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Improvement in overground walking after treadmill-based gait training in a child with agenesis of the corpus callosum

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Improvement in overground walking of a child with agenesis of the corpus callosum after treadmill-based gait training

Abstract

<u>Background and Purpose</u>: Agenesis of the corpus callosum (ACC) is a rare congenital brain defect that produces a wide variety of cognitive and motor impairments. Literature is scarce regarding this population's response to physical rehabilitation. Treadmill-based gait training (TT) has been shown to improve walking ability in some pediatric populations, but has not been investigated in children with ACC.

<u>Case Description</u>: Our subject was a 13-year-old female with ACC and cortical visual impairment who ambulated independently using a reverse walker for household and short community distances. We implemented a **home-based TT intervention** (two phases of 3-month training over six months) and **conducted a lab-based gait analysis** at four time points: baseline, after each of two training phases, and 3 months after cessation of training. The intervention consisted of weekly bouts of TT. Phase 1 incorporated 15-minute forward, backward, and incline walking; Phase 2 continued this protocol and added another 10-minute short-burst interval training. Data collected at each lab visit included spatiotemporal parameters and kinematics (joint angles) during overground and treadmill walking.

<u>Outcomes</u>: After both phases of training, our subject increased step length, decreased step width and foot progression angle**, and decreased variability of most spatiotemporal parameters**. Further, after Phase 2 our subject increased peak extension at the hip, knee and ankle, **decreased** crouch gait, and improved minimum foot clearance during overground walking. **Most gait improvements were retained for three months after cessation of the intervention.**

<u>Discussion</u>: This report demonstrates that TT may be a safe and effective treatment paradigm for children with ACC. Future research should investigate the effect of intervention dosage on gait improvements and generalization in individuals with ACC.

Introduction

Agenesis of the corpus callosum (ACC) is a congenital brain defect; its exact incidence is not well documented, but the highest estimates place it as occurring in seven of every 1000 births.[1] A wide variety of presentations, ranging from normal IQ and motor function to significant cognitive and motor impairments can be seen in ACC.[2-4] The incidence of specific presentations is unclear in the literature. A survey by Moes, Schilmoeller & Schilmoeller [5] reported that developmental delay was present in 66-79% of children with ACC and noted significantly delayed attainment of most gross motor milestones when compared to a typically developing sibling group. In contrast, a meta-analysis by D'Antonio, et al. [2] reported gross motor delays in just 4.4% of children with isolated complete ACC and cognitive delays in 15.2% and 17.3% of children with isolated partial and complete ACC, respectively.

Although the presentation of ACC varies significantly, it has been reported to affect individuals at all levels of the International Classification of Functioning, Disability and Health framework[6], including Body Structures and Functions, Activities, and Participation. Some of the most common sensorimotor impairments reported in individuals with ACC include low muscle tone, decreased cognitive function, difficulties in learning, and poor sensory processing, balance and bilateral coordination.[2,4,5,7-9] Delayed gross motor skills have been reported in children with low muscle tone[10] **and in children with** decreased cognition[11], suggesting that children with ACC who demonstrate hypotonia or cognitive delays may also be at risk for motor delays. Interestingly, Meyer, Roricht & Niehaus [3] reported on six individuals who were incidentally discovered to have callosal agenesis without any symptoms other than an inconsistent difficulty with achieving heel-toe gait. This suggests that abnormalities in gait may be present in otherwise unaffected individuals with ACC. However, the specific characteristics of gait in children with ACC have not been examined in the literature.

Additionally, despite evidence of the potential for motor delays in children with ACC[2,5,9], there is a lack of literature describing this population's response to rehabilitation. Chiappedi & Bejor [1] recommend that rehabilitation, including physical therapy (PT), begin early in children with ACC to minimize secondary complications and take advantage of the plasticity of the young child's nervous system. Akbal [12] described a case in which a 2-year-old child with ACC responded well to conventional PT intervention, gaining the ability to sit, stand, and walk with an assistive device over the course of five years of treatment. Pacheco, Queiroz, Niza, da Costa & Ries [13] also reported improved postural control and transfers in a 2-year-old child with ACC following PT intervention that focused on functional training. Examination of the efficacy of specific training protocols, as well as the response of older children to therapy, is lacking.

Treadmill training (TT) has **shown** its efficacy in accelerating the onset of walking and improving the quality of gait pattern in infants with Down Syndrome[14-17] although the literature supporting its efficacy in other populations is inconclusive.[15,18] However, improved walking speed following some TT protocols has been observed in children with cerebral palsy (CP)[19-21] and in ambulatory young children with developmental delay[18]. In their systematic review, Dewar, Love & Johnston [20] noted that ambulatory children with CP who participated in TT that progressively increased belt speed demonstrated the **greatest increase** in walking speed. Backward walking on a treadmill has also been reported to improve postural control[22], step length, walking speed, and postural symmetry[23] in children with hemiplegic CP. Incline walking on a treadmill has been found to increase the activity of the hip, knee, and ankle extensors in healthy young adults.[24] Further, Bjornson, Moreau & Bodkin [25] found that a TT protocol utilizing short-burst interval training (SBIT) globally improved walking performance in children with CP, increasing overground walking speed, Timed Up-and-Go performance, and amount of time spent engaging in moderate-to-high intensity walking during the day. As reduced capacity for rapid force generation is strongly correlated with decreased functional walking ability[26] and slower walking velocities[27] in individuals with CP, SBIT may potentially present an effective approach to augmenting training effects in other populations. However, to our knowledge, a TT paradigm including these components has not been investigated in children with ACC.

