2011

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Physical Therapy Journal of the American Physical Therapy Association

Phys Ther. 2011 Nov; 91(11): 1604–1617.
Published online 2011 Sep 1. doi: 10.2522/ptj.20100332: 10.2522/ptj.20100332

PMCID: PMC3367158
PMID: 21885449

Impact of Elliptical Trainer Ergonomic Modifications on Perceptions of Safety, Comfort, Workout, and Usability for People With Physical Disabilities and Chronic Conditions

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Received 2010 Oct 5; Accepted 2011 Jun 19.

Abstract

Background

The popularity of elliptical training has grown in rehabilitation, fitness, and home settings as a means for improving fitness and walking, yet many people with physical disabilities and chronic conditions experience difficulties when trying to use elliptical trainers.

Objective

The purpose of this study was to compare, for people with disabilities and chronic conditions, perceptions of safety, comfort, workout, and usability of 4 elliptical trainers before and after the development of a set of low-cost adaptations.

Design

This study was a quasi-experimental repeated-measures investigation.

Methods

Twenty adults with diverse medical conditions and functional abilities evaluated 4 elliptical trainers for safety, comfort, workout, and usability. Barriers to the use of the elliptical trainers and solutions to improve the use of the trainers were identified. Prototype modifications were designed, and participants reassessed the same features after the modifications were made.

Results

An integrated system (steps, bench, side rails, center rail or handle, deeper foot wells, and 1-handed heart rate monitor) was developed. Although at least 25% of participants required physical assistance to get on or off the elliptical trainers before modification, only one required this after modification. Before modification, only 1 participant was able to mount each device independently; after modification, 6 to 8 participants were able to do so. Up to 25% of participants continued to require assistance to initiate or sustain pedal movement. Compared with participants' ratings of the elliptical trainers before modification, those after modification were higher for safety (55% increase in visual analog scale ratings), comfort (43% higher), ability to achieve a good workout (23% greater), and usability (24% increase).

Limitations

To date, only 4 elliptical trainers have been studied with a small sample of convenience.

Conclusions

Elliptical trainers posed access challenges to people with disabilities, chronic conditions, or both. Implementation of low-cost modifications successfully reduced barriers and the need for assistance, enabling greater access for people who could benefit from using the devices for functional training and fitness.

Walking and maintaining cardiovascular fitness are important to many people with chronic conditions and physical disabilities. Unfortunately, a lack of affordable and accessible equipment can make it difficult for people with special needs to pursue optimal treatment programs in health care settings, community-based fitness facilities, and homes.[1–5]

Despite the development of several effective gait technologies to improve walking and fitness, many people are not able to access these options. Partial-body-weight–supported treadmill training (PBWSTT) is a frequently cited innovation[6–10]; however, it is not universally available, partly because of the costs associated with the equipment and the use of multiple therapists to guide body movements during training. Additionally, providing the assistance needed can be physically challenging for clinicians and can pose a risk for injury.[11] Recent advances in robotic gait trainers address some of the challenges associated with PBWSTT[12]; however, the expense (~$100,000–$275,000 [US dollars]) prohibits practical use in many clinics and hospitals.

The impact of equipment limitations extends beyond hospitals and into the community. Many people with activity limitations find it difficult to use fitness facilities because the equipment is inaccessible.[1–5,13,14] This situation is unfortunate because even moderate levels of sustained physical activity can help prevent or delay the onset of other chronic conditions[2,15–22] and lessen declines in function linked to inactivity.[2,15–20,22–26]

Elliptical trainers (also called cross-trainers) are widely available in fitness centers as well as many health care and home settings. The documented similarities in the movement patterns and muscle demands of elliptical training and walking[27] suggest that beyond serving as an exercise tool, elliptical training could help people regain the strength and flexibility required for walking.[28] Unfortunately, many people with weakness, pain, and balance and movement control problems find it difficult to access and use elliptical trainers.

The purpose of the present study was to systematically evaluate and reduce the barriers that people with various physical disabilities and chronic conditions experience when trying to use commercially available elliptical trainers. Given notable variations in design features across elliptical trainers, we decided to evaluate multiple devices to better understand the challenges that would be experienced across different designs. Information obtained from participants guided the development of a set of affordable modifications aimed at increasing the safety, comfort, workout, and usability of each elliptical trainer. We hypothesized that participants' perceptions of the safety, comfort, workout, and usability of the unmodified elliptical trainers would vary across devices with different design features and that a set of low-cost modifications could be implemented to improve safety, comfort, workout, and usability for people with various disabilities and chronic conditions. Given that many older adults and people with activity limitations seek to maintain or regain walking ability and fitness, identifying strategies that break down barriers to using this therapeutically promising equipment is warranted.

Method

Participants

Twenty adults with different levels of functional ability were recruited from Madonna Rehabilitation Hospital and the surrounding community to participate in evaluating the safety, comfort, workout, and usability of 4 elliptical trainers. To ensure a wide variety of impairments in strength, flexibility, movement control, balance, and joint pain, we specifically sought people with various medical conditions, including cerebral palsy, diabetes mellitus, hemiparesis, hip fracture, multiple sclerosis, osteoarthritis, Parkinson disease, lower-limb amputation, and traumatic brain injury (Tab. 1). We believed that the diversity represented by this group would provide important insights into the challenges that people with various physical limitations and chronic conditions experience when using elliptical trainers.

