MODULAR CONTROL OF HUMAN MOVEMENT: ADAPTATIONS TO ALTERED MECHANICAL DEMAND

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INTRODUCTION

Walking requires the coordination of a complex dynamic musculoskeletal system with highly non-linear intrinsic properties. Recent studies analyzing myoelectric (EMG) activity have provided evidence that the neuromuscular system may use a reduced control strategy based on modular activation of synergistic muscle groups [1,2]. Similar modular patterns have been identified using a number of statistical approaches across a wide range of locomotor activities, suggesting that these patterns may be fundamental neural control elements in human walking [1-3].

Recently, Neptune et al. [4] used experimentally derived activation modules to drive a forward dynamic simulation of normal walking. The results of that study showed that individual modules are associated with specific walking sub-tasks such as body support, forward propulsion and leg swing. In the present study, we test the robustness of the modules to perform other walking tasks by altering the mechanical demands on the system to asses whether simple scaling of existing modules is sufficient to produce the walking motions.

METHODS

Experimental data associated with the altered mechanical demands were collected in a previous study [5]. In addition to a control trial, subjects walked with added trunk loads (increasing both weight and mass: +W&M), with weight support (decreasing weight only: -W), and with a combination of equal added trunk weight and weight support (resulting in increased mass only: +M). Each perturbation was preformed at 25% of the subject's body weight for a total of 4 conditions.

Simulations of the experimental conditions were developed using a previously described 2-D bipedal musculoskeletal model [e.g., 4] using SIMM (MusculoGraphics, Inc.). The model consisted of rigid segments representing the trunk and two legs, with 13 total degrees of freedom and 26 Hill-type musculotendon actuators per leg. Ground contact was modeled using viscoelastic elements attached to the bottom of each foot. The equations of motion for the model were generated using SD/FAST (PTC).

Four previously derived excitation modules were used to drive synergistic muscle groups [4]. These modules consisted of the hip and knee extensors (Mod. 1), ankle plantar flexors (Mod. 2), tibialis anterior and rectus femoris (Mod. 3) and the hamstrings (Mod. 4). A fifth module driving the illiopsoas (Mod. 5) was modeled using a block excitation pattern due to lack of experimental EMG data. An optimization algorithm was used to fine-tune timing and magnitude of the module patterns to best reproduced the group averaged experimental data (ground reaction forces, kinematics and joint torques) for each condition. Ground reaction force decomposition and segment power analyses were used to examine the contributions of each muscle module to specific walking subtasks.

RESULTS AND DISCUSSION

Primarily through changes in module magnitude, excitation patterns were found which successfully reproduced the experimental data for all conditions. Consistent with previous studies [4], we found that Mod.1 acts to provide body support in early stance, while Mod. 2 acts to provide forward propulsion and body support in late stance. Modules 3-5 all contributed to leg swing. Consistent with these functional roles, contributions to the vertical ground reaction force and/or vertical trunk work from both Mod. 1 and Mod. 2 increased (decreased) in response to changes in body weight (Fig. 1A; +W&M and –W conditions). Mod. 2 also increased positive horizontal trunk work in response increases in body mass (Fig. 1B; +W&M and +M conditions). Increases in weight and mass (+W&M and +M) also increased the amount of power transferred from the leg to the trunk, predominately through Mod. 2. The experimental conditions did not substantially alter the mechanical output from Modules 3-5, likely because the perturbations were made to the trunk.

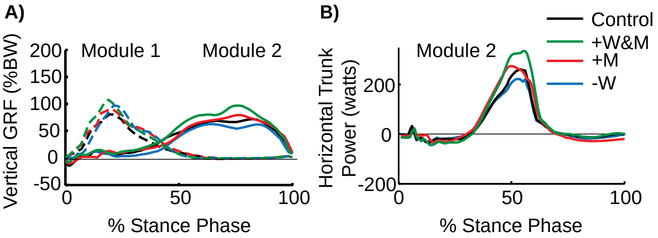

Figure 1. Individual module contributions to A) vertical ground reaction force and B) horizontal power during each condition.

CONCLUSIONS

Our results show that the module control framework is robust over a range of walking tasks. Despite substantial differences in mechanical demand, simply scaling the five module patterns was successfully able to reproduce walking patterns. Our results also indicate that the modules which perform specific subtasks during normal walking are modulated to meet increases in demand for specific tasks.

REFERENCES

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