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Increasing the Amount and Intensity of Stepping Training During Inpatient Stroke Rehabilitation Improves Locomotor and Non-Locomotor Outcomes

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Abstract

Background.—The efficacy of traditional rehabilitation interventions to improve locomotion post-stroke, including providing multiple exercises targeting impairments and activity limitations, is uncertain. Emerging evidence rather suggests attempts to prioritize stepping practice at higher cardiovascular intensities may facilitate greater locomotor outcomes.

Objective.—The present study was designed to evaluate the comparative effectiveness of high-intensity training (HIT) to usual care during inpatient rehabilitation post-stroke.

Methods.—Changes in stepping activity and functional outcomes were compared over 9 months during usual-care (n = 131 patients < 2 months post-stroke), during an 18-month transition phase with attempts to implement HIT (n = 317), and over 12 months following HIT implementation (n = 208). The transition phase began with didactic and hands-on education, and continued with meetings, mentoring, and audit and feedback. Fidelity metrics included percentage of sessions prioritizing gait interventions and documenting intensity. Demographics, training measures, and outcomes were compared across phases using linear or logistic regression analysis, Kruskal-Wallis tests, or χ^2 analysis.

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Results.—Across all phases, admission scores were similar except for balance (usual-care>HIT; $P < .02$). Efforts to prioritize stepping and achieve targeted intensities during HIT vs transition or usual-care phases led to increased steps/day ($P < .01$). During HIT, gains in 10-m walk [HIT median = 0.13 m/s (interquartile range: 0–0.35) vs usual-care = 0.07 m/s (0–0.24), $P = .01$] and 6-min walk [50 (9.3–116) vs 2.1 (0–56) m, $P < .01$] were observed, with additional improvements in transfers and stair-climbing.

Conclusions.—Greater efforts to prioritize walking and reach higher intensities during HIT led to increased steps/day, resulting in greater gains in locomotor and non-locomotor outcomes.

Keywords

locomotion; rehabilitation; exercise

Introduction

Recovery of independent locomotion in individuals early post-stroke is a key determinant of discharge location following inpatient rehabilitation.[1] Interventions targeting locomotor function are frequently employed during physical therapy (PT), although traditional strategies that include incrementally challenging patients above their current functional level and attention towards impairments have demonstrated limited success.[2,3] Rather, basic and applied findings suggest maximizing the amount of task-specific (i.e., walking) practice, particularly at higher cardiovascular intensities up to 85% predicted maximum heart rate (HR_{max}), may result in superior gains in locomotor capacity and performance.[4–7] Previous controlled studies suggest patients with subacute or chronic stroke can achieve 3000–4000 steps during 1-hour of high-intensity training (HIT) focused primarily on stepping. Focusing on HIT in turn leads to consistent gains in walking speed and distance up to 1.5–2 times greater than minimally important differences, with the amount of practice related to locomotor outcomes.[4,5,7]

Implementation of HIT during inpatient rehabilitation post-stroke could capitalize on the intrinsic neuroplastic changes occurring in the early stages following injury and enhance recovery. Unfortunately, the use of HIT during stroke rehabilitation is limited.[8–11] Previous and recent observational studies of therapeutic activities provided during inpatient rehabilitation post-stroke suggest patients receive limited stepping practice, averaging only 250–500 steps/session. Other studies also indicate PT interventions rarely reach aerobic thresholds, averaging 30–50% HR_{max}.[10–13] Minimal amounts of stepping practice at lower cardiovascular intensities may limit outcomes, contributing to reduced community mobility and participation upon discharge.

Barriers to performing HIT during routine inpatient rehabilitation post-stroke are multifactorial and may include minimal didactic education and training on psychomotor skills used to provide HIT in lower functioning individuals, lack of heart rate monitoring and gait training equipment, patient safety concerns, and the extent of many patients' physical deficits.[14,15] However, previous studies have shown that such implementation is feasible.[1,16] In particular, a cohort study of 201 individuals post-stroke receiving HIT focused on stepping during inpatient rehabilitation performed approximately 1500 steps/

day, with substantial gains in locomotor function as well as balance and transfers despite reduced attention towards these latter tasks.[1] The results of that study were limited by the lack of an adequate control group. However, more recent work from two Norwegian centers demonstrated similar outcomes with HIT using a historical comparative effectiveness paradigm.[16] Specifically, walking and balance outcomes collected over 1 year in a cohort of 54 patients provided HIT during inpatient rehabilitation were significantly greater than outcomes from a separate cohort (n = 56 patients) provided usual-care rehabilitation during the prior year.[16] While encouraging, these participants were higher functioning than those typically seen in US inpatient rehabilitation centers and it is unclear if regional differences in health care services may influence outcomes.

The purpose of this study was to evaluate the comparative effectiveness of attempts to implement HIT as a standard of care for individuals admitted to inpatient rehabilitation post-stroke. Using a quasi-experimental design at a single US site, the Focused Intense Repeated Stepping Training (FIRST)-Indiana project was designed to monitor therapeutic activities during inpatient rehabilitation for 9 months, followed by a progressive implementation strategy over the following 30 months that encouraged therapists to perform HIT with their patients. We hypothesized that if HIT was implemented with fidelity during inpatient stroke rehabilitation, significantly greater improvements in locomotor outcomes would be observed as compared to usual-care, without detriment to other functional tasks (balance and transfers).

