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The influence of crouch gait on sagittal trunk position and lower lumbar spinal loading in children with cerebral palsy

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ABSTRACT

Background: Crouch gait is a common pattern in children with CP. Little investigation has been performed as to the role of the trunk during crouch gait. A compensatory movement of the trunk may alter the position of the ground reaction force with the effect of reducing the moment arm about the knee or hip. While this may benefit these joints in the context of reduced loading, there may be implications further up the kinematic chain at the level of the lumbar spine.

Research Question: Are compensatory movements of the trunk present during crouch gait in children with CP and are levels of loading at the lower lumbar spine affected?

Methods: A full barefoot lower limb and trunk 3-dimensional kinematic and kinetic analysis, with kinetics estimated at the spinal position of L5/S1, was performed on 3 groups of children, namely CP Crouch, CP No-Crouch and TD. Differences in trunk position and L5/S1 loading were compared between groups.

Results: Mean trunk position in relation to the pelvis and laboratory was not statistically significant between groups. At the level of the spine, no differences were present in mean position between groups for L5/S1 sagittal moment or anterior/posterior force.

Significance: Crouch gait does not elicit a compensatory response of the trunk in children with CP and, consequently, reactive forces and moments at the lower lumbar spine remain within normal limits. With this in mind, it is unlikely that a crouch gait pattern will affect the health of the spine over time in these children.

1. Introduction

Crouch gait is a common gait pattern in children with cerebral palsy (CP) and manifests primarily as knee flexion outside normal limits for a significant proportion of the stance phase of gait [1]. Crouch gait has been reported to be present in more than 45% of children with CP with Gross Motor Function Classification System (GMFCS) level I and in more than 60% with GMFCS levels II to IV [2]. This type of walking moves the ground reaction force (GRF) away from the hip and knee centers and increases the internal extensor joint moments [3], requiring greater energy expenditure compared to a straighter gait pattern [4,5]. Crouch gait has been demonstrated to increase in magnitude with age [2], and can lead to chronic stress around the knee and the potential failure of the knee extensor mechanism [6].

The various effects of crouch gait on the lower limbs in subjects with CP have been well examined in the literature [1,3,4,6,7]. However, there has been limited investigation as to the effect of crouch gait on the position of the trunk. While attempting to quantify the relationship between torso motion and reduced hip abductor moment during stance, torso motion was examined in crouch gait subjects [7]. While no differences were reported in torso bending between Crouch and TD groups, the authors did not report planes of movement and no investigation was performed as to the effect of loading at the spine [7]. Where movement of the trunk has been examined during general CP gait, pathological movements, particularly in the coronal plane, have been reported that relate to both level of function and lower lumbar spinal loading [8–14]. As the trunk acts as an active segment rather than a passive unit during gait [15,16], it plays an integral role in dynamic balance where even small deviations in position of the trunk will affect position of the Centre of Mass (CoM) [17]. In a study where a trunk-flexed gait was adopted by able-bodied subjects, a sustained knee flexion during stance phase with significant changes in ground reaction force (GRF) were demonstrated [17]. Increased anterior pelvic tilt, ankle dorsiflexion and hip flexion were also demonstrated with changes reported in the position of the CoM. The authors suggested that these compensatory kinematic patterns positioned the CoM within the base of support (BoS) to maintain balance during walking and that the crouch gait type compensations were a means of biomechanically reorienting

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the trunk to a more vertical position [17]. If the reverse biomechanics are considered, where we are presented with a child with CP demonstrating a crouch gait pattern, the associated crouch features may force the trunk into a more flexed position. Consequently, a compensatory trunk-flexed position may be adopted with a similar aim of maintaining a vertical trunk position. However, movement patters of the trunk specifically during crouch gait in children with CP have not been reported.

