Intelligently Controlled Assistive Rehabilitation Elliptical (ICARE) Training: An Analysis of Lower Extremity Electromyographic (EMG) Demands with Varying Levels of Motor Assistance

Judith M. Burnfield, PhD, PT,[1] Thad W. Buster, BS,[1] Adam Taylor, BS,[1] Scott Keenan, MA,[2] Yu Shu, PhD,[1] Carl A. Nelson, PhD[3]

[1]Institute for Rehabilitation Science and Engineering, Madonna Rehabilitation Hospital

[2]Creighton University

[3]University of Nebraska-Lincoln

ABSTRACT

The ability to engage in appropriately challenging physical activity is essential to promote muscle strengthening and cardiovascular fitness in individuals with and without disabilities. This presentation highlights select biomechanical findings from the second year of a project aimed at developing ICARE, an affordable Intelligently Controlled Assistive Rehabilitation Elliptical trainer and therapeutic program to help individuals with disabilities regain walking ability and physical fitness in healthcare settings and community based fitness facilities. In particular, an intelligently controlled motor system was added to a commercially available elliptical trainer. The impact of three levels of motor assistance on lower extremity muscle demands (lateral hamstrings, vastus lateralis, gastrocnemius and tibialis anterior) was assessed.

Keywords:

electromyography, lower extremity, gait, exercise, physical disability

BACKGROUND

Regaining walking capacity and cardiovascular fitness are of critical importance to many clients in physical rehabilitation and these goals continue following discharge.[(7), (8)] Although novel treatments such as partial body weight support treadmill training and robotic therapy are available for use across the rehabilitation continuum,[(4), (6), (9)] extensive use is limited in part due to the expenses associated with purchasing the equipment and delivering the interventions. In the community, individuals with physical disabilities also face barriers to affordable and accessible training equipment.[(5), (11)] For example, elliptical trainers as designed by manufacturers, do not have the ability to adapt to and assist movements for individuals with weakness, joint pain or movement initiation problems. This is unfortunate because the similarity of movement patterns and muscle demands between walking and elliptical training suggest that beyond serving as an exercise tool, elliptical trainers could help people regain the strength and flexibility required for walking.[(1), (2), (3)] This presentation will summarize key findings from the second year of a three-year grant aimed at developing a financially affordable ICARE (Intelligently Controlled Assistive Rehabilitation Elliptical) trainer and therapeutic program to help physically challenged individuals regain or retain their walking ability and physical fitness in healthcare and fitness settings. Our objective during the first year was to identify the optimal elliptical trainer to redesign into the ICARE trainer based on accessibility and usability by persons with disabilities and the extent to which the elliptical trainer's movement patterns simulated normal gait.[(2)] Our objective during the second year was to develop, pilot test, and refine a prototype ICARE device in a controlled (laboratory) environment to optimize function, features, walking biofidelilty, and equipment durability. Seven adaptations were developed for the ICARE trainer based on feedback from individuals with and without disabilities. One modification included adding an intelligently controlled motor capable of generating sufficient torque to move the pedals at a constant speed while clients used the device. This modification was developed to enable individuals with lower extremity muscle weakness and/or reduced endurance to elliptical train. In this presentation, we highlight the impact of three levels of motor assistance on the lower extremity muscle demands experienced by 15 individuals while using the ICARE trainer at two predetermined speeds (25 and 60 revolutions per minute, RPM). We hypothesized that at each pre-selected training speed, the muscle demands occurring during the Active Assist mode (i.e., with the motor fully engaged) would be diminished compared to the Active Assist Plus and Resistive modes (the latter two modes reflected decreased levels of mechanical motor engagement).

METHOD

Fifteen adults participated. Five had chronic diseases or physical disabilities (e.g., diabetes, traumatic brain injury, amputation, and arthritis), while the remainder had no known disability. All were able to walk independently. Two used some form of assistive device. One individual used a transfemoral prosthesis and one required both a transtibial and a transfemoral prosthesis.