Instrumentation

Four commercially available variable-stride-length elliptical trainers were selected for evaluation (SportsArt Fitness E870, SportsArt Fitness, Woodinville, Washington; Life Fitness X7, Life Fitness Corp, Schiller Park, Illinois; True Fitness Technology TSXa, True Fitness Technology, St Louis, Missouri; and Octane Fitness Pro4500, Octane Fitness, Brooklyn Park, Minnesota); hereafter, these are referred to as SportsArt, Life Fitness, True, and Octane, respectively. As determined from an initial observational analysis and a subsequent biomechanical assessment,[27] each device promotes a movement pattern similar to gait. All of the devices have static handles. In addition, each device has a set of dynamic (nonfixed) handles that move reciprocally with leg motion (ie, if the right foot is posterior, then the right hand is anterior). The pedals and dynamic handles move freely within a predefined path of movement and contain no locking mechanism to prevent movement during mounting and dismounting. However, many other design features vary notably across the devices, such as the direction of mounting (side or rear entry), adjustable stride range, height of the pedals from the ground, height of the raised edge on the pedal, location of heart rate sensors, overall space requirements (footprint), and manufacturer's suggested retail price (Tab. 2).

Questionnaire data were recorded with a Motion Computing T003 Tablet PC (Motion Computing Inc, Austin, Texas) and Select Survey Version 2.3.4 software (ClassApps.com, Overland Park, Kansas) customized to address the specific question formats used in the present study. These included open-ended questions requiring short-answer text responses, 10-cm visual analog scale (VAS) ratings (level of precision=0.1 cm), and multiple-choice responses. Previous survey instruments, such as traditional occupational injury questionnaires (eg, the Standard Nordic Questionnaire)[29,30] and measures used to investigate barriers experienced by people with disabilities in fitness and recreation facilities,[31,32] did not meet the present study's need for unique questions specifically related to elliptical training and equipment modifications. Therefore, we adapted a survey questionnaire that our team previously used to evaluate the perceptions of 60 people (including people with and without disabilities) regarding safety, comfort, workout, and usability of 13 pieces of cardiovascular and strength training equipment. Questions were modeled after traditional Usefulness, Satisfaction, and Ease of Use[33] and VAS[34,35] survey instruments. Input from people with disabilities, fitness trainers, physical therapists, and a clinical psychologist guided the development of the questions and the anchors used for the VAS.

Procedure

The research study and informed consent form were approved by the Institutional Review Board at Madonna Rehabilitation Hospital, and all testing occurred at Madonna Rehabilitation Hospital's Institute for Rehabilitation Science and Engineering. After signing an informed consent form, each participant engaged in a minimum of 2 and a maximum of 4 sessions to experience all 4 elliptical trainers both before and after modification. The number of sessions varied because of the participants' endurance and scheduling availability. Although each initial session involved familiarization with and use of all 4 unaltered elliptical trainers, the final session always focused on the use of the 4 modified elliptical trainers. The order of use of the elliptical trainers was randomized during assessments of the unaltered and adapted elliptical trainers by use of a random-number generator program in MATLAB (The MathWorks, Natick, Massachusetts). Participants were provided with opportunities to rest throughout the sessions to reduce the potential impact of fatigue.

Clinical screening of participants and familiarization with and assessment of unaltered elliptical trainers. During each initial session, participants completed paperwork, participated in a brief clinical evaluation, were familiarized with the features of each elliptical trainer, and used and provided feedback on each device in its unaltered form. After basic anthropometric data were recorded, the Reintegration to Normal Living Index, the Berg Balance Scale, and the Dynamic Gait Index were administered by the same member of the research team to characterize each participant's functional capabilities. The team member administering the tests was an exercise professional with 5 years of clinical research experience.

The Reintegration to Normal Living Index, an 11-question index, quantitatively assessed the degree to which participants achieved reintegration into social activities (eg, recreation, community participation, and interaction in relationships). For each question, participants placed a mark on a 10-cm VAS. The measured distance along the scale indicated the level of reintegration, with 0 cm indicating no reintegration and 10 cm indicating complete reintegration. The scores were summed and normalized from 0 (minimum adjusted score) to 100 (maximum adjusted score). A score of 100 for self-perceived satisfaction with community reintegration indicated full satisfaction, scores of 60 through 99 indicated mild to moderate restrictions, and scores of less than 60 indicated severe restrictions.[35] The Berg Balance Scale, a 14-item scale measuring time and ability to carry out functionally relevant activities, characterized participants' ability to maintain balance. A perfect score on the Berg Balance Scale (56 points) indicates only a 10% risk of falling. In contrast, scores of 40 or lower are associated with nearly a 100% risk of falling in elderly people.[36] The Dynamic Gait Index tests 8 facets of gait to indicate the likelihood of falling. Scores of 19 or less are predictive of falls.[36]

After the functional assessments were completed, participants were familiarized with each elliptical trainer. A member of the research team reviewed key features, including methods for getting on and off, options for hand placement on the stationary and movable handles, controls for variable stride length and resistance, built-in heart rate sensors, and how to start and interpret each console's display.

After the features were reviewed, participants attempted to use each device independently (ie, with no assistance provided by members of the research team). If a participant was unable to safely and independently access an elliptical trainer, then 1 or more examiners provided physical assistance that was quantified into 1 of 2 categories: For the “standby” category, one or more examiners stood next to the participant because of potential safety issues (eg, concerns about loss of balance), but no physical contact was required; for the “manual assistance” category, hands-on assistance was provided for the participant to get on or off the device (eg, physically helping the participant step onto the pedals). If a participant received different levels of assistance from multiple examiners, then only the greatest level of assistance required was documented.

Once on the device, participants were encouraged to push and maintain pedal movement independently. If a participant was unable to do so after several attempts, a member of the research team pushed the handles to help initiate a full movement cycle. If a participant slowed or stopped after several cycles, additional assistance was provided to restart and sustain the movement cycle. The need for assistance to start or maintain elliptical movement cycles was documented. Participants used the device until they indicated sufficient familiarity.