Muscle driven simulation studies of CP crouch gait suggest that significantly more knee extensor strength is needed compared to unimpaired gait [7]. Consequently, a compensatory movement of the trunk in the sagittal plane, for example resulting in a reduction of the knee extensor moment arm, may reduce the effort required by the quadriceps during stance helping to reduce the elevated levels of energy expenditure required during crouch gait [5]. It may also help reduce stress at the knee and the potential for patella-femoral pain, features previously reported to be present during crouch gait [18–20]. However, while the knee may benefit in this case, the concern with this compensatory movement of the trunk is that there may be implications further up the kinematic chain at the level of the lower spine. A recent study reported an increase in reactive forces and moments at the spine in children with CP that were shown to have a positive correlation with trunk position [13]. While the impact of excessive trunk movement was demonstrated primarily in the coronal plane, a significant relationship was demonstrated between trunk range of motion (RoM) in the sagittal plane and L5/S1 anterior/posterior force ($r = 0.4$, $p < 0.01$) [13]. Consequently, if sagittal trunk position was altered during crouch gait, it may result in pathological forces and moments at the lower lumbar spine that may impact the health of the spine over time. With this in mind, the aim of this study was to investigate the sagittal position of the trunk, and corresponding levels of loading at the lower lumbar spine, during crouch gait in children with CP. The research hypothesis was that children with CP with a crouch gait pattern would demonstrate a forward tilted trunk position, and corresponding altered kinetics at the lower lumbar spine, compared to children with CP without crouch and children with TD. This hypothesis was based on the biomechanical assumption that a forward trunk lean would help provide for a better alignment of the GRF in relation to the lower limbs in these children.

2. Methods

2.1. Participants

Ethical approval was granted by the host institution's ethics committee. Participants were split into 3 groups. Group 1 (CP crouch) consisted of 12 children with diplegic CP who demonstrated a crouch gait pattern (9 M, 3 F, Mean age (SD): 11.3 (2.1) yrs.). Crouch gait was defined according to the criteria described by Wren and colleagues where children demonstrated a mid-stance knee position greater than 1 SD above the mean for normal [1]. Group 2 (CP No-Crouch) consisted of 11 children with diplegic CP who did not demonstrate a crouch gait pattern (6 M, 5 F, Mean age (SD): 9.6 (3.1) yrs.). Group 3 (TD) consisted of 12 children with typical development (TD) (7 M, 5 F, Mean age (SD): 8.6 (1.7) yrs.). Inclusion criteria for groups 1 and 2 were: diagnosis of diplegic CP and ability to walk independently. Walking independently required that the children were able to walk barefoot and without assistive devices. Children with CP were excluded if they had surgery within 1-year of presenting to the gait laboratory. Inclusion criteria for children with TD were: no history of musculoskeletal, neurological or orthopaedic problems. A participant information leaflet was provided to all participants who provided written informed consent.

2.2. Data collection

A full barefoot 3-dimensional kinematic and kinetic analysis was performed using a Coda cx1 active marker system. Kinematic data were captured at a rate of 200 Hz. Markers were placed on the lower limbs according to a modified Helen Hayes protocol [21]. Thorax kinematics were recorded using a previously validated rigid cluster protocol [22]. Reactive forces and moments were computed using an inverse dynamics "bottom-up" approach with kinetic data recorded at a rate of 100 Hz using 2 Kistler 9281B force platforms (Kistler Instruments Ltd., 13 Murrell Green Business Park, London Road, RG27 9GR Hook, Hampshire, UK) and 2 AMTI force platforms (176 Waltham Street, Watertown, MA). All force platforms were embedded into a walkway. The L5/S1 joint location was measured by placing a marker at the position of L5/S1 on the lumbar spine and creating a virtual point corresponding to 5% of the distance of the line between the L5/S1 marker and the midpoint of the Anterior Superior Iliac Spine (ASISs) [23]. This virtual point was then taken as the estimated L5/S1 joint position at which reactive forces and moments were predicted using an inverse dynamics approach. This approach has previously been used in a number of clinical and sport related applications and was considered acceptable for the purposes of this study [13,14,23].

Subjects walked unassisted at a self-selected speed. A number of clean walking trials were recorded for each subject and one representative walking trial with clean force data was chosen for further analysis. A clean walking trial was defined as having all markers inview with both left and right feet completely within the boundary of two consecutive force platforms during successive initial contacts of the same foot [13].

Data were captured using Codamotion ODIN software (v1.06 Build 01 09). Data were then analyzed and filtered (using a Butterworth filter of 8 Hz for Kinematic data and 20 Hz for kinetic data) in Visual 3D v4.96.0 software (C-Motion Inc., Germantown, MD, USA).