The elliptical trainer selected for study was the SportsArt Fitness E870.[(2)] The elliptical trainer was modified by adding a motor and control system that allowed for speed control and the ability to generate sufficient torque to move the pedals at pre-selected speeds as participants trained. In addition, modifications were added to enable greater ease of access and safety while using the device. The modified elliptical trainer was called "ICARE".

To determine the impact of the ICARE motor assistance on muscle demands, simultaneous recordings of electromyographic data (surface EMG of lateral hamstring, vastus lateralis, gastrocnemius and tibialis anterior; 1200 Hz) and elliptical trainer kinematics (12-camera motion analysis; 120 Hz) were performed as participants elliptical trained at two pre-selected speeds: 25 RPM (representative of a speed likely to be used by more physically disabled individuals during the early phases of recovery) and 60 RPM (representative of a speed possibly achieved during the latter stages of rehabilitation). Training velocity (RPM) was confirmed from the visual display provided on the SportsArt. Within each training speed, three motor conditions were assessed. In the first motor condition, Active Assist, the motor provided adequate force to help the client's legs move at the targeted speed. During this condition, participants were instructed to let the machine "guide your legs". In the Active Assist Plus mode, the motor disengaged whenever the client's speed exceeded the motor's threshold speed. Clients were asked to exert effort at a level that would maintain their elliptical training speed at 2 RPM higher than the targeted speed. Thus if the motor speed was set to 25 RPM, then participants pursued a target speed of 27 RPM. In the Resistive mode, the motor was not engaged and thus provided no physical assistance as participants trained at the 25 RPM and 60 RPM target speeds. Friction from the disengaged motor belt contributed additional resistance to the movement. All three training modes were performed at the participant's self-selected stride length, which remained constant across conditions. Participants were allowed up to five minutes for rest between each activity.

EMG data recorded during the final 30 seconds of a two-minute trial were used for subsequent analysis. The lateral hamstrings, vastus lateralis, gastrocnemius and tibialis anterior were selected for analysis as clinicians often focus on improving capacity of these muscles due to their role in providing controlled forward progression, stability, and limb clearance during gait.[(10)] EMG data were normalized to a maximal voluntary contraction recorded for each muscle and expressed as a percentage maximal voluntary contraction (% MVC). Reflective markers, placed on each device's footplates, defined movement cycle timing. A full movement cycle was demarcated as the period from the most anterior location of the reference limb's footplate marker to the next ipsilateral most anterior location of the marker. For each participant, at least seven, but no more than ten cycles per condition were used to calculate EMG variables (peak and duration of activity).

Descriptive statistics were performed for key variables using SigmaPlot 11.0 software. Within each training speed, separate one-way analyses of variance with repeated measures (3 x 1 ANOVAs) identified significant differences in EMG variables (peak, duration) across motor conditions (i.e., Active Assist, Active Assist Plus, and Resistive). When assumptions of normality were violated, Friedman's ANOVA on ranks was used to identify significant differences. Bonferroni adjustments accounted for multiple comparisons. Specifically, statistical significance was define as $P<0.05/n$, where n signified the number of variables analyzed within each family of data.

RESULTS

Peak muscle demands varied substantially across training modes. The greatest peak muscle effort occurred in the vastus lateralis when training at 60 RPM in the Resistive mode (average peak = 61% MVC), while the lowest effort was documented in the lateral hamstrings when training at 25 RPM in the Active Assist mode.

25 Revolutions Per Minute (Figure 1)

Peak muscle demands at 25 RPM were significantly lower during Active Assist training compared to the Active Assist Plus and Resistive modes for the lateral hamstrings (p=0.007), vastus lateralis (p<0.001), and tibialis anterior (p<0.001). Additionally, the duration of tibialis anterior muscle activity was briefer during the Active Assist compared to the Active Assist Plus and Resistive modes (p<0.001). No other significant differences were identified at the 25 RPM training speed.

Figure 1. Influence of training mode (Active Assist, Active Assist Plus, and Resistive) on lateral hamstring, vastus lateralis, gastrocnemius and tibialis anterior muscle activity when training at 25 RPM.