The purpose of this study, therefore, is to investigate the effect of a novel treadmill intervention paradigm on the gait parameters of a child with ACC. This intervention was designed with two phases, the first of which incorporated **15 minutes of** forward, backward, and incline walking (Phase 1), and the second of which maintained the protocol of Phase 1 and added **another 10 minutes of** SBIT (Phase 2). We hypothesized that our subject would improve (a) spatiotemporal gait parameters, such as increasing walking speed and step length, and (b) joint kinematics, such as increasing peak joint extension angles, following Phase 1 of TT, that our subject would demonstrate greater improvements in these same parameters following Phase 2, and that the improvements would persist three months following cessation of the TT protocol.

Patient Information

Our subject was a 13-year-old female with ACC and cortical visual impairment **that limited her vision both at a distance and in her lower visual field**. This study was approved by the institutional review board at the hosting university. A **parent consent** form was signed by the parent and assent was obtained from the subject.

Clinical Findings

At baseline, our subject demonstrated hypotonia throughout her trunk and extremities. She also demonstrated weakness about her trunk and lower extremities, most notably her abdominals, hip extensors, and ankle plantarflexors, as evidenced by a crouched stance and excessive anterior pelvic tilt during both standing and walking. She ambulated with modified independence using a reverse walker for household and short community distances and was able to transition independently in and out of her walker from both short-sitting on a chair and sitting on the floor. Her height and **body mass increased** from 116.5 to 122cm and from 26.3 to 27.4 kg, respectively, between visit 1 (before intervention) and visit 4 (three months after intervention).

Therapeutic Intervention

The subject received an intervention that consisted of once-weekly bouts of TT for two phases of twelve weeks each. All TT sessions were conducted by the same licensed physical therapist in the subject's home on a Life Fitness T3i home fitness treadmill (Rosemont, IL) **with a 137cm x 51cm belt.**

Phase 1

The protocol consisted of ten minutes forward incline walking followed by five minutes backward walking (Table 1); no rest was provided between forward and backward walking. This phase of the training protocol was designed to increase walking speed by combining progressive, incremental increases in belt speed with incline and backward walking to increase demand on hip, knee, and ankle extensors.[24,28]

137 The subject wore shoes and bilateral supramalleolar orthoses during the training. During forward walking, the subject held an anterior bar on the treadmill independently. During backward walking, the subject was given bilateral hand-held assist by the therapist. For forward walking, treadmill speed was initially set at 0.22 m/s, generally considered the minimum speed for household ambulation.[29] Speed was increased as quickly as possible, so long as the subject visually appeared to achieve near-full knee extension in terminal swing and maintain an upright trunk for >75% of steps (Table 1). Speed was progressively increased up to 1.34 m/s, the typical walking speed for community ambulators.[29] After a speed of 1.34 m/s was reached, the grade was increased by the increment of 0.5% and the speed was lowered when necessary. For backward walking a similar pattern was followed, although treadmill speed was only increased up to 0.36 m/s due to the subject's difficulty coordinating backward stepping and intolerance to higher speeds.

149 *Phase 2*

150 The protocol consisted of the protocol **at phase 1** immediately followed by ten minutes of SBIT consisting of alternating bouts of 30-second slow walking and 30-second fast walking (Table 1). This resulted in a total training time of 25 minutes for each session during Phase 2. Treadmill speed was adjusted following the same guidelines set forth in Phase 1. For the SBIT, the "slow" speed was set to 75% and the "fast" speed to 150% of the current forward walking speed.

157 **Timeline of gait evaluation**

158 Gait data **were** collected in our lab at four time-points: before the intervention (visit 1), within one week of completing Phase 1 (visit 2) and Phase 2 (visit 3) of the intervention, and three months after cessation of the intervention (visit 4). Gait data were collected using an eight-

camera Vicon motion capture system (Vicon, Denver, CO) with a Plug-In Gait Lower Body marker set and a sampling rate of 100 Hz. Reflective markers were placed bilaterally on the **anterior superior iliac spine, posterior superior iliac spine,** lateral thigh, lateral knee, lateral tibia, lateral ankle, heel, and toe. Anthropometric measures including height, weight, and leg length were collected. The subject walked barefoot overground **at a self-selected speed** for five good trials **in which the subject walked through the 10m camera field without stopping** with a reverse walker, and on a treadmill **at various speeds while holding onto an anterior bar** for two minutes. **Three treadmill speeds were used: her overground walking speed from the first visit, twice that speed, and three times that speed (which was approximately the top speed she achieved during TT); these speeds ranged from 0.4 to 1.2 m/s.**

Gait data were processed using Vicon Nexus 2.3 (Vicon, Denver, CO). Gait events (heel-strike and toe-off) were manually labeled for overground trials and were **identified** using an **anterior/posterior (AP) velocity** change of each heel marker for treadmill trials; a velocity change from positive to negative indicated a heel-strike event and a change from negative to positive indicated a toe-off event.[30,31] Spatiotemporal parameters and joint kinematics were calculated **for both overground and treadmill walking** using custom MATLAB (Mathworks, Natick, MA) programs.