2.3. Data analysis

Due to the replication of data at the L5/S1 joint and thorax during double support phase of gait, data were selected and analyzed for one side only. A random limb (chosen by coin toss) was selected for each participant in each group. As crouch gait is primarily a sagittal plane presentation during the stance phase of gait, only stance data in the sagittal plane were reported for the purposes of this study. Mean and RoM data were reported for the following kinematic parameters: Trunk Flexion/Extension (with respect to (w.r.t) laboratory and pelvic reference frames), Pelvic Tilt, Hip and Knee Flexion/Extension and Ankle Dorsi-Plantarflexion. Mean and RoM data were reported for the following kinetic parameters: Hip, Knee and Ankle Extensor moment, L5/S1 Sagittal Moment and L5/S1 Anterior/Posterior force. While the focus of this study concerned movement of the trunk and loading at the lower lumbar spine, data were reported for some lower limb kinematic and kinetic variables for completeness.

Data were checked for distribution using the Shapiro-Wilk normality test. Differences between CP Crouch, CP No-Crouch and TD were assessed using a one-way analysis of variance (ANOVA) with Bonferroni post-hoc tests for comparisons between groups. Dunnett's tests were also used to compare CP Crouch and CP No-Crouch with the TD group. Data following a normal distribution were summarized using mean and standard deviation. For data that violated the Shapiro-Wilk normality test, differences were assessed using a Kruskal-Wallis test and post-hoc Mann-Whitney U-tests. Non-normalized data were summarized using median and range. Variables that were non-normally distributed have been highlighted in Tables 1–3 using a star (*). All statistical analyses were performed using IBM SPSS Statistics (v23.0.0.2). The level of significance was set at 0.05. Additionally, ensemble average kinematic and kinetic profiles were visually analyzed for deviations between groups.

Table 1
Mean (Standard Deviation) and Post-hoc analysis for subject anthropometric data and walking speed. Difference, 95% Confidence Intervals (95% CI) and concurrent *p* values between groups are reported (TD–CP Crouch; TD–CP No Crouch; CP Crouch – CP No Crouch). Gray shading indicates statistically significant.

Subject Data	TD	CP Crouch	CP No-Crouch	Difference between: TD – CP Crouch	95% C.I	P	Difference between: TD – CP No Crouch	95% C.I	P	Difference between: CP Crouch – CP No Crouch	95% C.I	P
Age (yrs.)	8.6 (1.7)	11.3 (2)	9.6 (3.1)	-2.7	-4.8 to -0.5	0.02	-1.1	-3.3 to 1.2	0.46	1.6	-0.9 to 4.1	0.33
Weight (kg)	32.4 (11)	41.6 (15)	33.7 (14)	-9.2	-21.9 to 3.6	0.18	-1.3	-14.3 to 11.7	0.96	7.9	-6.4 to 22.1	0.52
Height (m)	1.33 (0.1)	1.47 (0.1)	1.35 (0.2)	-0.14	-0.27 to -0.01	0.03	-0.01	-0.14 to 0.12	0.96	0.13	-0.01 to 0.27	0.09
Speed (m/s)	1.24 (0.1)	1.03 (0.14)	1.04 (0.15)	0.22	0.09 to 0.34	<0.01	0.21	0.08 to 0.34	<0.01	-0.01	-0.15 to 0.13	1.00

3. Results

3.1. Subject data

Walking speed was significantly slower for both CP Crouch and CP No-Crouch groups compared to TD (0.22 m/s, $p < 0.01$ and 0.21, $p < 0.01$ respectively). There were no differences in walking speed between CP groups (Table 1). TD children were 2.7 years younger than CP Crouch children while no differences existed between CP No-Crouch and TD or CP Crouch (Table 1). TD children were taller than both CP groups (0.03 m, $p < 0.01$) while no differences were present between groups for weight.