After getting off each elliptical trainer, participants completed a questionnaire. The form included open-ended questions aimed at identifying potential barriers to the use of elliptical trainers as well as ideas for enhancing the design. Specifically, participants were asked the following questions: “What barriers would prevent you from using this piece of equipment?” and “What are three key ideas you have for how to make this equipment more usable for you?” In addition, a 10-cm VAS was used to rate perceptions of safety, comfort, likelihood of achieving a “good workout,” and the usability of the unmodified elliptical trainer. Ratings approaching 0 reflected perceptions of reduced safety, comfort, likelihood of achieving a good workout, and overall usability, whereas values nearing 10 reflected positive perceptions of these attributes. In particular, participants were instructed as follows: “Place an ‘X' on the scale to indicate how *safe* you feel when using this piece of equipment” (0=“not safe at all—I would injure myself if someone weren't here,” 10=“very safe—I could use the equipment without worrying about injury”), “Place an ‘X' on the scale to indicate how *comfortable* the equipment feels when you use it” (0=not comfortable at all, 10=very comfortable), “Place an ‘X' on the scale to indicate how *good of an exercise workout* you feel that you would be able to get when using this equipment as currently designed” (0=“a lousy workout,” 10=“a great workout”), and “Place an ‘X' on the scale to indicate how greatly you would *want to use this piece of equipment* if it were available in a fitness club” (0=“I wouldn't want to use it—it's useless for me,” 10=“I would really want to use it—it's ideal for me”).

Modification of elliptical trainers. The collective questionnaire responses from the 20 participants, in combination with the observations of members of the research team, guided the development of a set of modifications aimed at reducing barriers to safe, comfortable, and effective use of the elliptical trainers. In addition, the director of an outpatient clinic and the general manager of a fitness facility were consulted specifically regarding space constraints during the use of elliptical trainers in their respective settings. Modifications were intentionally made from low-cost materials, and function was emphasized over esthetic appeal.

Assessment of modified elliptical trainers. After a full set of adaptations was designed, fabricated, and installed, participants returned to try the modified elliptical trainers and provide additional feedback. The time between assessment of the unmodified elliptical trainers and assessment of the modified elliptical trainers varied depending on each participant's original test date and subsequent availability for final testing following the modifications. The average length of time was approximately 3 months ($\bar{X}$=96 days, SD=27).

During the final session, participants were refamiliarized with the basic design features of each elliptical trainer. Next, the modifications were described, and participants used each adapted elliptical trainer. Physical assistance was provided (and assessed) as previously described. The evaluation procedures were similar to those detailed earlier. In addition, participants rated whether each modification improved or hindered their ability to use each elliptical trainer. Specifically, for each modification (ie, stairs, bench, side rails, deeper foot wells, center handle, and one-handed heart rate monitor) and elliptical trainer, participants were asked the following questions: “Does this modification improve your ability to use the machine?” and “Does this modification hurt your ability to use the machine?” The 3 response options were “yes,” “no,” and “not needed.” The option “not needed” was provided because some features were not necessary given a participant's specific physical abilities (eg, a one-handed heart rate monitor). Similar procedures were used for each elliptical trainer.

Data Management

Data were exported from the Select Survey Version 2.3.4 software to an Excel (Microsoft Corp, Redmond, Washington) spreadsheet for subsequent analysis. Free-text responses were initially reviewed by each member of the research team to identify themes. A theme reflected at least one participant describing the same type of barrier for each elliptical trainer or 2 or more participants identifying a barrier for a single elliptical trainer. Then, the team members met to review themes, reach a consensus, and classify all comments. Responses with common themes or key words were grouped into 6 major categories. Visual analog scale data were exported from the Select Survey software for subsequent statistical analysis. Ambiguous responses to multiple-choice questions (eg, a participant checked none of 3 options or checked more than one option) were excluded from subsequent analysis. For all questions, at least 95% of participants provided valid answers.

Data Analysis

Descriptive statistics were performed for key variables with SigmaPlot 11.1 software (Systat Software Inc, Chicago, Illinois) and Excel. Frequency counts (converted to a percentage of the total valid responses for each question) described the extent to which the modifications improved or hindered device usage. Assumptions of normality for the VAS data were screened with the Shapiro-Wilk test. If assumptions of normality were met, then separate one-way analyses of variance (4 × 1 ANOVAs) with repeated measures were performed to identify significant differences in VAS ratings (safety, comfort, usability, and workout) across the 4 unmodified elliptical trainers. If assumptions were violated, then nonparametric Friedman 1-way analyses of variance on ranks (4 × 1 ANOVAs) for repeated measures were performed. If significant differences were identified, then *post hoc* analyses were performed with either Tukey (parametric) or Dunn (nonparametric) pair-wise comparisons to identify the location of the significant differences. The same analyses were performed for the modified machines.

To determine whether the modifications had an impact on the overall perceived safety, comfort, usability, and workout of the elliptical trainers, we performed separate paired *t* tests to compare participants' responses for all elliptical trainers before modification with those after modification. Before performing the *t* tests, we examined assumptions of normality with the Shapiro-Wilk test. Statistical significance was defined as $P<.05$. The 95% confidence intervals of differences were calculated when *t* tests were significant.

Role of the Funding Source

The contents of this technical report were developed under a grant (H133G070209) from the Department of Education, National Institute on Disability and Rehabilitation Research. However, the contents do not necessarily represent the policy of the Department of Education, and endorsement by the federal government should not be assumed.

Results

Clinical Findings

Many participants experienced challenges with fully participating in community activities, as evidenced by their Reintegration to Normal Living Index mean score of 72 (Tab. 1). Almost one half of the participants (9/20) had Berg Balance Scale scores that reflected a high risk of falling (ie, ≤40; Tab. 1), and more than three fourths of the participants (17/20) had Dynamic Gait Index scores reflecting notable challenges with walking and an increased risk of falling (ie, ≤19; Tab. 1).

