Physical Therapy Treatments Incorporating Equine Movement: A Pilot Study Exploring Kinetic Interactions between Children with Cerebral Palsy and the Horse

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Abstract

Background: Physical therapy treatments incorporating equine movement is recognized as an effective tool to treat functional mobility and balance in children with cerebral palsy (CP). To date, only a few studies examined kinematic outputs of the horses and children when mounted. In this pilot study, we examined the interaction between the horses and children with CP during physical therapy sessions where equine movement was utilized to better understand the effectiveness of this type of treatment.

Methods: Four children with CP participated in eight physical therapy sessions incorporating hippotherapy as a treatment intervention. Functional mobility was assessed using the Timed Up Go or 10m Walk Test. Inertial measurement unit sensors, attached to children and horses, recorded movements and tracked acceleration, angular velocity, and body orientation. Correlation between vertical accelerations of children and horses were analyzed. In addition, peak frequencies of vertical accelerations of children and horses were compared.

Results: Functional tests modestly improved over time. The children’s movements, (quantified in frequency and temporal domains) increasingly synchronized to the vertical movement of the horse’s walk, demonstrated by reduced frequency errors and increased correlation.

Conclusions: The findings suggest that as the sessions progressed, the participants appeared to become more familiar with the horse’s movement. Since the horse’s gait at a walk mimics the human gait this type of treatment may provide individuals with CP, who have abnormal gait patterns, an opportunity for the neuromuscular system to experience a typical gait pattern. The horse’s movement at the walk are consistent, cyclical, rhythmical, reciprocal and multi-dimensional which can facilitate motor learning. Thus, the increased synchronization between horse and the mounted participant suggests that physical therapy utilizing equine movement is a viable treatment tool to enhance functional mobility. This study may provide a useful baseline for future work.

Trial registration: Texas A&M University Institutional Review Board. IRB2018-0064. Registered 8 March 2018. Link: https://rcb.tamu.edu/humans/irb and https://github.com/pilwonhur/HPOT

Keywords: Hippotherapy; equine assisted therapy; interaction; children with cerebral palsy; functional mobility
Background

The primary goal of any physical therapy treatment is to improve a patient’s functional ability [1]. Functional mobility is defined as the way a person moves within their environment on a daily basis to interact with society and family [2]. Healthcare providers frequently treat individuals with cerebral palsy who have deficits in functional mobility as well as in other domains. The diagnosis of cerebral palsy (CP) refers to a non-progressive brain lesion in the developing brain which affects a person’s ability to move [3]. CP is the most common cause of motor disability in children [2, 4, 5] and Kirby et al. [4] reported that the prevalence of CP is 3.3 per 1,000 births in the United States, with 75-81% of those diagnosed with spastic CP. It often causes poor balance and muscle weakness [3]. These deficits lead to decreased postural control, which is essential for all movements [6, 7]. Therapy often spans years for individuals with CP, making it challenging for therapists to find effective, evidenced-based treatments that are also motivating for the patient.

One treatment strategy that may benefit persons with CP is physical therapy incorporating equine movement, traditionally known as hippotherapy (HPOT) [8, 9, 10, 11, 12, 13, 14]. HPOT is a treatment strategy applied by licensed therapists or therapist assistants of physical, occupational, and speech therapy in which the equine movement is utilized and manipulated by the therapists to attain functional goals [8, 10, 12, 13, 15]. During HPOT, activities are based on the participant’s position and movement while mounted [13]. HPOT can be part of an integrated treatment plan that addresses functional limitations and impairments to facilitate functional skills [8, 10, 12]. Specific physical therapy goals for an HPOT session often include improving overall function, balance, and posture [8, 12]. Previous studies describe the benefits of HPOT and therapist-designed adaptive riding for children with CP, including improved gross motor function, dynamic balance, and trunk postural coordination [9, 10, 12, 13, 14, 15, 16]. In this study, the term HPOT will be used to refer to physical therapy sessions that incorporate equine movement as a therapy tool.