3.2. Kinematic data

Mean trunk position in relation to the pelvis and laboratory during stance was not statistically significant between groups (Table 2). While both the CP Crouch and CP No-Crouch groups did demonstrate increased RoM for movement of the trunk with respect to the pelvis compared to TD (3.9°, $p = 0.04$ and 3.7°, $p = 0.02$ respectively) (Fig.1, Table 3), there were no differences between CP Crouch and CP No-Crouch groups for either measure of trunk movement (Tables 2 and 3).

Lower limb kinematic data for the CP Crouch, CP No-Crouch and TD children followed patterns anticipated for these groups. Pelvic tilt position followed a similar trend to that of the trunk with mean position similar between groups and no statistically significant differences were demonstrated (Fig. 1, Table 2). RoM was, however, increased for both CP groups compared to TD (2.9°, $p = 0.02$ and 4.3°, $p < 0.01$ respectively) (Fig. 1, Table 3). Mean hip and knee flexion were, as expected, increased for the CP Crouch children compared to TD while ankle dorsiflexion / plantarflexion demonstrated similar mean positions between all groups with no statistically significant differences present (Fig. 1, Table 2).

3.3. Kinetic data

At the level of the spine, no differences were present in mean position between groups for L5/S1 sagittal moment or L5/S1 anterior/posterior force (Fig. 2, Table 2). L5/S1 sagittal moment ensemble average profiles demonstrated an increased moment at the period of terminal stance leading into pre-swing phase (Fig. 2). However, this difference was not reflected statistically in mean or RoM parameters. While RoM was different for the CP No-Crouch group compared to TD for L5/S1 anterior/posterior force (Table 3), no differences were present for the CP Crouch group compared to TD or CP No-Crouch (Table 3). Ensemble average profiles did demonstrate an increased anterior force at the period of terminal stance leading into pre-swing phase (Fig. 2). However, similar to the sagittal moment, this was not statistically meaningful.

At the lower limbs, hip extensor moment demonstrated similar ensemble average profiles between groups (Fig. 2), with mean position reduced for the CP Crouch group compared to TD (0.2 Nm/kg, $p < 0.01$) (Table 2). Knee extensor moment demonstrated an increased mean position during stance for the CP Crouch group compared to CP No-Crouch and TD (0.15Nm/kg, $p = 0.01$ and 0.24 Nm/kg, $p < 0.01$ respectively) (Table 2), while no statistically significant differences

Table 2
Post-hoc analysis for Mean (Standard Deviation) data during stance. Difference, 95% Confidence Intervals (95% CI) and concurrent *p* values between groups are reported (TD–CP Crouch; TD–CP No Crouch; CP Crouch – CP No Crouch). *Indicates non-normally distributed data. Median and Range reported for non-normally distributed data while 95% CIs not reported. Data demonstrating significant differences have been highlighted. Gray shading indicates statistically significant.

Mean Parameters	TD	CP Crouch	CP No-Crouch	Difference between: TD – CP Crouch	95% C.I	P	Difference between: TD – CP No-Crouch	95% C.I	P	Difference between: CP Crouch – CP No-Crouch	95% C.I	P
Trunk (Pelvis) Flex/Ext (deg)	0.6 (10)	-0.6 (11)	-3.9(11)	1.2	-8.9 to 11.3	0.95	4.4	-5.9 to 14.7	0.52	3.2	-8.1 to 14.5	1.00
Trunk (Lab) Flex/Ext (deg) *	15.3 (17)	14.9 (21)	16.7 (26)	0.4	-----	0.55	-1.4	-----	0.61	-1.8	-----	0.79
Pelvic Tilt (deg)	15.9 (5.2)	17.6 (7.9)	18.5 (5.1)	-1.6	-7.5 to 4.3	0.76	-2.5	-8.6 to 3.5	0.53	-0.9	-7.5 to 5.6	1.00
Hip Flex/Ext (deg)	15.5 (6.9)	24.9 (9.7)	18.8 (5.5)	-9.5	-2.3 to – 17	<0.01	-3.3	-10.7 to 4.0	0.48	6.1	-1.9 to 14.2	0.19
Knee Flex/Ext (deg) *	15.6 (24)	28.9 (12)	13.8 (23)	-13.3	-----	<0.01	1.8	-----	0.83	15.1	-----	<0.01
Ankle Dorsi/Plant Flex (deg)	3.9 (3.1)	5.8 (6.3)	2.2 (4.1)	-1.8	-6.3 to 2.6	0.53	1.8	-2.8 to 6.3	0.61	3.6	-1.4 to 8.6	0.23
Hip Ext. Mom. (Nm/kg) *	-0.1 (0.9)	0.02 (0.3)	-0.02 (0.7)	-0.2	-----	<0.01	-0.1	-----	0.19	0.1	-----	0.35
Knee Ext. Mom. (Nm/kg)	0.12 (0.1)	0.26 (0.2)	0.02 (0.1)	-0.15	-0.3 to 0.0	0.01	0.1	-0.1 to 0.2	0.11	0.24	0.1 to 0.4	<0.01
Ankle Ext. Mom. (Nm/kg)	0.48 (0.1)	0.53 (0.2)	0.47 (0.1)	0.0	-0.2 to -0.1	0.74	0.0	-0.1 to 0.2	0.94	0.1	-0.1 to 0.2	1.00
L5/S1 Sag. Mom. (Nm/kg) *	0.2 (0.6)	0.3 (0.7)	0.3 (0.5)	-0.1	-----	0.08	-0.1	-----	0.35	0.1	-----	0.15
L5/S1 Ant/Pos Force (N/kg)	0.08 (0.2)	0.09 (0.1)	0.15 (0.4)	0.0	-0.3 to 0.3	0.99	-0.1	-0.3 to 0.2	0.81	-0.1	-0.2 to 0.4	1.00