Methods

Study Design and Sample

This study utilized a quasi-experimental pre-post design in which functional outcomes and therapy interventions, including stepping activity of patients early post-stroke, were monitored prior to and following attempts to implement HIT during inpatient rehabilitation. Two rehabilitation units at a single facility in Indianapolis, IN participated in this quality improvement project. The Rehabilitation Hospital of Indiana is a 64-bed facility admitting ~300 individuals post-stroke/year. All admitted individuals received 3 hours of rehabilitation 5 days/week across at least two disciplines (PT, occupational therapy, and speech) with PT sessions aimed at improving functional mobility and occupational therapy focused on upper extremity function and activities of daily living. Data were collected as part of standard PT services, which consisted of 30- or 60-minute sessions and varied daily to accommodate all services required. Individuals included in this analysis are comprised from two overlapping projects. The first was a prospective study of long-term outcomes of poststroke rehabilitation (IU #1608161738) while the second was a quality improvement project initiated by therapy leadership in June 2017 and involved monitoring physical activity throughout the therapy day. Data from individuals that participated in the quality improvement project, but not the prospective study, were retrospectively added after de-identification (IU #13178) according to Indiana University's Institutional Review Board policies. This project has been retrospectively registered on clinicaltrials.gov (NCT05393661), with methods and primary outcomes similar to efforts to implement HIT previously.[1,16–18] The usual-care phase occurred from January to September 2017, with efforts to implement HIT for all patients admitted post-stroke began thereafter. Data collection continued until research processes were halted in April 2020 due to the coronavirus pandemic.

While HIT was attempted for all patients post-stroke admitted beginning October 2017, only selected patients were considered in this analysis. Eligible participants were <2 months post-stroke and 18–89 years old. Individuals were only excluded if they had restrictions in lower extremity weight bearing (e.g., amputation or lower limb fracture), or were unable to ambulate >50 m prior to their most recent stroke. Additionally, individuals that discharged from rehabilitation to home after <1 week were categorized as inappropriate candidates for acute inpatient rehabilitation and excluded from the analysis. Patient demographic information, training parameters, and outcome measures were extracted from medical records and de-identified. Specific demographics included sex, age, duration post-stroke, lesion side, type (ischemic/hemorrhagic), and distribution [classified as cortical (anterior, middle, or posterior), subcortical (lacunar), subtentorial (brainstem or cerebellar), or multiple lesions]. The Charlson Comorbidity Index was also calculated with the most recent stroke not included.[19] Significant adverse events during the length of stay, including death, non-fatal cerebrovascular events, and readmission to an acute care hospital were recorded.[20] The incidence of falls throughout the rehabilitation stay were also documented.

Outcomes

In the months prior to the usual-care phase, therapists were trained on routine collection of an outcome measures battery with standardized instructions.[21] Therapists were encouraged to collect the 10-m walk test (10MWT), 6-minute walk test (6MWT) and Berg Balance Scale (BBS) at admission, weekly, and discharge. For primary measures, patients were instructed to “walk at your usual, comfortable pace” for the 10MWT and “cover as much ground as possible” during the 6MWT. During both assessments, physical assistance was permitted as necessary to maintain upright posture, but not advance forward. The level of assistance (LoA) was documented similar to the Functional Independence Measure (FIM)-Walk score (range: 1–7) but without distance requirements. Contact guard assistance or incidental contact in case of loss of balance was coded as LoA = 5.[1] Secondary measures include the individual FIM scores for bed to chair transfers (FIM-bed), toilet transfers (FIM-transfers), walking (FIM-walk) and stairs (FIM-stairs). Available sagittal-plane paretic lower extremity manual muscle testing scores at admission were averaged to characterize the patient’s strength.[1] Daily stepping activity was recorded as soon as possible after admission [median and interquartile range (IQR) = 3 (3–4) days post-admission] by a StepWatch (Modus Health, Edmonds, WA) placed on the paretic lower extremity on weekdays from 8:00 am to 5:00 pm.[9] Stepping activity during PT was determined using the session start and end times documented by treating therapists and scaled per hour of PT to account for varying session durations.