Barriers Identified and Impact on Perceptions

The most frequently cited barrier to the use of the elliptical trainers was that each was “hard to get on and/or off,” with more than one-half of participants identifying this challenge when attempting to use the SportsArt, Life Fitness, and True and a smaller percentage (20%) experiencing this difficulty when using the Octane (Fig. 1, left column). Feeling unsafe and unbalanced when accessing and using each elliptical trainer was the second most frequently cited issue, highlighted by 20% to 30% of participants across devices. Difficulty initiating or sustaining pedal movement was another common barrier named by participants when using the Octane (35%), SportsArt (25%), True (15%), and Life Fitness (10%). In contrast, one participant indicated that the pedals moved too easily (the pedals cannot be locked in place), resulting in instability when getting on or off each elliptical trainer. Feeling as though their feet would slide or roll off the pedals was identified by 2 participants as a barrier to using the Octane; only one participant identified this as a central issue when using the other devices. Two participants experienced difficulty operating the Life Fitness because of limited upper-extremity ability to control the dials and maintain balance simultaneously; one participant reported similar issues for each of the other devices. Despite design differences across the elliptical trainers, no statistically significant differences in perceptions of safety, comfort, workout, or usability were identified in ratings of the unmodified elliptical trainers (Tab. 3).

Recommendations to Reduce Barriers

The most frequently cited ideas for improving usability focused on solutions to ease getting on or off the elliptical trainers (Fig. 1, right column). This theme was important for the side-entry Life Fitness (100% of participants) and SportsArt (95%) in particular and for the posterior-entry True (65%) and Octane (25%) to a lesser extent. The addition of supports or rails to improve balance and stability while mounting and using the elliptical trainers was another theme frequently mentioned for the SportsArt (55% of participants), Octane (45%), True (45%), and Life Fitness (35%). Recommendations to develop a system to initiate or sustain pedal movement varied notably across devices; this need was cited more frequently for the SportsArt (45% of participants) and Octane (35%) than for the True (15%) and Life Fitness (5%). In contrast, the need for greater pedal stability was identified more often for the Life Fitness (35% of participants) and True (10%) than for the SportsArt (5%) and Octane (5%). Less frequently cited recommendations included deeper foot wells (5%–15% of the participants across elliptical trainers) and controls for improving one-handed use (0%–10%).

Modifications Developed to Address Barriers

Six modifications were developed, implemented, and assessed as a result of the recommendations: steps ($50), a bench ($90), side rails and a center rail or handle ($115), deeper foot wells ($25), and a 1-handed heart rate monitor ($15) (Fig. 2). A pair of staircases (Fig. 2A) was fabricated to enable participants to step onto the pedals of each elliptical trainer from a relatively even elevation when the pedals were at their lowest height. Each staircase consisted of 2 steps (step 1, approximately 20.3 cm [8 in] high, 26.0 cm [10.25 in] deep, and 61.0 cm [24 in] wide; step 2, approximately 16.5 cm [6.5 in] high, 27.9 cm [11 in] deep, and 61.0 cm wide); was fabricated from wood and screws; and included a set of standard stair stringers, 2 risers, and 2 treads.

Two wood benches were fabricated (Fig. 2B), 1 for side-entry elliptical trainers and the other for posterior-entry devices. The benches (approximately 36.8 cm [14.5 in] × 121.9 cm [48 in]) were designed to straddle each elliptical trainer, and the height was set at approximately 97.8 cm (38.5 in) for the side-entry elliptical trainers and 83.8 cm (33.0 in) for the posterior-entry devices. Steel corner brackets and joining plates provided additional stability for the framing. Foam padding was placed over the seat for comfort, and a vinyl covering allowed participants to sit and slide across the bench as a means of getting on or off the device instead of having to step onto the movable pedals. In addition, participants with notable lower-extremity weakness or balance problems could use an elliptical trainer in a seated position. Many participants also used the bench as a place to rest between trials or before getting off the device.

A set of side rails (Fig. 2C), made from approximately 1.91-cm (0.75-in) steel piping, was assembled and attached with approximately 1.91-cm floor flanges to the steps fabricated for the SportsArt, Life Fitness, and Octane (the True had side rails). A set of 90-degree steel elbow and tee fittings allowed the positions of the side rails to be optimized to not interfere with the use of the stationary or movable handles. Loctite Blue 242 Threadlocker (Henkel Corp, Westlake, Ohio) further stabilized all metal fittings. The side rails extended from the center console and provided additional support areas for participants with balance deficits and lower-extremity or trunk weakness. For comfort and increased friction for grasping, the rails were wrapped with cushioned bicycle handlebar tape. A center rail or handle (~40.6 cm [16 in] long), made from approximately 2.5-cm (1-in) polyvinyl chloride piping, was attached to each elliptical trainer with snap straps and provided an additional grip point for use when adjusting dials on the console (Fig. 2D).

Each pedal's foot wells were deepened to help participants with reduced sensation (eg, diabetic neuropathy) maintain foot placement without having to repeatedly look at their feet (Fig. 2E). This modification also helped prevent the feet of participants with equinovarus deformities (such as those that might arise from muscle imbalance attributable to stroke) from rolling laterally off the pedal. The modified foot wells, which were approximately 7.6 cm (3 in) high, were fabricated from 26-gauge sheet steel, formed and joined with rivets, and lined with a vinyl floor runner. The superior edges were wrapped with approximately 0.48-cm (3/16-in) rubber tubing to cushion ankles from potentially sharp metal edges. Industrial-strength hook-and-loop fasteners were used to attach the modified foot wells to the existing pedals.

The existing built-in heart rate sensors on the elliptical trainers required participants to grasp both handles for a heart rate recording. Because this task proved difficult for at least 1 participant because of limited hand and arm function, a heart rate monitor adapter was developed (Fig. 2F). It included an adjustable antistatic wrist strap and coiled cord (model 276-2395, Radio Shack, Fort Worth, Texas), but the cord's alligator clip was replaced with a 4.0-mm-diameter banana plug (model R8-B121, Radio Shack). A clamp was fabricated from a piece of aluminum (approximately 19.1 cm [7.5 in] × 2.5 cm × 0.06 cm [0.025 in]) that was bent to conform to the shape of the handle of each elliptical trainer so that the clamp could slide easily over the existing metal heart rate contact plate on the handle. A multipurpose nylon binding post (model 274-661, Radio Shack) was attached to the base of the clamp, and the banana plug was inserted into the binding post to complete the connection of the wrist strap and coiled cord to the elliptical trainer. The electrical signal normally transmitted through the hand's contact with the heart rate sensor could instead be transmitted via the heart rate monitor adapter.