Table 3
Post-hoc analysis for Range of Movement (RoM) (Standard Deviation) data during stance. Difference, 95% Confidence Intervals (95% CI) and concurrent *p* values between groups are reported (TD—CP Crouch; TD—CP No Crouch; CP Crouch – CP No Crouch). *Indicates non-normally distributed data. Median and Range reported for non-normally distributed data while 95% CIs not reported. Data demonstrating significant differences have been highlighted. Gray shading indicates statistically significant.

RoM Parameters	TD	CP Crouch	CP No-Crouch	Difference between: TD – CP Crouch	95% C.I	P	Difference between: TD – CP No Crouch	95% C.I	P	Difference between: CP Crouch – CP No Crouch	95% C.I	P
Trunk (Pel) Flex/Ext (deg)*	8.1 (11.3)	12 (14.4)	11.7 (46)	-3.9	-----	0.04	-3.7	-----	0.02	0.2	-----	0.98
Trunk (Lab) Flex/Ext (deg)*	6.8 (7.9)	8.1 (11)	8.7 (31)	-1.4	-----	0.27	-2.1	-----	0.19	-0.7	-----	0.79
Pelvic Tilt (deg)	4.3(1.8)	7.2 (1.7)	8.6 (3.7)	-2.9	-5.3 to -0.55	0.02	-4.3	-6.7 to -1.8	<0.01	-1.33	-4.0 to 1.3	0.64
Hip Flex/Ext (deg)*	45.1 (21)	38 (15.1)	45.1 (25)	6.8	-----	<0.01	-0.02	-----	0.74	-6.8	-----	<0.01
Knee Flex/Ext (deg)	30.7 (5.2)	26.4 (7.7)	36.8 (11)	4.3	-3.5 to 12.2	0.35	-6.2	-14.2 to 1.9	0.15	-10.5	-19.to -1.7	0.02
Ankle Dorsi/Plant Flex. (deg)	30.7 (5.6)	25.4 (5.4)	22 (7.4)	5.3	-0.5 to 11.2	0.08	8.7	2.8 to 14.7	<0.01	3.4	-3.1 to 9.9	0.6
Hip Ext. Mom. (Nm/kg)	2.3 (0.4)	2.0 (0.7)	2 (0.3)	0.3	-0.2 to 0.8	0.24	0.3	-0.2 to 0.8	0.32	-0.03	-0.5 to 0.5	1.00
Knee Ext. Mom. (Nm/kg)*	1.02 (0.8)	1.1 (2.1)	0.8 (0.6)	-0.1	-----	0.48	0.2	-----	0.02	0.3	-----	<0.01
Ankle Ext. Mom. (Nm/kg)*	0.9 (0.5)	1.08 (1.7)	1.0 (0.6)	-0.1	-----	0.14	0.0	-----	0.88	0.1	-----	0.21
L5/S1 Sag. Mom. (Nm/kg)*	0.9 (0.8)	0.9 (2.4)	0.9 (0.6)	0.0	-----	0.84	0.1	-----	0.88	0.0	-----	1.00
L5/S1 Ant/Pos Force (N/kg)	1.2 (0.4)	1.6 (0.4)	1.8 (0.4)	-0.3	-0.7 to 0.01	0.06	-0.5	-0.9 to -0.2	<0.01	-0.2	-0.6 to 0.2	0.8