Interventions

Prior to the usual-care phase, therapists were trained or retrained on available therapy equipment for walking practice and provided heart rate monitors but without guidance on their clinical application. Specific equipment included three treadmills with harness support systems and two overground walking systems. Four rehabilitation aides were available for assistance during therapy as needed throughout all phases of data collection, and were trained on the use of the training equipment. Physical interventions provided to patients during this phase were chosen by the therapists without influence from the research staff. Estimates of the types and approximate durations performing different therapeutic activities during the usual-care phase were evaluated over a subsample of 63 sessions (n = 21 patients) as part of a separate validation study (please see Supplemental Figure and Results).[9]

Implementation of HIT was undertaken using an established implementation framework (i.e., Knowledge to Action cycle)[22] utilized previously for similar quality improvement efforts in inpatient rehabilitation.[16,18] During the implementation phase, therapists were encouraged to prioritize walking practice and attempt to achieve higher cardiovascular intensities during all possible sessions. No additional personnel, equipment or time resources were allotted during attempts to implement HIT. The details of the training paradigm have been delineated previously.[4,7] Briefly, stepping was performed on treadmills and overground with gait belts or harness systems and body weight support as needed to ensure successful stepping (e.g., defined as generating positive step lengths, absence of limb collapse or postural instability).[7] Specific tasks included walking in different directions, over obstacles or on uneven, compliant surfaces, and on stairs/steps. Tasks were progressed by the treating therapist by increasing task demands. Physical assistance was provided as needed to continue stepping but no effort was made to normalize gait kinematics. A key feature of the intervention was the focus on attempts to reach 75%–85% age-predicted HR_{max} (208–0.7*age)[23] and Borg ratings of perceived exertion (RPE) of 15 (hard) to 17 (very hard). In patients prescribed β-blockers, targeted HR ranges were reduced 10–15 beats/min.[1] In patients with greater cardiovascular risks as determined by the supervising physician (25/525 or 5% patients), PTs provided moderate intensity training, targeting 65%–75% HR_{max} and RPEs of 13 (somewhat hard) to 15 (hard). HRs were monitored continuously using the OH1 arm band (Polar Electro Oy, Kempele, Finland), Rad-5v forehead sensor (Masimo Inc, Irvine, CA), or PalmSAT 2500 earlobe sensors (Nonin Medical Inc, Plymouth, MN) and therapists were encouraged to document cardiovascular or subjective intensities of interventions.

Strategies to facilitate clinical adoption of HIT and overcome aforementioned barriers were multi-faceted and began in Oct 2017 with a 9-hour in-person educational course and 8 online recorded sessions to reinforce information regarding application of HIT. Continuing efforts included inpatient co-treatments with research staff early during implementation of HIT to better integrate concepts articulated in the courses, with subsequent assistance for more impaired individuals. Audit and feedback strategies were utilized to ensure collection of outcomes and implementation of HIT. Specific feedback on weekly documentation of outcomes were conducted every ~1–2 months early during the usual-care phase, with feedback every ~4–6 months during the implementation phase. Specific feedback during attempts to implement HIT included patient-stratified stepping activity during initial efforts (months 10–27) as compared to stepping amounts achieved in previous implementation efforts.[1] During months 28–39, feedback of patient stepping activity was transitioned to stratify by individual therapists. Throughout attempts to implement HIT, feedback of documentation of training activities was provided every 3–6 months and included 4 questions related to delivery of HIT (scored as “yes”/“no” responses per session). Questions included: (1) was any walking performed during PT, (2) was walking practice prioritized during PT, defined as when the primary activities involved walking practice early during sessions as opposed to other strategies (i.e., static balance, strengthening, transfers) (3) were HRs or RPEs documented, and (4) was the target intensity achieved. If neither HR nor RPE was documented for a given session, it was assumed that the target intensity was not achieved. Sessions which consisted only of outcome measures, family training, home exercise prescription, toileting or orthotics assessments were not included in the analysis. With expectations of difficulties performing HIT due to other unscheduled events, the primary fidelity target was prioritization of walking documentation for approximately 80% of sessions (4/5 days) consistent with previous implementation efforts,[1,16] with a secondary fidelity target of documentation of HRs or RPEs during PT sessions.

Statistical Analysis

Data and statistical analyses for patient outcomes and training characteristics were separated during the usual-care phase and attempts to implement HIT, with further separation of the implementation phase based on specific criteria and implementation strategies. Initial implementation efforts were designated as a “transition phase,” during which the primary fidelity target were not reached (i.e., prioritizing walking ~80% of sessions). At the conclusion of the transition period, two specific factors likely contributed to therapists’ ability to achieve the fidelity targets. First, as indicated above, feedback of patient stepping activity was altered to provide feedback for individual therapists. Second, therapy administrators met with therapists to clearly indicate that performing evidence-based practices, including HIT, was an organizational priority and an expectation for treating clinicians. Following these events, therapists began to approach fidelity targets (>70% of sessions prioritized walking), with this period then designated the “HIT phase” (months 28–39). Data were therefore stratified into a usual-care phase (months 1–9), a transition phase (months 10–27; quarters 1–6 of attempt to implement HIT), and a HIT phase (months 28–39; quarters 7–10).

Demographic, training, and outcome measures data were tabulated, with missing weekly outcomes measures imputed from the previous week. Outcome measures were not considered if admission scores were not recorded, unless total assistance or no attempt was entered for admission FIM-Walk and missing data for admission 10MWT or 6MWT scores were recorded as 0 m/s or 0 m, respectively.[1] Data were tested for normality using Kolmogorov-Smirnov assessments, revealing all data were positively skewed, and medians (interquartile range) are presented. Stepping activity was averaged across all days of the length-of-stay, with data for PT sessions presented for all participants and separated for initial LoA. Additional metrics include stepping frequency and total stepping time during PT sessions. Group differences in demographics and therapy activities were tested with Kruskal-Wallis assessments and post-hoc pairwise comparisons with Bonferroni corrections or χ^2-tests of homogeneity with post-hoc *z*-tests as indicated.