Impact of Modifications

Assistance required for mounting elliptical trainers. Although at least 25% of the participants required manual assistance to get on or off each elliptical trainer before modification (6, 5, 6, and 5 participants for SportsArt, Life Fitness, True, and Octane, respectively), only one participant required this level of help with all elliptical trainers after modification. Before modification, only one participant was able to mount each device independently, in notable contrast to the 30% to 40% of the participants who were able to access each device independently after modification (7, 8, 6, and 6 participants for SportsArt, Life Fitness, True, and Octane, respectively).

Assistance required for initiating and sustaining pedal movement on elliptical trainers. Before the elliptical trainers were modified, 15% to 35% of the participants required help starting (7, 4, 3, and 7 participants for SportsArt, Life Fitness, True, and Octane, respectively) and maintaining (7, 3, 4, and 5 participants for SportsArt, Life Fitness, True, and Octane, respectively) pedal movement; the largest number of participants required help with the SportsArt and Octane. Although 5% to 25% of the participants (5, 4, 1, and 4 participants for SportsArt, Life Fitness, True, and Octane, respectively) still required assistance starting the pedals after modification, the participants were notably more independent in sustaining movement on the Life Fitness (no participant required assistance) and True (no participant required assistance) in particular and on the Octane (2 participants required assistance) and SportsArt (3 participants required assistance) to a lesser extent.

Participants' perceptions of modifications. The steps, bench, and rails were most often rated positively, with at least 80% of the participants indicating that these modifications improved their ability to use each elliptical trainer (Fig. 3, top). The steps did not hinder device usage by any participant (Fig. 3, bottom). In contrast, 10% of the participants reported that the bench hindered the use of Life Fitness and Octane, and 5%, 16%, and 5% of the participants indicated that the side rails hindered the use of SportsArt, Life Fitness, and Octane, respectively. Having the bench too close to the side rails made it difficult for some participants with a wider girth to get onto the devices. The deeper foot wells improved usage for approximately 50% of the participants but hindered the use of SportsArt for 10% of the participants because of difficulty stepping over the elevated edges. The center handle aided usage for approximately 30% to 40% of the participants across devices. However, 5% of the participants using SportsArt and a similar percentage of participants using Octane found that the center handle hindered usage because it pressed against their abdomens. Not unexpectedly, the one-handed heart rate monitor was needed by only a small percentage of participants (20%). The majority indicated that the modification was not personally needed (ie, they had the manual dexterity and strength to hold onto both handles). The presence of the heart rate monitor did not hinder usage by any participant.

Compared with participants' ratings of the elliptical trainers before modification, those after modification were significantly higher for safety (55% increase in VAS ratings), comfort (43% higher), workout (23% greater), and overall usability (24% increase) (Tab. 3). Verbal comments indicated that the side rails and bench made people "feel safe" and reduced the fear of "falling off" while mounting and using the elliptical trainers.

Additional feedback on modified elliptical trainers. Participants identified additional design recommendations. These included making the height and anterior or posterior location of the bench adjustable, adjusting the length of the side rails so that people with a wider girth could more easily fit between the rails and the bench when mounting the device, and creating adjustable-size foot wells to secure the feet. Although the increased ease in mounting the device afforded some additional strength reserve to initiate and sustain pedal movement, several participants indicated that pedal movement was still too difficult and thus remained a barrier.

Discussion

The importance of exercise for all people is underscored by the inclusion of specific fitness goals in Healthy People 2020, a health promotion and disease prevention initiative aimed at extending the quantity and quality of life of all people living in the United States.[37] Unfortunately, the lack of accessible, appropriately challenging, and functionally relevant equipment inhibits many people with functional limitations during their quest to improve fitness and function. Clinicians and fitness professionals are readily positioned to help people achieve the fitness targets of Healthy People 2020, not only by providing people with the knowledge and skills needed to exercise safely but also by working to break down barriers to exercising on equipment that is readily available in many fitness and home settings. The research described in this article demonstrates how low-tech, affordable modifications can be developed to improve the ability of people with functional limitations to use such equipment.

Although no significant differences were identified in measures of safety, comfort, workout, and usability across the 4 elliptical trainers, the types of barriers inhibiting use of the trainers and the types of assistance needed to use the trainers did vary. For example, the unmodified side-mount elliptical trainers (SportsArt and Life Fitness) were identified as being difficult to mount by more participants than the posterior-mount elliptical trainers. The higher pedals on the side-mount elliptical trainers (5–15 cm further from the ground at the lowest point than those on the posterior-mount devices) and the need to step sideways across the pedals were difficult for many people, particularly those with quadriceps muscle weakness, balance deficits, knee pain (eg, osteoarthritis), and movement control challenges. Although not statistically significant, the lower safety ratings (on the VAS) for SportsArt and Life Fitness and more frequent recommendations for developing modifications to facilitate getting on or off SportsArt and Life Fitness likely reflected the greater challenges experienced in trying to mount these devices than in trying to mount the other elliptical trainers. The unmodified Octane, a posterior-entry device with the lowest pedals, was cited least frequently as being difficult to get on or off, received the highest safety rating, and was given the fewest recommendations for developing modifications to improve getting on or off. Once on the devices, more participants experienced difficulty initiating and sustaining pedal movement on SportsArt and Octane than on Life Fitness and True. As a result, more participants required physical assistance from an examiner to train on SportsArt and Octane than on the other 2 devices.

