIGMS with a controlled platform and WEARABLE ASSISTIVE DEVICE (WAD) to strengthen balance strategies. Conventional rehabilitative interventions based on robots and virtual reality facilitate cognitive and sensorimotor recovery by supporting and motivating participants. WADs are promising task-oriented tools for rehabilitation in highly compromised individuals but have not been systematically used for fall prevention. This is due to technical challenges, lack of ergonomic designs, elevated costs of conventional WADs, and limited knowledge of the optimal control strategies to implement. We envision a WAD prototype with characteristics that allow both rehabilitation sessions in a controlled environment and the ensuing evolution, in future research, as an assistive device for daily activities. Balance rehabilitation, up to now, has not been based on the principles of neural plasticity. This project will contribute to developing a novel experimental paradigm and a WAD building on the complex interaction of neurophysiology and biomechanics to strengthen the neuromuscular networks responsible for balance.

Project activities

This project will primarily contribute to activities foreseen in Phase II and III of the REBALANCE project, particularly the design, implementation, and validation of a hip WAD and a neurophysiological interface for

LoB prediction based on the data and knowledge gathered during Phase I. These two technologies will be then integrated into a closed-loop wearable assistive device.

Methods

The WAD aims to provide a suitable set of torque patterns at the hip joints to increase the interaction with the ground and stabilize the body Center of Mass (CoM) [Monaco et al, 2017]. When activated by the control system, the WAD, embedded in a light wearable frame connected at its extremities to the thigh and pelvis, will apply a braking torque. The connection system will be similar to commercial orthotic components: different solutions will be considered to obtain a rigid though comfortable connection, avoiding any relative motion between the limb and the device. To overcome the overall complexity of designing and developing an active lower limb exoskeleton [Seo et al, 2018], a mechanism based on clutches or visco-elastic elements will be devised. The resistive effects will be designed in accordance with the biomechanical strategies identified in Phase I against the LoB induced by the perturbing paradigm.

The WAD will be designed to be used inside the lab for a rehabilitation training program and, in future development, outside the lab (ecological environment) as an assistive device for daily activities.

The WAD will work in two modalities:

- free mode, with the WAD transparent to the subject’s body;

- assistive mode, with the control law of the WAD acting to reinforce the user’s biomechanical balance strategy.

When a LoB is detected, the control system triggers the brake, and a torque is applied to the hip by contributing to restoring balance. Different braking solutions will be investigated for the best compromise between the device’s dimensions and promptness. The WAD will be integrated with the neurophysiological module developed by UNIPD.

In its final stage, the project will also contribute to analyzing the experimental data collected during Phase III to validate the integrated set-up.

Expected results

- WAD mechanical design and construction
- Control law definition and implementation
- WAD experimental testing and clinical validation

References

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