Step length was calculated as the AP difference between the ipsilateral and contralateral heel markers at heel strike. Step width was calculated as the medial/lateral (ML) difference between the heel markers at heel strike. Foot progression angle (FPA) was calculated as the angle between the toe marker and the heel marker in reference to the line of forward progression. Positive FPA values represent out-toeing, while negative FPA values represent in-toeing. Temporal variables included cycle, stance, swing, and double support times of gait cycle. Cycle time was defined as the elapsed time between two consecutive ipsilateral heel strikes. Stance time was defined as the time between each ipsilateral heel strike and subsequent toe off, while swing time was defined as the time between each ipsilateral toe off and subsequent heel strike. Double support time was calculated for the first double support phase of each gait cycle.

We determined peak joint extension angles at the hip, knee, and ankle. Hip joint angles were calculated as the angle between the vector formed by the knee and thigh markers and a line perpendicular to the vector formed by the ipsilateral ASIS and PSIS, projected onto the sagittal plane. A positive angle represents hip flexion and a negative angle represents hip extension. Knee joint angles were calculated as the angle between the vector formed by the knee and thigh markers and the vector formed by the knee and tibia markers; angles were subtracted from 180° to give the anatomical angle. Ankle joint angles were calculated as the angle between the vector formed by the knee and ankle markers and the vector formed by the heel and toe markers. Angles were subtracted from 90°; positive values represented dorsiflexion and negative values represented plantarflexion. Joint angles were time-normalized to 100% of a full gait cycle, and peak joint extension angles were defined as the maximum angle at each joint for each gait cycle. Normalized trials across each visit were then averaged together to produce mean angles for each joint. **As kinematic patterns of treadmill walking at each visit were found to be similar, regardless of speed, we collapsed the kinematic treadmill data across all speeds prior to further analysis.** To investigate the variability of our variables, coefficient of variation (CV) was calculated as the ratio of standard deviation to mean value for each variable. All trials within each visit were combined when calculating the CV.

Additionally, our subject demonstrated a crouched gait pattern at baseline, an often-progressive abnormality associated with increased knee flexion, decreased foot clearance in swing phase[32], and increased fatigue.[33] We therefore evaluated both progression of crouch, defined as the amount of knee flexion at initial contact[34], as well as minimum foot clearance (MFC). To calculate MFC, the trajectory of the toe marker during swing phase of each step was plotted and visually identified as either a bimodal pattern with two peaks or a unimodal pattern with only one peak (Fig. 1a-b).[35] The percentage of steps following a bimodal pattern was calculated. MFC was calculated on all steps following a bimodal pattern and was defined as the minimum vertical height **of the toe marker** between the two peaks of the toe marker during swing phase[36].

Outcomes

Treadmill intervention

The subject completed 10/12 recommended training sessions over each phase of intervention. Missed sessions were due to subject illness or travel. **The subject was able to tolerate increases in treadmill parameters at most visits without report of adverse effects** (Table 1).

Overground spatiotemporal gait parameters and variability

The subject demonstrated improvements in some overground spatial gait parameters over the course of study. Although her walking speed initially increased after Phase 1, this increase was not maintained after Phase 2 and returned to baseline by visit 4 (Table 2); cadence followed a similar pattern (Fig 2a). Step length increased by 36.9% from visit 1 to visit 4 (Fig 2c). Step width decreased at visits 2 and 3 and remained 48.3% decreased from baseline at visit 4; it demonstrated substantially greater improvements

following Phase 2 than following Phase 1 (Fig 2e). FPA decreased consistently across all visits, demonstrating an 18.4% decrease from baseline at visit 4 (Fig 2g).

Several spatiotemporal parameters demonstrated decreased variability over the course of the study. Variability of cadence (Fig 2b), step length (Fig 2d), FPA (Fig 2h), cycle time, stance time, and swing time (Table 2) all decreased across the course of the study. Step width variability was less consistent, increasing initially but returning to baseline by visit 4 (Fig 2f).

Overground *peak joint extension angles*

All peak joint extension values were found when the joints were in flexed positions; however, their values substantially decreased following Phase 2 of the intervention (Table 3). At visit 4, peak hip extension was 19.57° (21.6% increase from baseline), peak knee extension was 23.93° (13.0% increase from baseline), and peak ankle plantarflexion was 2.49° (60.6% increase from baseline). The measured changes in our subject's joint angles generally exceed the minimal detectable change for healthy adults[37], indicating that these changes are outside the measurement error associated with motion capture.

Overground *crouch angle*

Crouch angle worsened between visits 1 and 2 but demonstrated a notable improvement following Phase 2 (Table 3). **Average crouch angle decreased to 23.97° at visit 3 and was 32.33° at visit 4, remaining 12.6% decreased from baseline.**

Overground *minimum foot clearance*

The subject demonstrated improvements in MFC both during and after training. **While both bimodal (Fig 1c) and unimodal (Fig 1d) trajectories were seen at all visits, the percentage of steps in which the toe marker followed a bimodal trajectory increased to**

34.9% by visit 4, a 29.3% increase from baseline (Fig. 1e). Typically developing children demonstrate a MFC of approximately 2 cm[38]; our subject's MFC during steps with a bimodal trajectory increased to 1.46 cm by visit 4, a 33.9% increase from baseline (Fig 1f).