The principles of HPOT derive from the movements a horse provides to the individual astride the equine. Studies have been done to look at the kinematic movement patterns of the horse and rider. MacPhail et al. [11] used kinematic analysis to look at the pelvic movement of the horse and lateral trunk movements of riders; six with CP and seven with no disabilities. Markers were placed at C7 and L5 vertebrae on each rider and on each horse at the right and left hip joints. Kinematic analysis revealed that the horse’s pelvis appeared to move in a dual frequency sinusoidal curve pattern, as opposed to a simple sinusoidal curve, leading researchers to note that this more complicated movement pattern increased the need for postural adjustments of riders. They reported that normal equilibrium responses (using the children who were typically developing as the reference) were elicited in 65-75% of the responses for riders who had diplegic CP and 10-35% of the responses for riders with quadriplegic CP. The researchers concluded that for children with diplegic CP, it might be an effective way to elicit and practice sitting equilibrium reactions [11].

Haehl et al. [17] examined movement patterns using a 60-Hz camcorder to collect kinematic data on riders and horses. Markers were placed on each child at C7 vertebra, between the posterior-superior iliac spines, and mid-way between those points.
Markers on each horse were at the withers, T17 vertebra, and the lumbosacral junction. The investigators first looked at two children without special needs and tracked the kinematic relationship. They found that the riders demonstrated a biphasic movement pattern in reaction to the horse’s movements. Second, they examined two children with CP for 12 weekly HPOT sessions. Data found that the biphasic movement patterns seen in the typically developing children were approximated in the children with CP as the session progressed. Also, both participants with CP demonstrated enhanced coordination between upper and lower trunk, exhibiting the most overall postural stability during the final HPOT session, and one child improved in his transfers and ambulation skills. The authors stated that HPOT might provide opportunities for a child to explore new movement strategies [17].

A study conducted by Garner and Rigby [18] examined three-dimensional pelvis motion of six children without disabilities. Five kinematic measures were taken, using motion capture systems to observe the inexperienced riders wearing a customized pelvic belt with LED markers attached. The participants rode each of the four horses at walk, then walked on foot, through the two observational spaces. Similarities in significant pelvic motions were found, such as the number and shape of valleys and peaks, for both riding and walking [18].

A study by Uchiyama et al. [19] used acceleration data to evaluate the similarity between the movements of children and horse based on the hypothesis that the horse’s pelvic movement during therapeutic riding sessions are similar to the human pelvic movement while walking. Three-dimensional accelerometers collected acceleration of both horses and humans walking for a three-minute period and stride-phase data was generated from foot movements. The results showed that the frequency peaks of human walking corresponded with those of the horse walking, especially during the stride-phase. The authors concluded that riding a horse at a walk provides sensory and motor input to the rider comparable to the human activity of walking, thus offering a potential treatment option for individuals with gait abnormalities [19].

While studies have shown potential benefits in enhancing functional performance of the children with CP, it is still unclear how the enhancement is accomplished. Interaction between the children with CP and the horses is deemed to be the main enabler of the successful rehabilitation. However, studies showing association between kinematics of horse movement and children’s movement with CP failed to systematically examine how the interaction affects the functional performance of the children with CP. The objectives of this study are to examine i) how the use of HPOT in physical therapy treatments affects the functional performance of the children with CP, ii) how physical therapy incorporating equine movement affects the interaction between the rider (i.e., children with CP) and the horse, and iii) how the functional performance is correlated with the interaction. To investigate the interaction between the rider and the horse, kinetic variables were analyzed.

**Methods**

**Participants**

This repeated-measure design study consisted of functional assessments and kinetic sensor measurements. A convenience sample of participants was recruited.
Approvals of Institutional Review Board and Animal Use Protocol from Texas A&M University (TAMU) were obtained. Consent forms and signed releases were completed by parents of the participants. Inclusion criteria were:

- ages 2.5 - 14 years of age diagnosed with spastic cerebral palsy
- GMFCS (Gross Motor Function Classification System) level I, II, or III
- ability to reliably signal pain, fear, or discomfort and follow simple directions
- lack of or mild scoliosis
- no botulinum toxin treatments, orthopedic, or neurosurgery in the six months preceding initiation of HPOT sessions

Subjects were recruited from two Professional Association of Therapeutic Horsemanship International (PATH Intl.) Premier Accredited Centers: TAMU Courtney Cares in College Station, TX and ROCK in Georgetown, TX. Clients who were eligible for research participation according to the inclusion criteria were asked, under the guidance of their legal guardian, if they were interested participating.