60 Revolutions Per Minute (Figure 2)

Peak muscle demands at 60 RPM were significantly lower during Active Assist training compared to the Active Assist Plus and Resistive modes for the vastus lateralis (p<0.001) and tibialis anterior (p=0.005). Muscle activity duration did not vary significantly across any of the conditions and no other differences in peak amplitude were identified at the 60 RPM training speed.

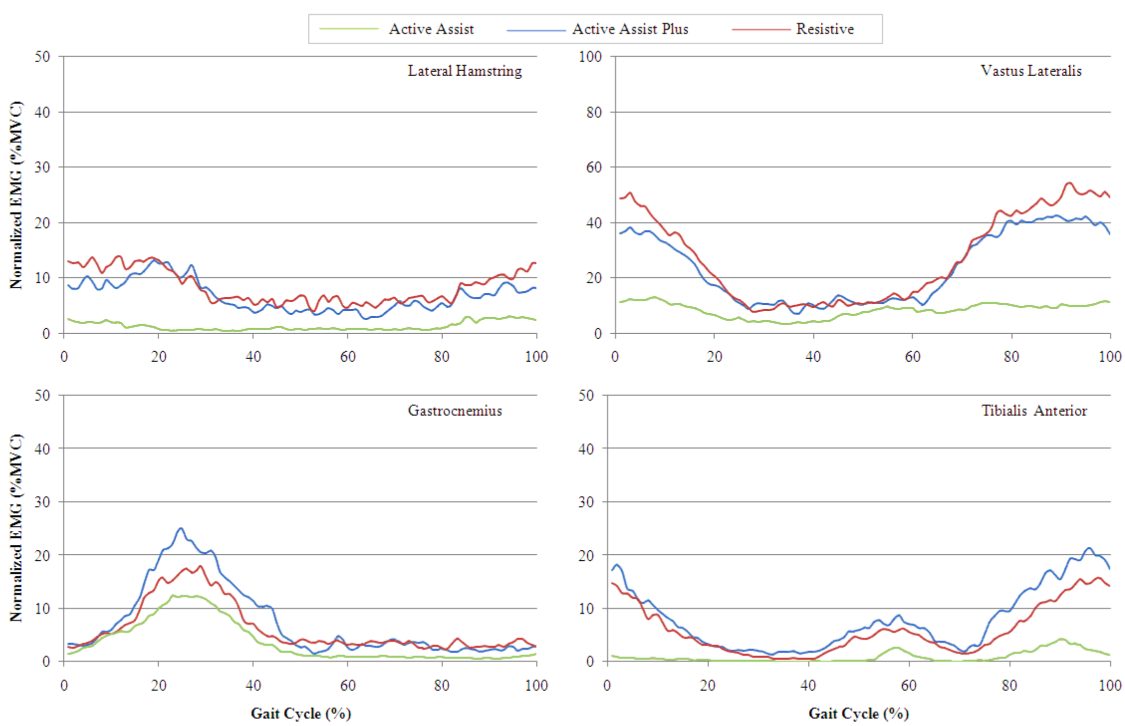

Figure 1: Influence of Training Mode on Muscles at 25RPM

DISCUSSION

Individuals with physical disabilities often face barriers to participating in community based fitness programs, in part due to a lack of accessible exercise equipment that provides an appropriately challenging level of resistance to key muscles. The focus of this study was to assess whether an intelligent motor system could be added to a commercially available elliptical trainer and used to modify the demands placed on an individual's muscles while elliptical training.