Treadmill peak joint extension angles and crouch angles

Kinematic patterns were distinct between overground and treadmill walking at all visits, with treadmill patterns more closely approximating typical movement (Fig. 3). **At visit 4, peak hip extension was 16.67° (35.1% increase from baseline), peak knee extension was 20.13° (29.7% increase from baseline), and peak ankle plantarflexion was -0.84° (112.2% increase from baseline). Like overground walking, peak joint extension during treadmill walking demonstrated greater improvements following Phase 2 than following Phase 1 and retained for three months after cessation of the intervention. Crouch angles during treadmill walking also demonstrated notable improvements; it decreased to 13.97° at visit 3 and was 21.25° at visit 4, remaining 30.0% decreased from baseline.**

Discussion

Overall, TT was found to be a **safe**, well-tolerated, and effective paradigm to improve the walking ability of our subject with ACC. TT is regarded as an effective rehabilitation tool not only because it allows for controlled, repetitive practice of stepping, but because its parameters can be modulated to induce specific desired gait adaptations.[15] For example, typically developing children adapt to faster walking speeds by increasing step length and cadence.[39] Our subject with ACC demonstrated similar adaptation by walking overground with increased step length **and peak extension angle at the hip, knee, and ankle joints** following training. Additionally, the width of the treadmill belt provides an environmental constraint to the medial-lateral base of support during walking; this pattern also appeared to generalize to overground walking as our subject decreased both her step width and FPA following training. **While some of our observed changes in overground walking speed and cadence did exceed the reported minimally clinically important differences (MCID) of children with cerebral palsy[40], they lacked consistency. For this reason, we believe that the changes in these parameters represents variability rather than clinically important differences; this also suggests that published MCID values for other pediatric populations may not be valid for children with ACC.**

SBIT has been proposed as an effective way to increase muscle power and promote higher stride rates during community walking in children with CP.[25] Our subject's primary gait abnormalities at baseline were her decreased walking speed and crouched gait pattern. Weakness of the plantarflexors is strongly associated with crouch gait.[41] A SBIT protocol, therefore, could address both impairments by increasing demand on the plantarflexors and facilitating increased community walking speed. Our subject's **reduced** crouch following Phase 2 of our intervention suggests that it may have been effective at improving strength in this muscle group. Both backward and incline walking are known to **increase** the demand on hip and knee extensors and ankle plantarflexors in healthy adults[24,28], however no improvements in crouch or peak joint extension were noted during overground walking following Phase 1. Increases in walking speed increase demand on the plantarflexors in typically developing children.[39] It may be that only the SBIT component of Phase 2, which involved walking at the highest speeds, generated sufficient challenge to our subject's plantarflexors to induce strength gain. Further, we saw improvements in our subject's MFC following Phase 2 of training. At baseline she demonstrated low foot clearance, placing her at risk for trip-related falls[42]; she also demonstrated a high percentage of steps with a unimodal toe trajectory, which has been proposed as a strategy to minimize falls in other special populations.[35] In addition to demonstrating increased MFC over time, she also demonstrated an increasing percentage of steps wherein her toe trajectory followed a bimodal pattern. This suggests that her gait pattern improved to such a degree that she was not obligated to use as many compensations to clear her foot during swing phase. Crouch gait frequently leads to abnormal joint kinematics in the swing phase of gait[32], so the improvements in crouch may have enabled our subject to achieve more normalized foot clearance. Additionally, the changes in variability of spatiotemporal parameters represent clinically meaningful improvements. Impaired variability of movement can be seen in a variety of special populations and limit the efficiency of performance.[31,43,44] Given her excessive variability at baseline, our subject's ability to decrease the variability of several spatiotemporal parameters may represent improved movement consistency, rhythmic timing control, and postural stability during gait.

Our subject produced a significantly more typical gait pattern on the treadmill than she did overground, suggesting that she can produce a much more normalized pattern than she utilizes during daily walking activities. The moving belt of the treadmill is known to provide a stimulus that encourages push-off and regular stepping.[45] A trend toward a more upright gait pattern with increased hip and knee extension in stance was noted over time, as was increased movement into plantarflexion near toe-off, suggesting an improved push-off. The improvements seen during treadmill walking suggest that our training paradigm was effective at improving the subject's ability to walk at faster speeds, with a more upright posture and a more normalized gait pattern. Generalization of these improvements to overground walking was more limited; similar changes were seen, but to a lesser degree than were exhibited during treadmill walking. It is critical to note, however, that our subject has a cortical visual impairment that has the potential to alter her overground gait pattern; **her lower field limitations, in particular, may predispose**

her to choose strategies that allow her to respond easily to unexpected obstacles. We proposed that she was capable of producing such a normalized gait pattern on a treadmill **within a relatively fixed environment**, but she chose a more cautious gait pattern during overground walking **due to her limited visual ability to perceive the environment**. Alternatively, the dosage of **our TT intervention** might be insufficient to allow for complete generalization **from treadmill** to overground walking. Pilot work investigating the effects of SBIT on children with CP found overground walking speed improved only in the group which trained at a high frequency of 5 times per week.[25] However, many aspects of our subject's **spatiotemporal parameters** improved from visit 1 to 4, which **supports, to a certain degree**, the dosage of our training.