In total, four subjects participated in the experiment. The first three subjects, all GMFCS Level II, had spastic hemiplegia CP. The fourth subject, GMFCS Level III, had spastic quadriplegia CP and used a rolling walker for assistance when ambulating (Table 1). GMFCS describes the gross motor function of persons with CP by using a five-level, simple grading system and is the most recognized and established functional classification measure for CP [20]. It was selected for the criteria as it provides a method of describing function that is quick, easy to use, and meaningful to health care professionals.

**Experimental Protocols**

*Functional mobility tests*

The experiment was conducted at two PATH International Premier Accredited Centers and at TAMU Parson’s Mounted Cavalry Headquarters. Data were collected on days one, four, and eight of the eight sessions, with functional assessments performed prior to and immediately after each HPOT session (Fig. 1). The Timed Up and Go (*TUG*) measures the time it takes a child to stand up from a chair, walk 3 meters, turn around, walk back to the chair, and sit down. The *TUG* was used because it is commonly used measure to test dynamic and functional balance [21]. In children, the *TUG* is used to identify deficits in dynamic balance that may delay motor skill acquisition and could cause motor delay [21]. In addition, it has been shown to correlate well with other measures of balance, postural sway, and gait speed [22].

The fourth participant ambulated with a rolling walker, had a decreased cadence, and found sit-to-stand transitions challenging, making the *TUG* impractical and necessitating a different assessment tool. The 10 Meter Walk Test (*10mWT*) was chosen, which measures the time it takes a person to walk at a comfortable speed from markers at 2-8 m within the designated 10 m pathway. It is cost effective, easy-to-use, safe, and has been shown to have excellent inter-rater and intra-rater reliability [23].

*Sensors*

To examine how the riders and horses interact and to investigate the causes (i.e., kinetics) of movement (i.e., kinematics including displacement, velocity), one inertial measurement unit (IMU) (9DoF Razor, SparkFun, Boulder, Colorado, United
States) was attached on the head/helmet of the rider and one additional IMU at the low back of the horse (Fig. 2). The SparkFun 9DoF Razor was selected because it was tiny, lightweight and contained a board with a microprocessor, IMU and a microSD card. Since the Razor IMU was tiny and lightweight, it had minimal chance to distract the children with CP and the horse during the HPOT sessions. The IMU data on each Razor IMU were logged to the microSD card embedded to it with a sampling rate of 100 Hz. Before each HPOT session began, all Razor IMUs were synchronized by a single sync signal triggered by an external push button (Fig. 2).

**Intervention during sessions**

The horses were led by a trained horse handler and accompanied on each side by a physical therapist and an assistant. The equine partners were fitted with a saddle pad, bareback pad, girth, and side-pull or halter. Participants wore approved riding helmets and rode in a forward-astride position. The riding pattern was designed by the two physical therapists conducting the study, both Hippotherapy Clinical Specialist-certified by the American Hippotherapy Certification Board. The pattern was designed to maintain consistency of the movement patterns and was never altered. The trajectories of the horse and walking distances were controlled as much as possible between arenas.

Eight 20-minute physical therapy sessions incorporating HPOT were conducted (Fig. 1). A series of figure-of-eight patterns were made, at a steady pace, across the arena for the initial 10 minutes. For the second 10-minute period, the horse continued the pattern, walking at the same steady pace but with walk-halt-walk transitions at one-minute intervals. Three of the four children were given a ring-shaped toy to hold with both hands during the second 10-minute period, to reduce the impulse for upper extremity protective extension with changes in perturbations. The fourth child was not given a toy as she needed her hands on a weight-bearing surface to maintain stability. The first half of the session allowed the riders to feel to the slow, rhythmical, multi-dimensional aspect of the horse’s gait at a walk. The second part of the session further challenged the rider’s balance, righting reactions, and trunk control.

Throughout the session, the physical therapist monitored the participant’s position and midline orientation. If the rider shifted off midline, the physical therapist had the horse handler stop the horse so that the rider could regain midline orientation. Each rider needed a static surface to regain midline orientation, but with varying degrees of assistance.