Participants provided valuable feedback that served as the basis for developing an affordable set of adaptations to enhance the usability of elliptical trainers for people with physical disabilities and chronic conditions. Although the supplies to build the 6 adaptations cost less than $300, the impact translated to a notable decrease in the amount of physical assistance required for participants to use the elliptical trainers. Participants' perceptions of safety, comfort, and workout also increased significantly after implementation of the modifications. As a result, they reported being more likely to use the elliptical trainers after the modifications were made than before. Although not all participants were wholly independent after the modifications were made, the overall improvements suggested that more people with physical disabilities and chronic conditions could use modified elliptical trainers independently in personal and public settings or at least would require less assistance.

The variability in barriers to the use of the equipment in the present study was significant. More accessible elliptical trainers could provide some people with the opportunity to train independently, without the need for assistance from a clinician, fitness trainer, or family member. Such a situation promotes greater autonomy and supports engagement in activities important for maintaining health and function. Multiple factors, including space requirements, pricing, warranties, and design features (such as consoles and fans), influence equipment selection. Our research suggests that accessibility issues, the capacity to readily modify devices, or both also should be weighed during the selection of equipment for use in community settings by people with a range of physical abilities.

Despite our demonstration that an affordable set of modifications reduced barriers to the use of elliptical trainers by people with physical limitations, additional work is necessary. Up to 25% of the participants continued to require assistance to initiate or sustain pedal movement and therefore could not independently use the modified elliptical trainers. It is likely that if people with more severe physical disabilities had been recruited (such as those in the early stages of recovering from a stroke or a recent exacerbation of multiple sclerosis), even more people would have required assistance to initiate or sustain pedal movement. Given current motor learning principles emphasizing the importance of mass repetition for neuroplastic changes[38] and the similarities documented between elliptical training and walking,[27] it appears to be therapeutically desirable to further refine elliptical trainers to allow sustained training even by people with profound weakness and movement control problems.

The work described in this article represents early steps in our team's efforts to develop ICARE, an Intelligently Controlled Assistive Rehabilitation Elliptical training system. Our goal with ICARE is to create an affordable and accessible therapeutic training device for use across multiple settings to improve walking and cardiovascular fitness in people with physical disabilities and chronic conditions. Our subsequent work has focused on integrating a motor-drive system[39] and a commercially available body weight support system with the ergonomic, comfort, and safety enhancements described in the present article. The newest modifications enable mass repetition of a movement pattern similar to gait[27] and allow customization of the muscle demands to the strength capabilities of the client.[39]

The rapidly expanding proportion of adults more than 60 years of age in the global population,[40] combined with medical advances enabling survival after life-threatening injuries and illnesses, has contributed to a growing number of people living with chronic conditions, mobility restrictions, and physical disabilities. Although engaging in exercise for cardiovascular fitness is important for controlling and preventing secondary medical complications, such as cardiovascular disease and diabetes mellitus, many people lack equipment options that are readily available for use in community and home settings. Physical therapists have the skills and the responsibility to help eliminate barriers to engaging in therapeutically beneficial exercise, not only during formal rehabilitation but also as patients transition to nonmedical settings. The desire of fitness trainers and exercise physiologists to meet the exercise needs of people with physical limitations and chronic conditions across a variety of settings[2,41] further highlights the importance of developing exercise equipment options.

Limitations

To summarize the free-text responses from participants, we used a consensus process to classify all comments and identify key barriers experienced by participants when attempting to use elliptical trainers. However, one limitation to this approach was that a barrier identified by only a single participant for a single device may not have been addressed during the modification process. Additionally, sometimes participants used different terms to describe similar barriers (eg, “hard to start” and “resistance too high”). In these situations, the terms were collapsed into a single category.

Recruiting a limited number of people with various medical conditions may not necessarily encompass all barriers experienced by larger populations of people with specific combinations of impairments and functional limitations. Additionally, the people who opted to participate in the present study may already have had a propensity toward participating in exercise activities. Thus, they may have been more likely to use elliptical trainers than people not inclined to exercise. Further research, focused on specific sets of impairments (eg, a paretic upper extremity), may provide insights into additional equipment modifications needed for selected populations.

Conclusions

In the present study, we validated the twofold hypothesis regarding the use of elliptical machines by people with disabilities or chronic conditions—that the ability of participants to use unmodified, off-the-shelf elliptical trainers would vary across the devices and that a set of low-cost modifications could be implemented to improve usability for people with various disabilities and chronic conditions. In particular, key improvement targets were identified, and straightforward design solutions were carried out to obtain gains in perceived safety, comfort, usability, and workout in addition to a reduction in assistance needed. Such improvements are significant because they enable people with physical disabilities and chronic conditions to engage in health-promoting behaviors with greater autonomy. The design of the present study provides a framework with which clinicians can systematically evaluate and eliminate barriers experienced by patients transitioning to community-based exercise environments.

Footnotes

Dr Burnfield and Dr Nelson provided concept/idea/project design. All authors provided writing. Dr Burnfield, Mr Buster, and Mr Taylor provided data collection. Dr Burnfield, Dr Shu, Mr Buster, and Mr Taylor provided data analysis. Dr Burnfield and Mr Buster provided project management. Dr Burnfield provided fund procurement, facilities/equipment, and institutional liaisons. Dr Nelson provided consultation (including review of manuscript before submission).

The contents of this technical report were developed under a grant (H133G070209) from the National Institute on Disability and Rehabilitation Research, Department of Education. However, the contents do not necessarily represent the policy of the Department of Education, and endorsement by the federal government should not be assumed.

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Figures and Tables

Table 1.