Consistent with the initial hypothesis, peak muscle demands were lower during the Active Assist mode compared to the more challenging Active Assist Plus and Resistive modes in five of the eight conditions assessed, and three of the four muscles evaluated. Only peak gastrocnemius activity failed to demonstrate a significant reduction in activity during the Active Assist training. It is possible that the constrained self-selected stride length in combination with continuous double limb support across the training modes prevented any further significant reduction in calf muscle activity. Our previous work demonstrated a diminished demand on the calf muscles

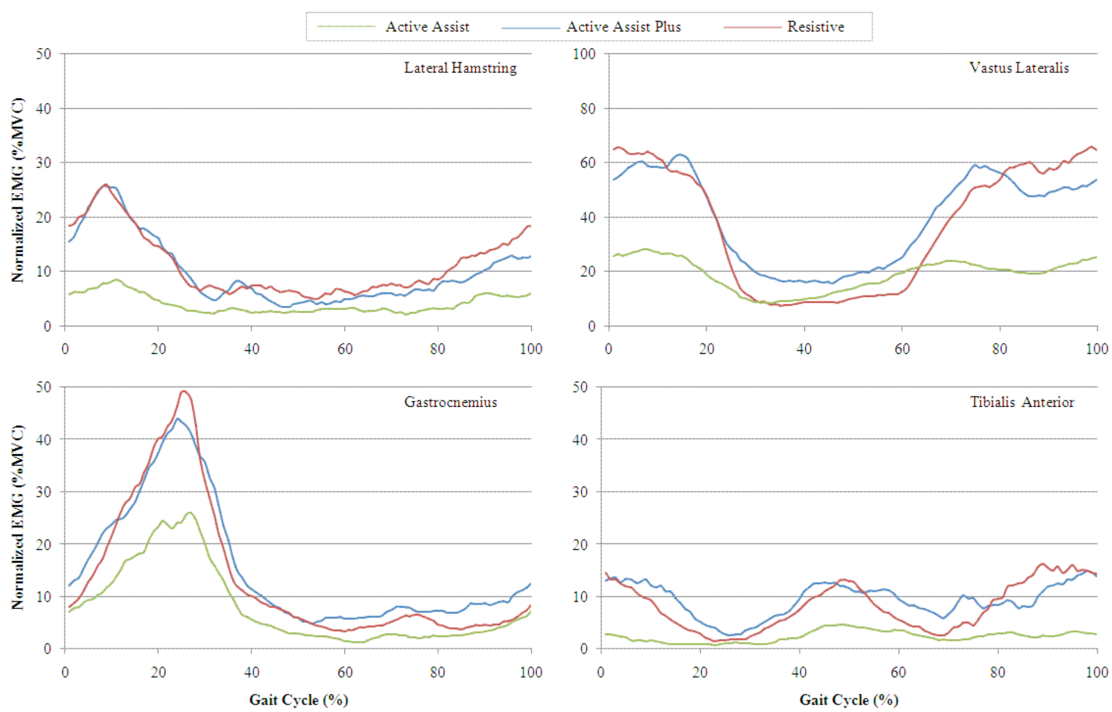

Figure 2. Influence of training mode (Active Assist, Active Assist Plus, and Resistive) on lateral hamstring, vastus lateralis, gastrocnemius and tibialis anterior muscle activity when training at 60 RPM.

during elliptical training compared to gait.[(2)] In this earlier study, we hypothesized that the calf demand was reduced because of the lack of a single limb support period during elliptical training.

The duration of muscle activity varied significantly only in the tibialis anterior at the slowest speed (25 RPM). The briefer tibialis anterior duration encountered at the slowest speed during the Active Assist mode, reflected the reduced demand on the muscle. Tibialis anterior typically assists with foot clearance during swing limb advancement and controlled foot lowering during weight acceptance. The continued periods of double limb support encountered during elliptical training reduced the need for sustained tibialis anterior activity throughout the elliptical training movement cycle.

Collectively, the peak and duration findings from the current study suggest that the addition of an intelligent motor system did provide a greater range of lower extremity muscle demands. The ability to customize elliptical trainer demands to the unique needs of individuals recovering from a physical disability should help reduce the barriers individuals face when trying to use an elliptical trainer in the community. The findings from this work, in combination with our previous findings highlighting similarities in kinematic patterns between elliptical training and walking,[(2)] suggest that the ICARE trainer may provide a therapeutic tool for helping individuals regain strength and movement ability in muscles required for gait. Further work is currently underway to assess the feasibility of using the ICARE trainer in an inpatient rehabilitation setting, outpatient rehabilitation setting and community-based fitness facility.

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