**Data Analysis**

The time (in seconds) taken to complete TUG were recorded. Alternatively, when the TUG was not feasible due to functional limitations of the participant, the time taken to complete 10mWT were recorded. These functional mobility tests were measured before and after HPOT sessions 1, 4 and 8 (Fig. 1). To analyze how the riders and horses interact, we focused on a kinetic variable rather than a kinematic variable. Among all available IMU data, we examined vertical acceleration data, ACCz, from all sensors since the majority of the movement was in the vertical direction. ACCz indicates changes in gravity that generate physical changes in
movements of the body [24], and may represent the interaction force normalized by the mass of the body. In this study, we analyzed the data from the first 10 minutes of the sessions (Fig. 1), when the equine movement was continuous, to observe the uninterrupted repetitive and rhythmical patterns. Data from the second half of the sessions will be analyzed in the future study.

For simplicity, we assumed that the signal from the horse’s back was the reference signal and that the signal from the rider’s head was affected by the reference signal. The cross-correlation between the reference $ACC_z$ and the $ACC_z$’s from the rider’s head was studied. The correlation between the two signals indicated the similarity between the two, ranging from $-1$ to 1. Due to the nature of the interaction between the horse and the rider, the two signals may have had a time difference (Fig. 3). Therefore, the time shift (in seconds) of the reference signal that produced the maximum correlation was also examined. Th higher correlation and smaller time shift may indicate that two systems (i.e., the horse and the rider) were interacting more tightly.

In addition, $ACC_z$ was analyzed in the frequency domain via the fast Fourier transform (FFT) to study the dominant frequencies of the signals. Specifically, harmonics, i.e., multiple peaks, of the transformed data were analyzed. Assuming that harmonics of the horse’s back were the reference signals, harmonics from the IMU on the rider’s head were compared (Fig. 4). The errors between the reference harmonics and the rider’s harmonics at these dominant frequencies were examined. Smaller harmonics errors may indicate that two systems (i.e., the horse and the rider) were interacting more tightly. No statistical analyses were performed due to small sample size ($n = 4$) in this pilot study.

### Results

#### Functional Mobility Tests

Participants 1-3 performed the TUG whereas participant 4 found sit-to-stand transitions challenging, making the TUG impractical. Therefore, participants 1-3 performed TUG and participant 4 performed 10mWT. On average, the times taken to finish the TUG decreased by 18.3% and 27.5% for session 4 and session 8 compared to session 1, respectively (Fig. 5). A few exceptions existed. For example, subjects 2 showed increased TUG after HPOT session 4 compared to session 1 whereas subject 3 showed increased TUG before HPOT session 4 compared to session 1.

Notably, the TUG results were more variable after the HPOT sessions (s.d.: 4.17) than before (s.d.: 3.56) (Fig. 5 top left vs. bottom left). Specifically, variability drastically reduced during sessions 4 and 8 for Pre-HPOT whereas variability remained relatively constant throughout the sessions for Post-HPOT. Anecdotally, the youngest child (age 32 months) did not comply with instructions to sit in the chair at the end of the test; instead, just prior to sitting she chose to go look for her mother.

Participant 4, who required a rolling walker and contact-guard assistance, demonstrated improved times on the 10mWT over the sessions (Fig. 5 right column). On average, the times taken to finish the 10mWT decreased by 36.6% and 37.1% for session 4 and session 8 compared to session 1, respectively (Fig. 5). Further, at the end of her first HPOT session she appeared tired (i.e., increased drooling) and was
easily distracted; at the conclusion of her eighth and final session, she was talkative
and attentive. There was no variability measured for 10mWT since there was only
one participant for it.

Interaction: ACCz
Overall, the time series data from both IMU sensors tended to resemble each other
as the HPOT session progressed. The maximum correlation between the reference
signal (i.e., ACCz from horse’s back) and ACCz from rider’s head increased 84.7%
for session 8 compared to session 1 (Fig. 6 left). Similarly, the time shift also de-
creased 23.3% and 23.3% for session 4 and session 8, respectively, compared to
session 1 (Fig. 6 right).