Selected Medical, Anthropometric, and Clinical Data for Each Participant[a]

Participant	Diagnosis	Sex	Age (y)	Height (m)	Mass (kg)	Berg Balance Scale Total Score	DGI Total Score	RNLI Score
1	Cerebral palsy	F	56	1.68	59	34	1	79
2	Cerebral palsy	F	61	1.65	98	21	2	65
3	Diabetes mellitus	M	65	1.78	90	56	24	76
4	Diabetes mellitus	F	86	1.65	90	37	9	65
5	Hemiparesis	F	34	1.68	63	34	6	24
6	Hemiparesis	M	53	1.78	75	53	11	95
7	Hip fracture	F	86	1.60	73	35	13	53
8	Hip fracture	M	90	1.83	85	3	0	32
9	Multiple sclerosis	F	27	1.75	68	50	16	75
10	Multiple sclerosis	F	62	1.75	125	44	15	68
11	Osteoarthritis	M	67	1.73	77	52	18	100
12	Osteoarthritis and TKR	F	71	1.65	100	48	19	51
13	Osteoarthritis and TKR	M	72	1.68	109	44	14	65
14	Parkinson disease	M	65	1.78	100	50	17	98
15	Parkinson disease	F	71	1.68	94	40	9	56
16	Transfemoral amputation	M	31	1.73	111	37	23	91
17	Transtibial amputation and diabetes mellitus	F	73	1.68	111	28	11	80
18	Traumatic brain injury	F	56	1.60	150	51	20	97
19	Traumatic brain injury	F	19	1.70	54	55	19	86
20	Traumatic brain injury	F	45	1.73	54	41	12	78
$\bar{X}$			60	1.70	89	41	13	72
SD			20	0.06	25	13	7	21

[a]DGI=Dynamic Gait Index, RNLI=Reintegration to Normal Living Index, F=female, M=male, TKR=total knee replacement.

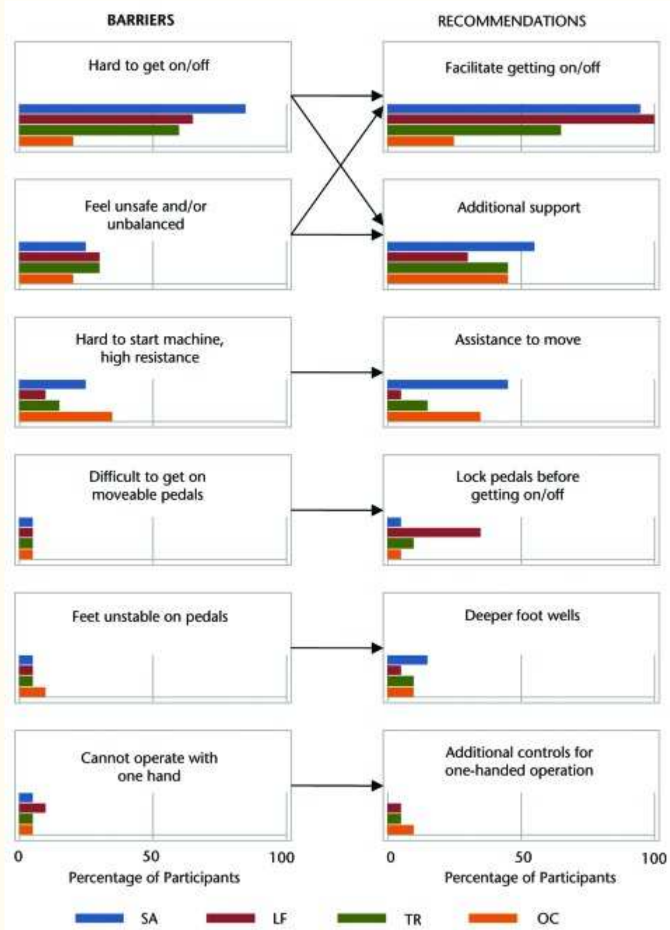
Table 2.

Design Features of Selected Commercially Available Elliptical Trainers[a]

Elliptical Trainer	Mounting Direction	Stride Length Range (cm)	Pedal Height From Ground (cm)	Pedal Edge Height (cm)	Heart Rate Sensor Handle Location	Footprint (cm)	MSRP (US $)
SportsArt	Side	43–74	33–51	4.0	Movable	66×226	5,499
Life Fitness	Side	46–61	31–49	4.5	Static	66×211	4,299
True	Rear	43–66	26–44	4.5	Static	81×166	4,099
Octane	Rear	46–58	18–37	3.5	Static	79×180	5,599

[a]MSRP=manufacturer's suggested retail price.

Figure 1.



Barriers to and potential solutions for barriers to the use of elliptical trainers, as identified by participants. LF=Life Fitness, OC=Octane, SA=SportsArt, TR=True.

Table 3.

Participants' (n=20) Visual Analog Scale Ratings of Elliptical Trainers Before Modification (Pre) and After Modification (Post)[a]

Elliptical Trainer	Safety		Comfort		Workout		Usability	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SportsArt	4.4 (2.7)	7.6 (2.0)	4.5 (2.7)	7.3 (2.5)	6.1 (3.0)	7.3 (2.7)	5.2 (3.6)	6.8 (3.1)
Life Fitness	4.8 (2.8)	8.4 (1.4)	5.3 (2.7)	8.2 (1.5)	6.5 (3.2)	8.5 (1.4)	5.6 (3.4)	8.0 (2.1)
True	6.0 (2.5)	8.4 (1.2)	6.1 (2.4)	8.4 (1.7)	6.9 (2.6)	8.1 (1.7)	6.6 (2.9)	7.6 (2.5)
Octane	6.2 (2.6)	8.3 (1.2)	6.4 (2.8)	8.2 (1.7)	6.2 (3.3)	7.6 (2.4)	6.2 (3.2)	6.8 (2.9)
Total	5.3 (2.7)	8.2 (1.5)	5.6 (2.7)	8.0 (1.9)	6.4 (3.0)	7.9 (2.1)	5.9 (3.3)	7.3 (2.7)
Main effect								
Elliptical trainer (*P*)	NS	NS	NS	NS	NS	NS	NS	NS
Pre vs post								
P		<.001		<.001		<.001		.007
Mean difference (95% CI)		2.9 (2.2–3.5)		2.4 (1.7–3.2)		1.5 (0.6–2.3)		1.4 (0.4–2.4)

[a]Values are mean (SD) unless otherwise indicated. NS=no significant difference, CI=confidence interval.