To evaluate comparative improvements in primary (10MWT, 6MWT, LoA) and secondary outcomes (BBS, all FIM scores) across different training phases (usual-care, transition and HIT), we modeled each of the post-intervention outcomes in a regression model.

Specifically, an ordinary least squares linear regression model and ordinal logistic regression model were formulated for continuous outcomes (10MWT, 6MWT and BBS) and ordinal outcomes (LoA, all FIM scores), respectively. Different phases were included in each of the regression models as indicator variables, with the usual-care phase designated as the reference level. Effects of more intensive training interventions were evaluated by testing the corresponding regression coefficients. In addition to adjusting the regression models for admission scores for the outcome tested, the models were additionally adjusted for baseline BBS (higher during usual-care) and length-of-stay differences (longer during HIT) due to significant between-group differences.

For the primary ratio outcomes 10MWT and 6MWT, associations between steps/day and changes in outcomes were assessed using correlation (Spearman), with linear regression analyses to allow graphical comparisons between phases. Finally, the incidence of significant adverse events and falls during the inpatient admission were compared across implementation phases using χ^2-tests and odds ratios for each event occurring during implementation phases relative to usual-care.

Results

During the project time period, 958 individuals post-stroke were admitted to the rehabilitation facility. Of those individuals, 134 did not meet the inclusion criteria for this analysis, 92 had lengths of stay that were <7 days and specifically discharged to home, and 76 were admitted during the usual-care phase prior to the initiation of the quality improvement project and unable to be consented. As a result, a total of 656 individuals were included across the three phases (n = 131 in usual-care, n = 317 in transition, and n = 208 in HIT phases; Figure 1). Admit and discharge 10MWT, 6MWT, and BBS were collected with 92%, 88%, and 88% compliance, respectively. Patient demographics are detailed in Table 1, with a longer length of stay during the HIT phase ($P < .01$) and a greater admission BBS during the usual-care phase ($P = .03$).

Training Activities

Training activities throughout each phase are detailed in Table 2. During usual-care, estimates of the types and durations of different interventions were collected over a subsample of 63 PT sessions,[9] with the average percentage of time for individual activities presented (Supplemental figure 1). The data indicate a large proportion of time (47%) was directed towards walking activities, although many different interventions were performed. Across all usual-care sessions, walking activities were performed during 62% of sessions, but prioritized only during 14% of sessions (Table 2, Figure 2). Accordingly, median steps/day were only 780 (226–1360) steps throughout usual-care, with only 168 (34–688) steps during PT sessions across all LoAs. Documentation of intensity was nearly absent (1%), and higher intensities never achieved.

During the transition phase, a slight but significantly greater 70% of sessions involved stepping activities and 45% of sessions prioritized stepping practice (both $P < .01$ vs usual-care, Figure 2). In addition, measures of intensity were documented for 34% of sessions, but higher intensity rarely achieved. Accordingly, steps/day were not significantly different from usual-care [834 (302–1577)], although steps during PT sessions did increase significantly across all LoAs [338 (50–866) steps/session]. Increases in minutes and rates of stepping were also greater in the transition vs usual-care phase (Table 2).

Within the HIT phase, all stepping and intensity metrics were significantly different from usual-care and transition phases (Figure 3, $P < .01$). Specifically, greater steps/day [1100 (512–1938)] and steps/PT session [616 (275–1154)] were observed across all patients. Improvements were observed in both the amount and rate of stepping, with greater frequency of stepping performed (91%) and prioritized (78%), and intensity documented more consistently (63% sessions), with targeted intensities achieved in 38% of sessions (Table 2).

Outcomes

Assessment of outcomes determined whether gains in stepping and intensity metrics were sufficient to significantly improve locomotion and performance of other functional tasks. Table 3 details admission and changes in primary and secondary outcomes at discharge. For primary walking outcomes, modest improvements in 10MWT were observed during usual-care [0.07 m/s (0–0.24)] and transition phases [0.08 m/s (0–0.30)] at discharge, with larger median gains during HIT [0.13 m/s (0–0.35)]. More substantial improvements were observed for the 6MWT during HIT [50 m (9.2–116)] as compared to usual-care [2.1 m (0–56)] or transition phases [9.1 m (0–80)], with small (1 point) changes in 6MWT LoA favoring the HIT phase (Table 3). Ordinary least squares linear regression analysis indicated that gains in10MWT during the HIT phase were 0.085 m/s greater compared to usual-care ($P = .01$; 95% CI: 0.020–0.152) and 0.048 m/s greater than the transition phase ($P = .04$; 95% CI: 0.001–0.096), with no differences between usual-care and transition phases ($P = .24$) after adjusting for the baseline score, admission BBS and length of stay. Furthermore, the 6MWT during the HIT phase was 129 m greater than the usual-care phase ($P < .001$; 95% CI: 52–206) and 75 m greater than the transition phase ($P < .001$; 95% CI: 22–127), with no differences between the first two phases ($P = .15$). The ordinal logistic regression analysis indicates that the odds of achieving higher 6MWT LoA after HIT was not significantly greater that those after the usual-care and transition phases (Table 3).