Dominant frequencies were observed at around 1.5, 3.0, and 4.5 Hz for both the
horses and the riders, which agrees with the literature [19] (Fig. 4). Components at
the lower frequencies (e.g., less than 1 Hz) are the constant artifacts due to gravity,
and thus are not considered for the analysis. The data revealed that as the physical
therapy sessions utilizing HPOT treatments progressed, the dominant harmonics of
ACCz for both the horses and the riders converged to each other, suggesting that
all participants demonstrated an increase in synchronization with the horse during
the horse’s movements at a walk. Of note, the Root Mean Square Error (RMSE) of
the dominant peak frequencies of ACCz for both the horse’s back and the rider’s
head decreased by 26.5% and 74.5% for session 4 and session 8 compared to session
1, respectively (Fig. 7). Interestingly, variability of the RMSE decreased by 32.1%
and 81.1% for session 4 and session 8 compared to session 1, respectively (Fig. 7).
Reduced RMSE mean and variability may indicate that the riders and the horses
interacted in more consistent and synchronous ways.

Discussion
Due to limited number of participants, statistical analyses could not be performed.
Instead, mean and standard deviation (s.d.) were reported in the result section. In
sum, with continued HPOT sessions, children with CP showed improved functional
mobility (Fig. 5). For children with CP, functional deficits are often a result of poor
postural control [6]. Yet motor skills improve when postural control improves [25].
HPOT may facilitate equilibrium and righting reactions through the variations in
the horse’s velocity, direction, and stride length [12]. In a study by MacPhail et
al. [11], the researchers noted that involuntary postural reactions of the trunk and
head—specifically, equilibrium and righting reaction—were a result of the passive
displacement of the rider’s center of gravity. The movement imparted to the rider
when the horse is walking plays a crucial role in HPOT treatments.

With continued HPOT sessions, vertical movements (i.e., ACCz) of children with
CP and horses appeared to became more synchronized (Figs. 6, 7). Participants may
have become more familiar with the horse’s movement pattern. This observation
is significant for therapists who may want to incorporate equine movement as a
treatment strategy. One reason is that for children, motor learning requires the
effective training of motor function [26]. Despite limitations, the child must problem-
solve and be an active learner to obtain new age-appropriate skills [26]. Children
differ from adults in that, typically, they are not trying to regain function as they
lack a motor image of how to perform a new task [26]. To learn new motor skills, the new skill must be practiced multiples times, which may be why the horse’s gait at a walk can be an effective tool in gaining postural control. According to Janura et al. [27], a frequency of 90-100 impulses per minute are imparted to the rider, providing many opportunities for postural adjustments, even within a limited time period. This is significant since proximal stability and postural control are the foundation on which children learn functional motor skills [17].

Another factor supporting HPOT as a treatment strategy is that the movement of the horse at a walk follows a sinusoidal wave pattern [18, 25]. This pattern puts a demand on the rider’s automatic postural responses as they must coordinate and control their movements [11, 17]. Also, the dynamic treatment and changing environment may affect multiple systems, including vestibular and proprioceptive systems [10, 12]. With the dynamic movement on the horse, compensatory postural strategies may be reinforced or explored [15, 17]. The cyclical and repetitive movements provide numerous opportunities for practice of postural adjustments [10]. Silkwood-Sherer et al. [15] suggested that with this type of therapy children can improve reactive and anticipatory postural control strategies in response to complex sensory input. Maintaining postural control while simultaneously moving through space and adjusting perceptual skills, facilitates the refinement and exploration of new movement patterns, which in turn, enhances functional mobility [15].

A third factor in favor of integrating HPOT into physical therapy treatments is that the horse’s movement at a walk simulates the human gait pattern [14, 18, 19, 25]. Many children with CP have diminished ambulation skills, due in part to poor balance control [7, 25]. Liao et al. [25] found that rhythmic weight-shift training may facilitate improved walking performance for children with CP. It appears that HPOT may provide an opportunity for balance skills and ambulation skills to be addressed simultaneously for this population.

Last, many children with CP are restricted by slow gait speed which is one measure of walking performance [1, 26, 25]. Quality of life and functional ability are also linked to walking [5]. While the findings from this study are not statistically significant, it is noteworthy that the participant who performed the 10mWT demonstrated a considerable improvement in gait speed. Her walking speed improved substantially during the course of the study and her parents reported a significant increase in her transfer skills at home. These results corroborate the findings observed by Casady and Nichols Larson [10] that HPOT may influence skill acquisition of motor tasks in daily functional tasks.