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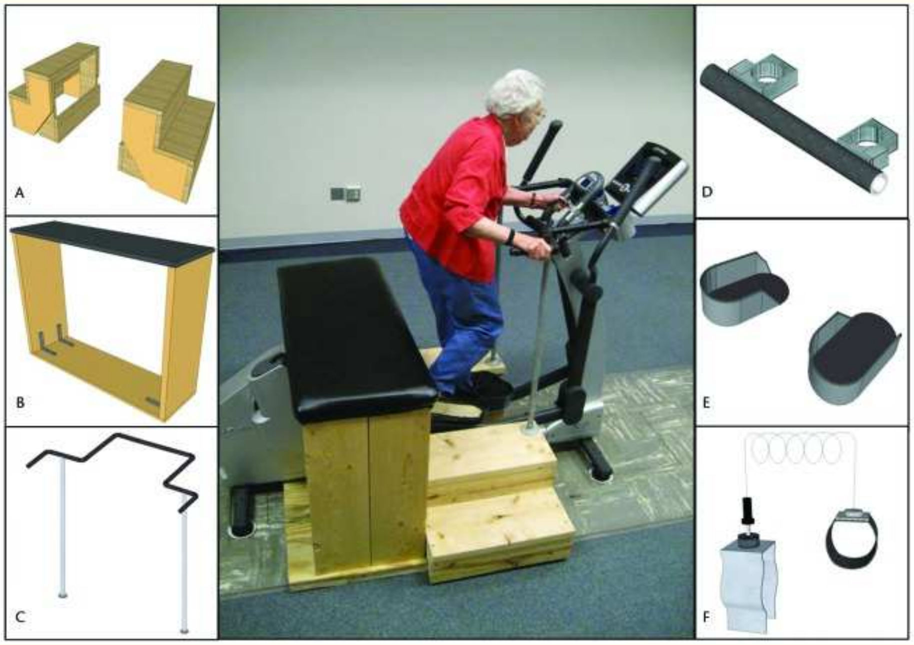
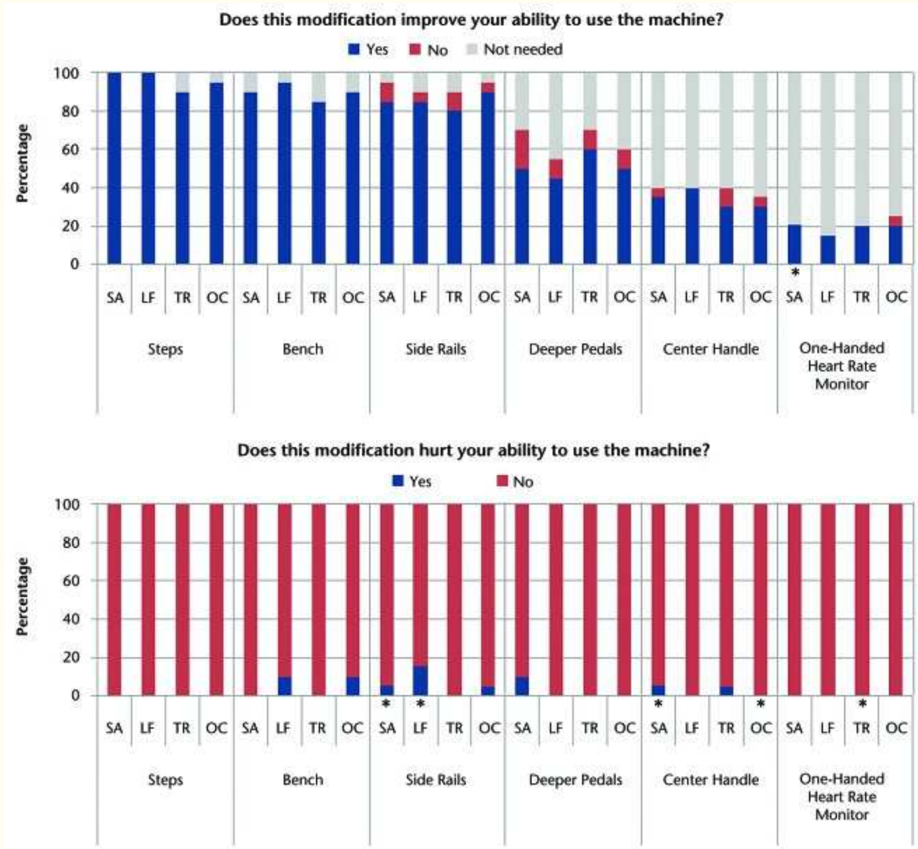
Figure 2.



Modifications developed to improve universal access of elliptical trainers. (A) Staircase to ease getting on or off. (B) Bench to assist with transfers, to rest on between exercise bouts, and to use for seated elliptical training when impairments prevented device usage while standing. (C) Side rails to assist with getting on or off device and balance when using the elliptical trainer. (D) Center rail to facilitate balance while standing. (E) Deeper foot wells to control foot position on pedals for people lacking normal sensation or with equinovarus deformities. (F) One-handed heart rate monitor for people unable to simultaneously grasp the built-in heart rate sensors on the elliptical trainer.

Figure 3.



Frequency counts reflecting participants' ratings of whether each modification improved or hindered their ability to use each elliptical trainer (n=20 unless denoted by an asterisk, in which case n=19). LF=Life Fitness, OC=Octane, SA=SportsArt, TR=True.