For non-walking outcomes, changes in BBS across the length of stay were relatively similar across all phases (9–12 point median gains), and not significantly different between groups (Table 3). However, 1-point greater median gains in FIM-bed, FIM-transfers, and FIM-stairs were observed during HIT as compared to usual-care or transition phases (all $P < .01$), with inconsistent differences in FIM-walk (Table 3). Ordinal logistic regression indicated a 106% greater probability [odds ratio = 2.06 (95% CI: 1.33–3.21)] for achieving a higher FIM-bed score in HIT vs usual-care, and 95% [1.95 (1.38–2.76)] for HIT vs transition phase, after adjusting for the baseline score, admission BBS and length of stay. For FIM-transfers, the odds of achieving a higher score with HIT were 122% [2.22 (1.43–3.47)] and 122% [2.22(1.56–3.15)] greater than usual-care or transition phases, respectively. Similar findings were observed for FIM-stairs, with 97% [1.97(1.24–3.15)] and 127% [2.27(1.56–3.31)] greater probabilities of achieving better outcomes with HIT vs usual-care or transition phases, respectively.

Associations between steps/day and changes in 10MWT and 6MWT were analyzed to evaluate potential dose-responses relationships.[1,16] Figure 3 indicates significant associations between 10MWT (r_s = 0.52) and 6MWT (r_s = 0.64; both P < .001) changes and steps/day, with depiction of both usual-care and HIT phases and similar associations observed during the transition phase (not shown). Regression lines for both usual-care and HIT phases depict depict similar relations, indicating greater amounts of stepping practice during HIT were associated with proportionally greater outcomes.

Significant adverse events are detailed in Table 3 with no differences in the total number of significant adverse events across phases (P = .22), and no differences for individual significant adverse event categories or falls. Odds ratios were similarly unremarkable with the exception of falls which increased in the HIT phase when compared with usual care (odds ratio = 2.2, 95% confidence intervals [1.0–4.6]).

Discussion

The present study detailed the comparative effectiveness of attempts to perform HIT in individuals with substantial disability early post-stroke to usual-care during inpatient rehabilitation. Over the course of 30 months following initial attempts to implement HIT, therapists increased the frequency of prioritizing walking interventions and the cardiovascular demands during PT interventions, resulting in greater amounts of stepping practice as compared to usual-care. In turn, increased stepping practice contributed to greater gains in locomotor and non-locomotor outcomes, with no increased frequency of significant adverse events.

While evidence-based practice has long been a tenet of the PT profession, there is limited data to indicate that conventional therapeutic strategies utilized in stroke inpatient rehabilitation optimize outcomes. Rather, previous and the present data suggest therapists utilize various exercises targeting multiple impairments and functional limitations in patients post-stroke, resulting in minimal practice of any single task[9–11,13] (e.g., Table 2 and Supplemental Table). Additional findings also suggest limited efforts to achieve higher cardiovascular intensities.[10,12,13] Despite accumulating evidence over the past two decades supporting the contributions of amount and intensity of task-specific practice, entry-level and continuing education strategies have not resulted in changes in clinical practice.[24]

Despite these challenges, the present study suggests that sustained implementation efforts can effectively shift inpatient PT practice patterns. Significant changes in the prioritization of stepping practice and attempts to reach higher intensity were achieved, resulting in greater amounts of stepping practice and gains in specific patient outcomes, consistent with dose-response relationships observed here (Figure 3) and previously.[25] Importantly, there was no change in equipment or additional personnel utilized to implement HIT and greater outcomes were achieved during HIT, even with lower functioning individuals, providing greater value of therapy services.[26] Similar implementation efforts have been demonstrated previously during inpatient stroke rehabilitation in US,[1] although the lack of a control group limited conclusions regarding the comparative effectiveness of HIT. A more recent study indicated differences in outcomes between HIT and usual-care following similar implementation efforts in two Norwegian rehabilitation centers.[16] However, the patient populations in these centers were much higher functioning than those typically seen in the US. In addition, local contextual factors facilitated more rapid implementation without a protracted transition period. Indeed, the transition phase in the present study represented a substantial difference between previous attempts to implement HIT, during which statistically significant but small increases in stepping activity were insufficient to affect outcomes. This transition has been observed previously during attempts to implement circuit training in inpatient stroke rehabilitation,[27] although data characterizing the 3-month interval between usual-care and circuit training were not described. In the present study, the shift away from this transition phase required additional implementation strategies, including use of more direct (therapist-focused) audit-and-feedback of stepping activity. These types of feedback strategies are common in implementation studies and have been shown to facilitate greater use of evidence-based practices.[28,29] In addition, demonstration of leadership encouragement to provide evidence-based interventions was likely also critical, as previous data indicate organizational support may be the most important determinant of the success of implementation efforts.[30] While the relative contributions of those factors are unclear, the goal of improved stepping activity and efforts to reach higher intensities was achieved in the HIT phase, which was sufficient to elicit improved patient outcomes.