were present between groups for ankle moment (Tables 2 and 3).

4. Discussion

Crouch gait is a common walking pattern seen in children with CP. While the impact of this pattern on lower limb kinematics and kinetics has been well examined, limited investigation has been conducted above the level of the pelvis. Due to the role of the trunk as an active segment during gait, the potential exists for aberrant patterns of movement and loading of the trunk and spine respectively. The aim of this study was to examine the impact of a crouch gait pattern on these variables. Results demonstrated only minor differences for the trunk position in the sagittal plane and for lower spinal loading between crouch and non-crouch groups.

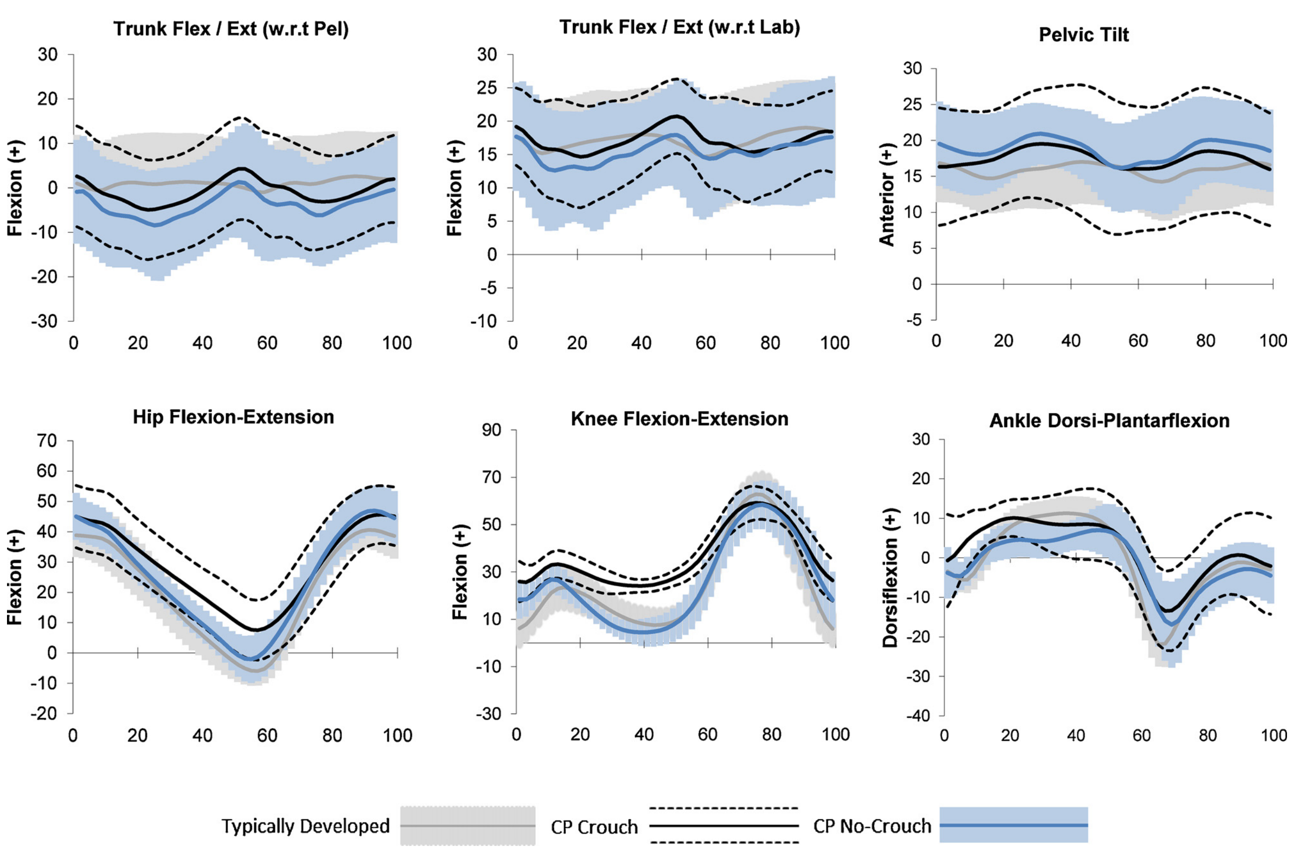

Fig. 1. Ensemble average profiles for lower limb and trunk kinematic data (Grey – Typically Developed, Black – CP Crouch, Blue – CP No-Crouch). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