Given a single subject in our study, the generalizability of our findings **is limited to the wide variety of presentations within individuals with ACC**. **Another limitation** was that our subject walked overground at a higher speed at visit 2 than at other visits. While it is possible that Phase 1 of our training protocol induced this, its lack of persistence with continued training suggests that this instead represents natural variability in the subject's gait speed. Several gait parameters demonstrated apparent declines from baseline at this visit; notably, crouch increased, peak joint extension decreased, and MFC decreased with an increased percentage of atypical toe trajectories in swing phase. Rather than representing adverse effects of our training protocol, we believe that these are simply compensations observed during fast walking. This is also supported by a lack of these compensations during treadmill walking at visit 2, when speed was controlled and comparable to other visits. This alteration in preferred overground walking pace at visit 2 represents a confounding factor when comparing the relative effectiveness of the two phases of our protocol. **Finally, the discrepancy in training time between the two phases also**

represents a confounding factor when comparing their relative effectiveness. Although we believe that the SBIT component of Phase 2 represents a novel task for our subject, we cannot be certain that its inclusion did not simply increase the dosage of task-specific walking practice on the treadmill from 15 to 25 minutes, and that it was the dosage increase rather than the specifics of the SBIT that caused the increased improvements seen following Phase 2.

Overall, this study demonstrates that TT can be a safe and effective treatment paradigm to use for improving the gait patterns of children with ACC. Future research is needed to determine if these findings can be reproduced **and generalized** in other individuals with ACC, specifically those of different ages and who present with different motor impairments. Additionally, more TT protocols, particularly with different SBIT designs, should be investigated in this population to determine if increased generalization to overground walking can be seen with increased dosage **for individuals with ACC**.

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Table 1: Details of the completed treadmill training protocol.

	Session	Forward speed (m/s)	Forward incline (% grade)	Backward speed (m/s)	Backward incline (% grade)	Interval training speed (slow/fast, in m/s)
Phase 1	1-3	1.03	3.0	0.27	0.5	n/a
	4-5	1.07	3.0	0.27	0.5	n/a
	6	1.07	3.0	0.31	0.5	n/a
	7	1.12	3.0	0.31	0.5	n/a
	8-9	0.94	3.5	0.31	0.5	n/a
	10	0.98	3.5	0.31	0.5	n/a
Phase 2	1	0.98	3.5	0.31	0.5	0.72/1.43
	2-3	1.03	3.5	0.31	0.5	0.72/1.43
	4	1.07	3.5	0.31	0.5	0.72/1.43
	5	1.07	3.5	0.36	0.5	0.76/1.52
	6	1.07	3.5	0.36	0.5	0.72/1.43
	7	1.07	3.5	0.36	0.5	0.76/1.52
	8	1.07	3.5	0.36	1.0	0.76/1.52
	9	1.12	3.5	0.36	1.0	0.76/1.52
	10	1.12	3.5	0.27	1.5	0.76/1.52

At Phase 2, the slow and fast interval training speeds were 75% and 150% of the forward walking speed, respectively. Total training time for each session in Phase 1 was 15 minutes (10 minutes forward, and 5 minutes backward). Total training time for each session in Phase 2 was 25 minutes (10 minutes forward, 5 minutes backward, and 10 minutes intervals). n/a: not applicable.

Table 2: Mean (SD) and coefficient of variation (CV) of temporal gait variables during overground walking

		Speed (m/s)	Cycle time (sec)	Stance time (sec)	Swing time (sec)	Double support time (sec)
Mean (SD)	Visit 1	0.30 (0.06)	1.17 (0.25)	0.82 (0.19)	0.36 (0.08)	0.23 (0.09)
	Visit 2	0.39 (0.17)	1.15 (0.12)	0.82 (0.10)	0.33 (0.07)	0.25 (0.07)
	Visit 3	0.23 (0.06)	1.47 (0.10)	1.00 (0.11)	0.46 (0.06)	0.27 (0.06)
	Visit 4	0.28 (0.13)	1.24 (0.07)	0.84 (0.08)	0.40 (0.04)	0.22 (0.07)
CV	Visit 1	**20.0**	**21.0**	**23.5**	**23.5**	**36.6**
	Visit 2	**42.1**	**10.6**	**12.0**	**20.3**	**29.5**
	Visit 3	**23.7**	**6.9**	**10.5**	**13.1**	**22.7**
	Visit 4	**44.2**	**5.7**	**9.5**	**10.7**	**32.0**

Note that for gait analysis, visit 1 was before the intervention, visit 2 was after phase 1 (three months) of the intervention, visit 3 was after phase 2 (another three months) of the intervention, and visit 4 was the follow-up (three months after phase 2 of the intervention). Variability is expressed as the coefficient of variation (CV).

Table 3: Mean (standard deviation) of peak extension angles at the hip, knee, and ankle and crouch angle during overground (OG) and treadmill (TM) walking.