The present study focused on implementing HIT as a strategy to improve locomotor outcomes, although changes in transfers and balance are of additional interest. Namely, attention to non-walking tasks during PT sessions were likely reduced given the greater effort towards prioritization of stepping activities (i.e., Table 2). Nonetheless, greater gains in FIM-bed and FIM-transfers were observed during HIT, with no differences in BBS between phases. Gains in non-walking outcomes with attention primarily towards locomotor activities has been reported previously in controlled[4,5,16,31] and observational[1,3] studies. The phenomenon was first described by Horn et al.[3] as the "leap-frog hypothesis," where lower-level tasks were improved with practice of higher-level activities. More recently, the term "reverse transfer" was used[31] to describe how locomotor practice may improve non-walking outcomes if walking tasks were biomechanically similar to unpracticed behaviors. The combination of greater walking gains with HIT while simultaneously improving non-walking tasks, and without increasing the incidence of significant adverse events, may minimize the concerns of therapists and improve the efficiency of PT services.

One additional, unexpected finding of interest was a significant 2-day increase in length of stay in the HIT phase as compared to the usual-care phase. Given the significant differences in many primary and secondary outcomes between phases, the opposite findings of reduced length of stay may have been expected. Reasons for this finding are likely multifactorial, but could reflect the greater initial deficits (i.e., Berg scores) during the HIT phase or encouragement by the clinical team to extend length-of-stay in an effort to maximize outcomes. In previous efforts to implement HIT in inpatient rehabilitation in Norway,[16] much longer increases in length of stay were observed during the HIT vs usual-care phase (average 12 day increase), primarily for this latter reason.

Limitations

Limitations of this study include the use of a non-randomized quasi-experimental design, including the absence of a concurrent control group, which could be associated with potential historical changes in medical or rehabilitation services. However, in the US with rehabilitation services funded by third-party payers, these barriers are difficult to avoid. Additionally, data were only collected at a single site and it is unknown whether similar results might be obtained in other contexts. While data from higher functioning patients in the Norwegian study demonstrate similar findings,[16] variations in local contexts can interfere with implementation efforts, as suggested with the protracted transition phase observed here. A separate limitation of the analysis is the dissimilarity of admit BBS scores across phases. While therapists' collection of outcome measures was standardized across the project, there was initial difficulty in getting therapists to collect outcomes on very impaired individuals. Furthermore, this difference may have contributed to the greater incidence of falls throughout inpatient rehabilitation. Additionally, the potential effects of HIT implementation on the other therapy disciplines (e.g., occupational and speech therapy) are unknown, Finally, fidelity targets were often not met, particularly in the transition phase, while only 38% of sessions achieved their target intensity during the HIT phase. Possible explanations include the severity of motor deficits, high incidence of beta-blockers, and therapists either neglecting to document the intensity of their interventions or choosing to do other interventions. Indeed, efforts to achieve >70% age-predicted heart rates are difficult in ambulatory individuals post-stroke (i.e., less motor deficits),[5] and this difficulty is compounded in this study by the greater severity of motor deficits early poststroke. Despite this limitation, observed gains in locomotor function in this and other studies[4,5,7] suggest substantial neuromuscular and cardiovascular adaptations are elicited with application of HIT.[32–35] Nonetheless, it is unknown what effect further implementation efforts might have on fidelity metrics and patient outcomes with additional implementation efforts beyond those achieved during the HIT phase.

Conclusion

Increasing the amount and cardiovascular intensity of gait training during inpatient stroke rehabilitation was feasible and led to significant improvements in locomotor outcomes without detrimental effects on less practiced tasks of balance and transfers. Greater gains achieved during HIT were associated with greater steps/day and attempts to reach targeted intensities, although further efforts towards achieving greater changes in therapy activities may be needed to maximize outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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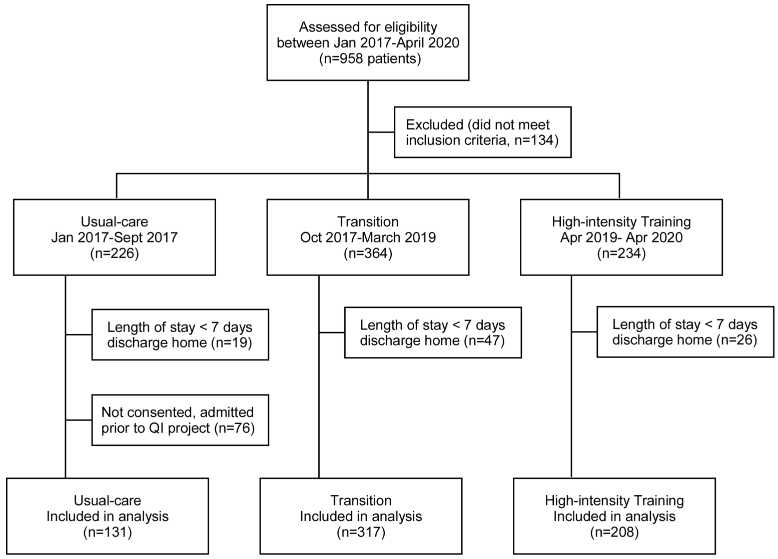

Figure 1.