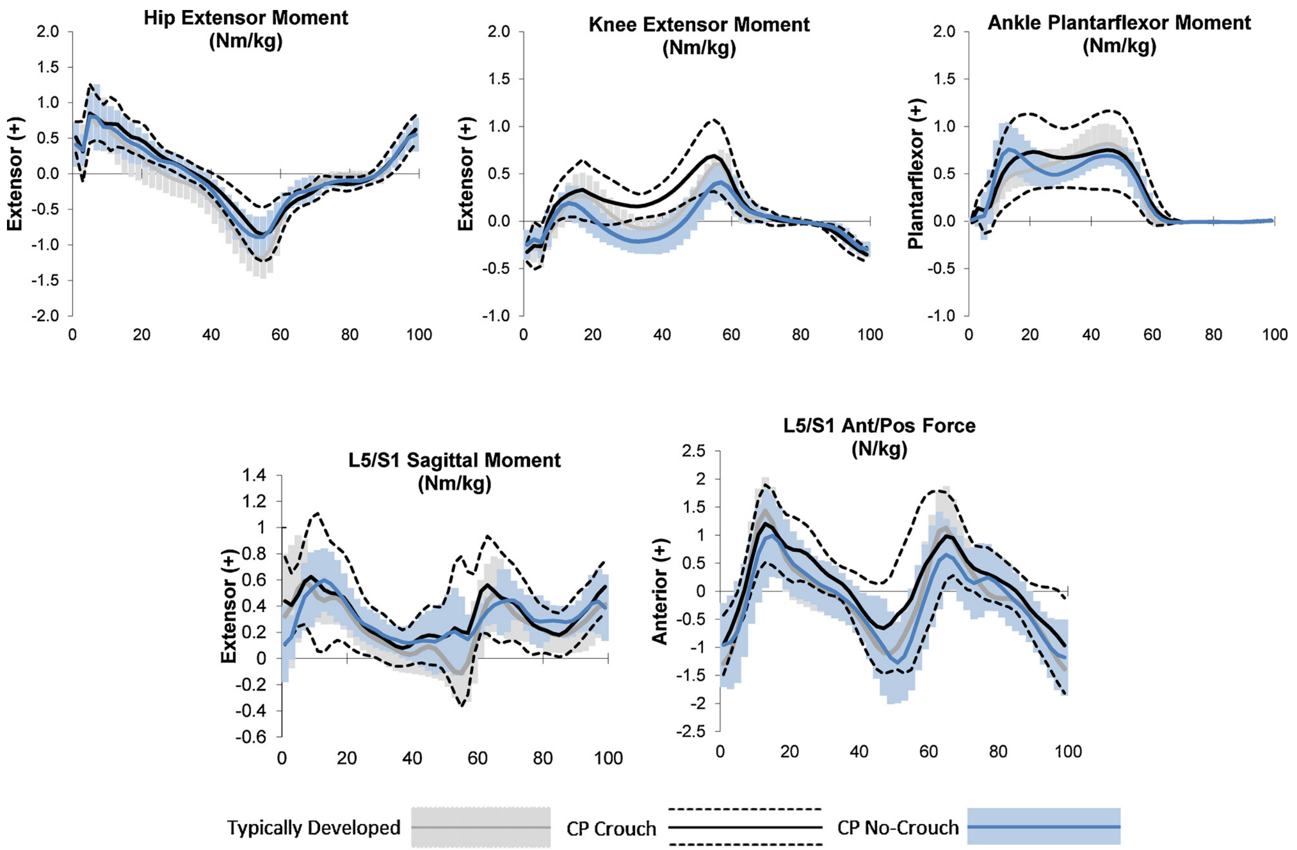

Fig. 2. Ensemble average profiles for lower limb and L5/S1 kinetic data (Grey – Typically Developed, Black – CP Crouch, Blue – CP No-Crouch). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Lower limb kinematic and kinetic profiles between groups were as expected (Fig. 1). The CP Crouch children demonstrated an increased hip and knee flexion in conjunction with an increased knee extensor moment. While the lower limb results were consistent with what was expected, in reality they presented no new information as to what is already known for these children. However, when these results were considered in conjunction with kinematics and kinetics above the level of the pelvis, it was clear that the impact of a crouched position had little effect on the trunk in the sagittal plane. Little difference existed in relation to mean trunk position between groups, a finding that was in contrast to our hypothesis that these children would forward flex their trunk as a mechanism to alter the position of the GRF. The findings of this study suggest that the similar pelvic position adopted by the CP Crouch group with that of the other groups, in conjunction with a flexed hip and knee, allowed these children to maintain an upright trunk position regardless of the crouch gait. It appears that while there was greater loading about the knee, evidenced by the increased knee extensor moment, it was not preferable to forward flex the trunk in an attempt to reduce the knee extensor moment arm and thus counteract the increased loading. Balance impairment is a common problem in children with cerebral palsy [24,25], and maintaining the trunk upright will help maintain the CoM within the BoS thus helping to maintain balance. It is possible that maintaining dynamic stability in these children was more important than altering the sagittal position of the trunk in an attempt to reduce loading about the knee.

Both groups of children with CP, both Crouch and No-Crouch, demonstrated an increased RoM of the trunk in the sagittal plane. Interestingly, this was not specific to just the children with crouch gait suggesting the crouch pattern had little or no contribution to this excessive movement. These findings of excessive movement during CP gait are consistent with the literature [10,11], and are thought to relate to reduced anterior/posterior stability confirmed by the “double-bump” patterns evident in the kinematic graphs [11]. It has been