To our knowledge, this is the first study to investigate the interactive forces produced by the movement patterns of a horse at walk with a rider, a child with CP. While the findings are encouraging, this study had several limitations: a) small sample size; b) range in ages and ability levels of participants; c) two functional mobility tests were administered; d) only one of the three dimensions of the horse’s movement pattern at a walk was analyzed; e) causal relation between enhancements in functional mobility and synchronized interaction may not be determined; and f) the observed synchronized interaction may not tell us whether horses affected the children with CP more or vice versa. Future studies will examine these factors to extrapolate the findings to a broader population of children with CP. Also, future
research could focus on other planes of movement imparted to the rider by a horse at walk to better understand the dynamics of the interaction of the forces during a HPOT session.

**Conclusion**

Benda et al.[8] noted that in addition to developing skills, HPOT provides social, emotional, cognitive, and physical stimulation in a way not typically seen in conventional treatment. HPOT has been shown to positively influence skill acquisition, including balance and postural control, the foundations of movement. In this study, we questioned whether HPOT can lead to improved functional mobility in children with CP. Outcome measures demonstrated a trend towards improvements in the functional mobility of participants, indicating a positive response to the physical therapy treatments incorporating equine movement.

The findings from this study suggest that with continued HPOT sessions, participants appeared to become more familiar with the horse’s movement. The horse’s gait at a walk is consistent, cyclical, rhythmical, bilateral, and symmetrical. Given that it also mimics the human gait [18, 19, 25], the increasing synchronization between horse and rider suggests that HPOT is a viable physical therapy treatment tool to facilitate functional mobility goals. Despite the limited number of participants, this study may provide a useful baseline for future work.

**Competing interests**

The authors declare that they have no competing interests.

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**Ethics approval and consent to participate**

All patients provided informed consent, and the study protocol was approved by Texas A&M University Institutional Review Board (IRB2018-0064).

**Consent for publication**

Consent forms and signed releases were completed by parents of the participants who agreed the publication of the research data and findings.

**Availability of data and materials**

Summary data of the study are included on GitHub repository [28]. All data collected in the study are available from the corresponding author upon reasonable request.

**Author’s contributions**

PL designed, coordinated and conducted the experiments and wrote significant portion of the manuscript. YL conducted the experiments, analyzed the data and wrote significant portion of the manuscript. NK designed and coordinated the experiments. PH designed, coordinated, and conducted the experiments, analyzed the data and wrote significant portion of the manuscript. All authors read and approved the final manuscript.

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**Figures**

**Figure 1** Experimental protocol. Functional mobility tests were performed before and after the HPOT sessions. Each 20-min HPOT session consisted of 10-min continuous riding and 10-min riding with multiple go-stops. The figure-of-eight patterns were made during the HPOT session.

**Figure 2** IMU sensors to capture the sinusoidal wave pattern of the horse's gait at a walk [18] and to examine how the rider and the horse interact.

**Figure 3** Sample plots of ACCz for both rider's head (i.e., IMU1 from Fig. 2) and horse's back (i.e., IMU2 from Fig. 2). ACCz from IMU1 (in blue) lags ACCz from IMU2 (in red).

**Figure 4** Power Spectral Density of ACCz from head and ACCz from horse back.

**Figure 5** Bar graphs of the functional mobility tests. Top graph shows TUG results for participants 1-3 whereas bottom graph shows 10mWT for participant 4. Error bars in the top graph indicate one standard deviation. Bottom graph does not have the error bars since it involves with only one participant.

**Figure 6** Maximum correlation (top) and time shift for the maximum correlation (bottom). Error bars indicate one standard deviation.

**Figure 7** Root Mean Square Error (RMSE) between the peak harmonics of head ACCz and horse's back ACCz. Error bars indicate one standard deviation.
## Tables

### Table 1  Participant Demographics and Characteristics

| Participant | Age (years) | Sex | GMFCS | Type of CP   | Ambulation Assistive Device |
|-------------|-------------|-----|-------|--------------|----------------------------|
| 1           | 2.5         | F   | II    | Hemiparesis | None                       |
| 2           | 4.3         | M   | II    | Hemiparesis | None                       |
| 3           | 12.5        | F   | II    | Hemiparesis | None                       |
| 4           | 10.8        | F   | III   | Quadriparesis | Rolling Walker             |