CONSORT-Type Figure to Provide Timeline of Monitoring Outcomes and Stepping Activity both During Usual Care and Attempts to Implement HIT.

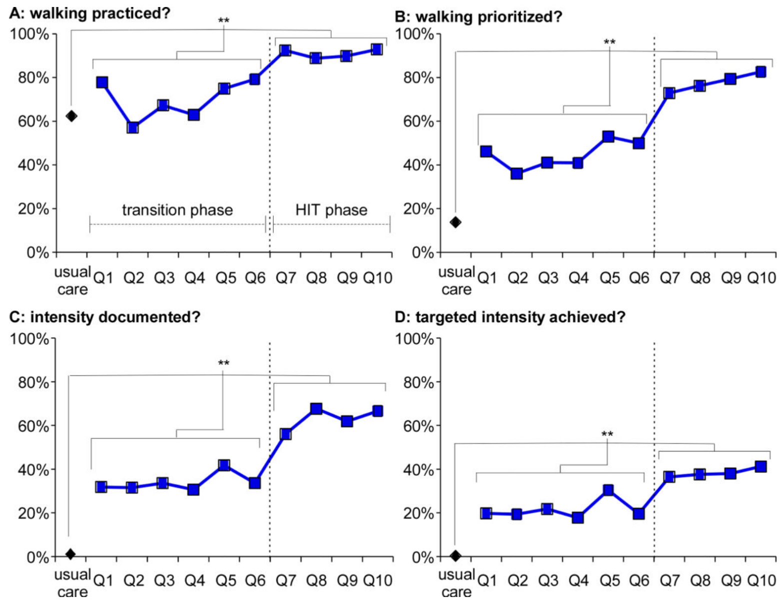

Figure 2.

Intervention Fidelity Metrics Across the 9-month Usual-Care Phase Over the First 9 months (black diamond), during the 18-month Transitional Phase Over Quarters 1–6 Q1-Q6), and 12-month HIT Phase (Q7-Q10); (A) Percentage of Session Walking was Practiced, (B) Percentage of Sessions Walking was Prioritized, (C) Percentage of Sessions Intensity was Documented, and (D) Percentage of Sessions during which Targeted Intensity was Reached.

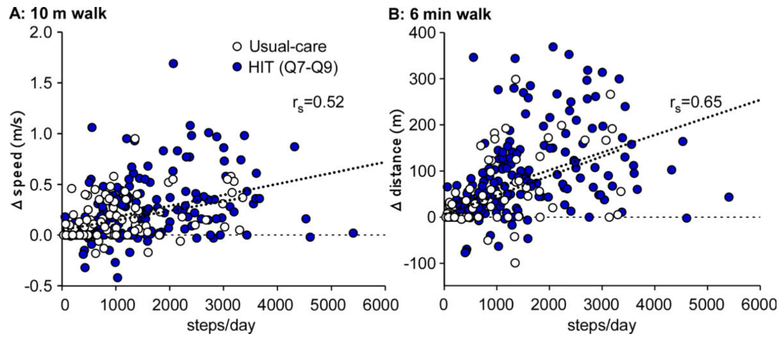

Figure 3.

Dose-Response Relationship for 10MWT (A) and 6MWT (B) Indicating Significant and Similar Relationships in both Usual-Care (white circles) and HIT Phases (blue circles).

Table 1.

Participant Demographics.

	Usual-care (n = 131)	Transition (n = 317)	HIT (n = 208)
Demographics			
Age (y)	63.3 (54.8–75.0)	66.9 (58.7–74.8)	68.2 (57.4–76.3)
Gender: male (%)	67 (51%)	178 (56%)	113 (54%)
Lesion location: right	55 (42%)	141 (44%)	96 (46%)
Left	63 (48%)	143 (45%)	83 (40%)
Bilateral	12 (9%)	28 (9%)	25 (12%)
Lesion distribution: cortical	66 (50%)	160 (50%)	89 (43%)
Subcortical	23 (18%)	65 (21%)	47 (23%)
Subtentorial	12 (9%)	24 (8%)	25 (12%)
Multiple/unknown	30 (23%)	68 (21%)	47 (23%)
Lesion type: ischemic	99 (76%)	240 (76%)	151 (73%)
Hemorrhagic/unknown	32 (24%)	77 (24%)	57 (27%)
Beta-blockers, n (%)	77 (59%)	153 (48%)	120 (58%)
Duration poststroke (d)	8 (6–13)	9 (6–16)	9 (6–19)
Charlson comorbidity index	2 (1–4)	2 (0–3)	2 (0–3)
Baseline assessments			
Paretic leg strength	2.8 (1.0–3.7)	2.8 (0.3–3.7)	2.8 (0.8–4.0)
Berg balance scale	20 (4–33)	6 (3–25)	6 (4–25)
10 mwt (m/s)	0.05 (0.00–0.42)	0.00 (0.00–0.35)	0.08 (0.00–0.32)
10 mwt LOA	1 (1–5)	1 (1–4)	2 (1–4)
6 mwt (m)	0 (0–82)	0 (0–81)	20 (0–92)
6 mwt LOA	1 (1–5)	1 (1–4)	2 (1–4)
FIM-bed	3 (2–4)	3 (1–4)	3 (1–4)
FIM-transfers	3 (2–4)	3 (1–4)	3 (1–4)
FIM-locomotion	1 (0–2)	1 (0–2)	1 (1–3)
FIM stairs	0 (0–2)	0 (0–2)	1 (1–2)
Training characteristics			
Length of stay (d)	20 (13–25)	19 (14–24)	22 (15–29)