	Hip angle (degrees)		Knee angle (degrees)		Ankle angle (degrees)		Crouch angle (degrees)	
	OG	TM	OG	TM	OG	TM	OG	TM
Visit 1	24.97	25.69	27.51	28.62	6.33	7.38	36.98	30.35
	(12.10)	(5.25)	(12.77)	(6.90)	(12.62)	(3.45)	(4.90)	(7.30)
Visit 2	26.36	25.82	34.97	29.69	11.93	5.05	43.78	31.77
	(8.52)	(6.28)	(11.80)	(4.99)	(12.96)	(4.75)	(13.55)	(4.64)
Visit 3	18.58	16.64	17.94	12.91	6.69	1.66	23.97	13.97
	(10.08)	(7.72)	(6.73)	(4.61)	(3.83)	(3.42)	(6.14)	(5.03)
Visit 4	19.57	16.67	23.93	20.13	2.49	-0.84	32.33	21.25
	(15.84)	(8.61)	(8.65)	(4.14)	(12.78)	(2.60)	(4.69)	(3.90)

At the hip, negative values represent hip extension while positive values represent hip flexion. At the knee, negative values represent knee hyperextension while positive values represent knee flexion. At the ankle, negative values represent plantarflexion while positive values represent dorsiflexion. Crouch is defined as the amount of knee flexion present at initial contact. Note that for gait analysis, visit 1 was before the intervention, visit 2 was after phase 1 (three months) of the intervention, visit 3 was after phase 2 (another three months) of the intervention, and visit 4 was the follow-up (three months after phase 2 of the intervention).

Figure captions

Fig 1: Toe trajectories in swing phase and minimum foot clearance **during overground walking** at visits 1-4. A representative (a) bimodal and (b) unimodal toe trajectories during swing phase, averaged (c) bimodal and (d) unimodal trajectories at each visit, (e) percent of steps which demonstrated bimodal trajectories at each visit, and (f) minimum foot clearance during bimodal steps at each visit.

Fig 2: Mean (SD) and coefficient of variation (CV) of gait variables during overground walking at visits 1-4. (a) Cadence mean, (b) cadence CV, (c) step length mean, (d) step length CV, **(e) step width mean, (f) step width CV,** (g) foot progression angle mean, and (h) foot progression angle CV. Note that visit 1 was before the intervention, visit 2 was after phase 1 (three months) of the intervention, visit 3 was after phase 2 (another three months) of the intervention, and visit 4 was the follow-up (three months after phase 2 of the intervention).

Fig 3: Mean joint kinematics over a **time-normalized** gait cycle at visits 1-4 at the (a) hip, (b) knee, and (c) ankle during both overground (OG) walking, represented by a dashed line, and treadmill (TM) walking, represented by a solid line. Positive joint angles represent flexion and negative joint angles represent extension. Toe-off during OG walking is represented by a vertical grey line, and toe-off during treadmill walking is represented by a vertical black line. Note that visit 1 was before the intervention, visit 2 was after phase 1 (three months) of the intervention, visit 3 was after phase 2 (another three months) of the intervention, and visit 4 was the follow-up (three months after phase 2 of the intervention).

Fig 1:

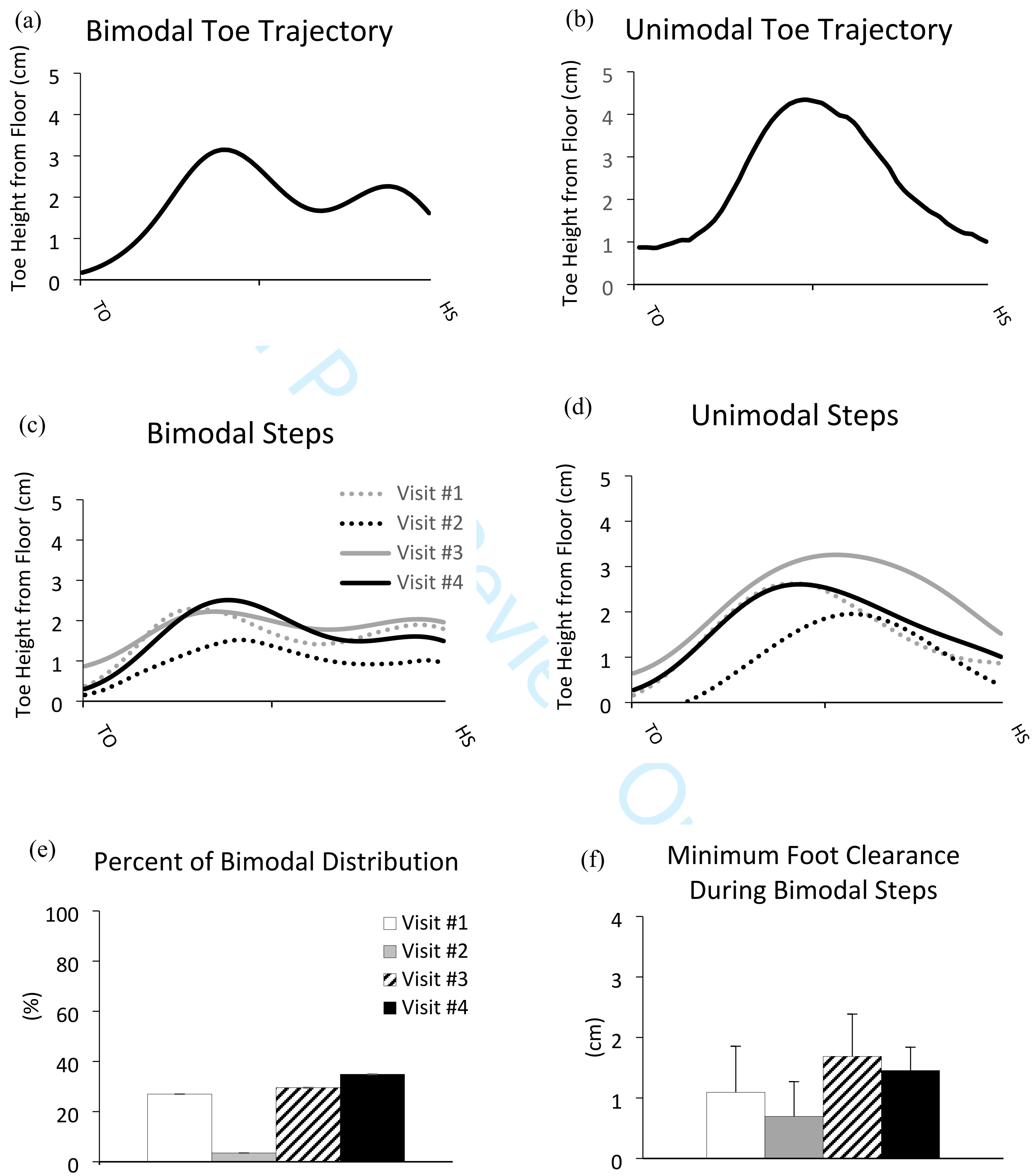

(a)
Bimodal Toe Trajectory
Toe Height from Floor (cm)
0
1
2
3
4
5
TO
HS
(b)
Unimodal Toe Trajectory
Toe Height from Floor (cm)
0
1
2
3
4
5
TO
HS
(c)
Bimodal Steps
Toe Height from Floor (cm)
Visit #1
Visit #2
Visit #3
Visit #4
0
1
2
3
4
5
TO
HS
(d)
Unimodal Steps
Toe Height from Floor (cm)
0
1
2
3
4
5
TO
HS
(e)
Percent of Bimodal Distribution
(%)
0
20
40
60
80
100
Visit #1
Visit #2
Visit #3
Visit #4
(f)
Minimum Foot Clearance
During Bimodal Steps
(cm)
0
1
2
3
4

Fig 2:

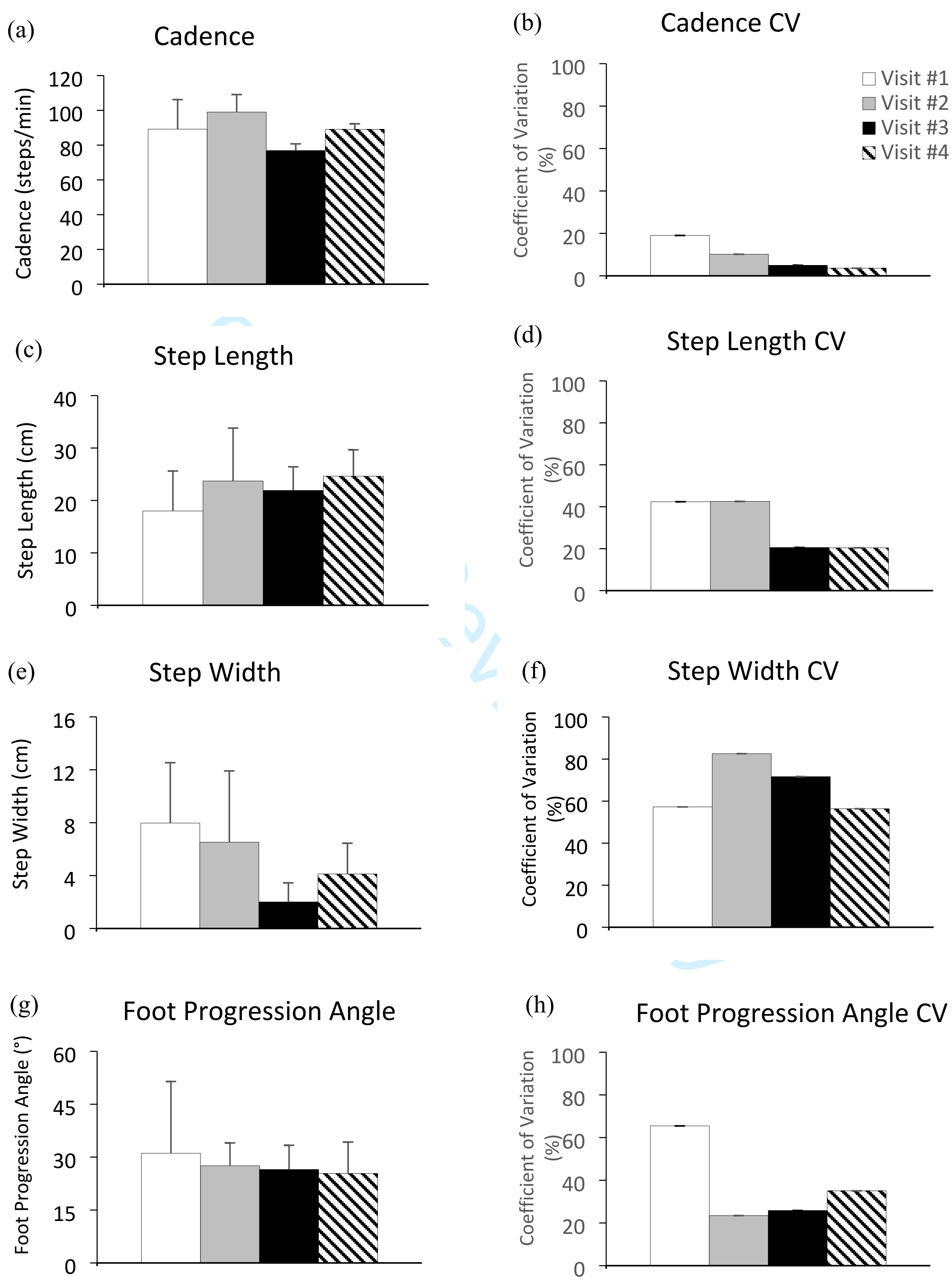
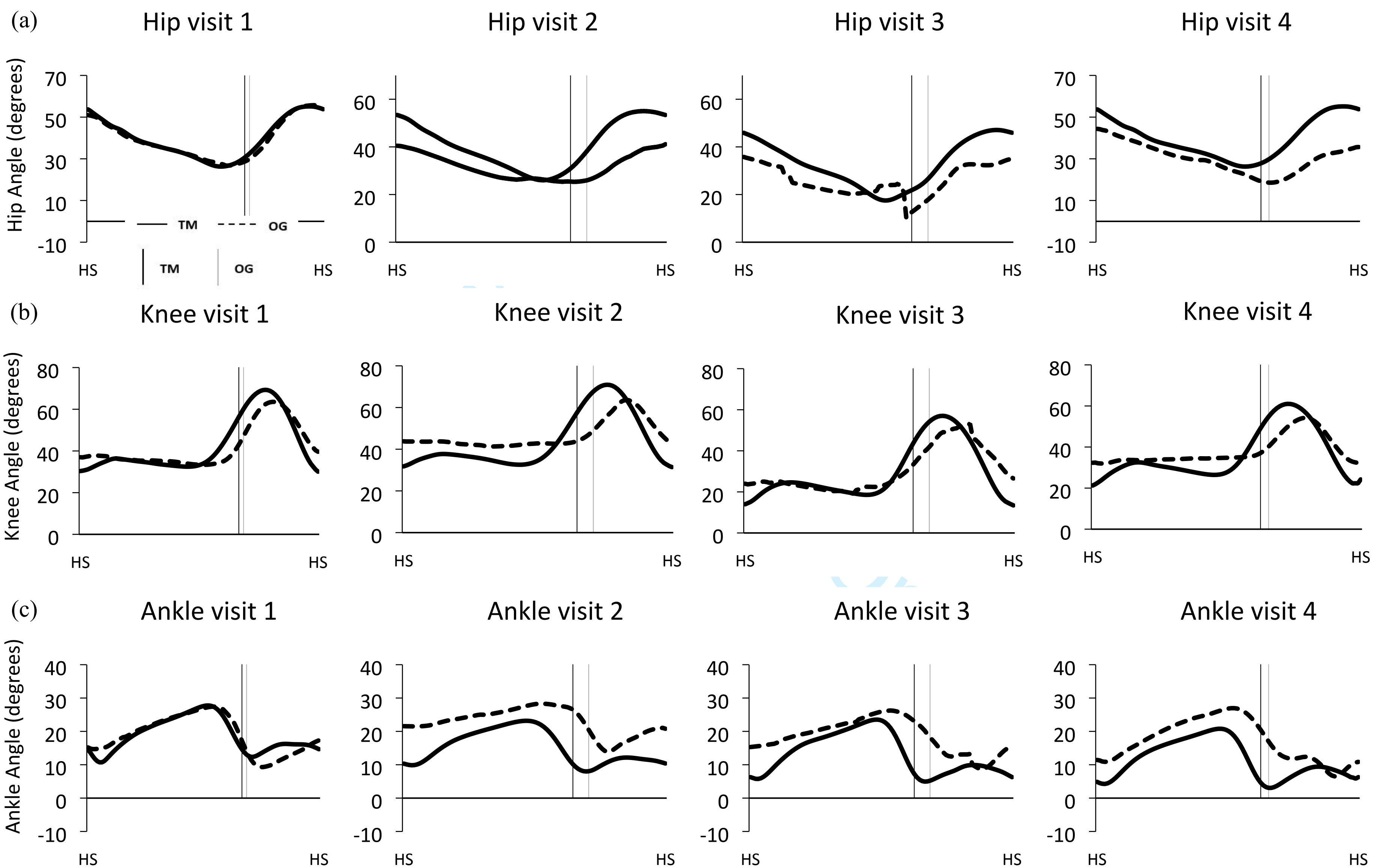

(a)
Cadence
Cadence (steps/min)
120
100
80
60
40
20
0
(b)
Cadence CV
Coefficient of Variation (%)
100
80
60
40
20
0
Visit #1
Visit #2
Visit #3
Visit #4
(c)
Step Length
Step Length (cm)
40
30
20
10
0
(d)
Step Length CV
Coefficient of Variation (%)
(e)
Step Width
Step Width (cm)
16
12
8
4
0
(f)
Step Width CV
Coefficient of Variation (%)
(g)
Foot Progression Angle
Foot Progression Angle (°)
60
45
30
15
0
(h)
Foot Progression Angle CV
Coefficient of Variation (%)

Fig 3:


(a)
Hip visit 1
Hip visit 2
Hip visit 3
Hip visit 4
Hip Angle (degrees)
TM
OG
HS
(b)
Knee visit 1
Knee visit 2
Knee visit 3
Knee visit 4
Knee Angle (degrees)
(c)
Ankle visit 1
Ankle visit 2
Ankle visit 3
Ankle visit 4
Ankle Angle (degrees)