suggested that a move of the thorax back towards extension at these points could be a dynamic compensation to offset pelvic movement towards anterior tilt [11]. While this fits with the findings of our study, it also highlights the need for children with CP to maintain a good sagittal position of the trunk, and consequently the head, during gait. As previously mentioned, this may be an attempt to maintain dynamic balance and may be more important than performing a compensatory forward movement of the trunk to alter the position of the GRF in relation to the knee or hip.

When loading at the lower lumbar spine was considered, no differences were present in reactive forces or moments between groups (Fig. 2, Tables 1 and 2). A positive correlation has been previously reported between trunk position and lower lumbar spinal loading [13]. Considering that the children with a crouch gait demonstrated a similar sagittal trunk position to the other groups our finding was therefore not surprising. While there was a slightly increased anterior force leading from terminal stance into swing for children with the crouch gait pattern, the impact of crouch gait on lower lumbar spinal loading was negligible.

For the purposes of this study, children were instructed to walk at a self-selected speed. Walking speed was not controlled for or normalized. While walking speed has been show to impact on both kinematics and kinetics [26], the purpose of this study was to examine actual differences between children with CP and TD and it was felt that controlling or matching for speed (either asking CP children to walk faster or TD children to walk slower) would have affected these findings.

In conclusion, this study investigated the role of the trunk and the impact on loading at the lower lumbar spine during crouch gait in children with CP. Expected differences in lower limb kinematic and kinetic parameters were evident. However, no major differences were present at the level of the trunk. At the lower lumbar spine, results demonstrated only minor differences between the crouch and non-crouch groups. This suggests that the impact of a crouch gait pattern above the level of the pelvis in children with CP is small and it is unlikely that this type of pattern would affect the health of the spine over time.

Conflict of interest

None of the authors had any financial or personal conflict of interest with regard to this study.

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