	Usual-care (n = 131)	**Transition (n = 317)**	**HIT (n = 208)**
Pt sessions	18 (12–23)	17 (12–21)	18 (13–23)
Pt units/day	3.1 (2.8–3.3)	3.0 (2.8–3.3)	3.0 (2.8–3.3)

Table 2.

Training and Documentation Fidelity Metrics Across Phases.

	Usual-care	Transition	HIT	Significance
Training activities				
Steps/day	780 (226–1360)	834 (302–1577)	1100 (512–1938)	<0.01; HIT > Trans & UC
Steps/hour pt	168 (34–688)	338 (50–866)	616 (275–1154)	<0.01; HIT>Trans>UC
Max-total assist	34 (14 – 79)	80 (24–350)	342(108–642)	<0.01; HIT>Trans>UC
Min-mod assist	356 (156–679)	512 (175–970)	833 (426–1315)	<0.01; HIT>Trans>UC
Contact guard or less	778 (419–1150)	978 (588–1454)	1195 (699–1749)	<0.01; HIT>Trans>UC
Minutes stepping/hour pt	5 (0–16)	10 (0–19)	16 (8–24)	<0.01; HIT>Trans >UC
Stepping rate	18 (0–38)	25 (10–43)	34(19–51)	<0.01; HIT>Trans >UC
Documentation				
Gait practiced	62%	70%	91%	<0.01; HIT>Trans >UC
Gait prioritized	14%	45%	78%	<0.01; HIT>Trans >UC
Intensity documented	1%	34%	63%	<0.01; HIT>Trans >UC
Peak heart rate (% HR_{max})	67 (46–74)	67 (58–75)	66 (59–76)	0.12
Peak RPE	13 (13–14)	15 (13–17)	16(15–17)	<0.01; HIT>Trans>UC
Target intensity achieved	0%	21%	38%	<0.01; HIT>Trans >UC

Table 3.

Outcomes at Admission and Change at Discharge.

	Usual-care	Transition	HIT	Significance
Primary outcomes				
10MWT (m/s)				
Admit	0.05 (0.00–0.42)	0.00 (0.00–0.35)	0.08 (0.00–0.32)	
Δdischarge	0.07 (0.00–0.24)	0.08 (0.00–0.30)	0.13 (0.00–0.35)	0.01; HIT>Trans/ UC
6MWT (m)				
Admit	0 (0–84)	0 (0–81)	19 (0–92)	
Δdischarge	2.1 (0–56)	9.1 (0–80)	50 (9.3–116)	< 0.01; HIT>Trans/UC
6MWT LoA				
Admit	1 (1–5)	1 (1–4)	2 (1–4)	
Δdischarge	0 (0–1)	0 (0–1)	1 (0–2)	0.07
Secondary outcomes BBS				
Admit	20 (4–33)	6 (3–25)	6 (4–25)	
Δdischarge	12 (3–18)	9 (2–18)	12 (3–22)	0.30
FIM-bed				
Admit	3 (2–4)	3 (1–4)	3 (1–4)	
Δdischarge	1 (1–2)	1 (1–2)	2 (1–3)	<0.01; HIT>Trans/UC
FIM–transfers				
Admit	3 (2–4)	3 (1–4)	3 (1–4)	
Δdischarge	1 (1–2)	1 (0–2)	2 (1–2)	<0.01; HIT>Trans/UC
FIM–walk				
Admit	1 (0–2)	1 (0–2)	1 (1–3)	
Δdischarge	2 (1–4)	2 (1–3)	2 (0–3)	0.42
FIM–stairs				
Admit	0 (0–2)	0 (0–2)	1 (1–2)	
Δdischarge	2 (1–3)	1 (1–3)	2 (0–3)	<0.01; HIT>Trans/UC
Adverse events (total incidence and odds ratio [95% confidence interval] versus usual-care)				
All significant	13	31	25	0.22
	-	1.0 (0.48–2.2)	1.3 (0.58–2.8)	

	Usual-care	Transition	HIT	Significance
Death	1	0	0	0.13
	-	N/A	N/A	
Cerebrovascular event	2	4	6	0.38
	-	0.82 (0.14–4.6)	1.9 (0.38–9.6)	
Rehospitalization	10	27	19	0.86
	-	1.2 (0.53–2.8)	1.3 (0.53–3.1)	
Falls (with injury)	12 (1)	70 (1)	38 (3)	0.11
	-	1.8 (0.85–3.6)	2.2 (1.0–4.6)	