Tesis Doctoral Internacional / International Doctoral Thesis

THE USE OF TROLLIES AND BACKPACKS FOR LOAD CARRIAGE IN ELEMENTARY SCHOOL STUDENTS: A BIOMECHANICAL ANALYSIS AND RECOMMENDATIONS.

EL CARRO Y LA MOCHILA EN ESCOLARES DE EDUCACIÓN PRIMARIA: ANÁLISIS BIOMECÁNICO, RECOMENDACIONES Y HÁBITOS DE TRANSPORTE

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"Un científico en su laboratorio no es solo un técnico: es también un niño colocado ante fenómenos naturales que le impresionan como un cuento de hadas."

Marie Curie

Esta Tesis Doctoral Internacional ha sido realizada por la doctoranda Dña. **Mª Eva Orantes González** como beneficiaria de una ayuda para la Formación de Profesorado Universitario (FPU) del Ministerio de Educación, Cultura y Deporte (código: FPU13/00162) por Resolución de 22 de agosto de 2014 de la Secretaría de Estado de Educación, Formación Profesional y Universidades.

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Granada, 24 de julio de 2018

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1. Producción relacionada con la Tesis Doctoral

En relación con la Tesis Doctoral Internacional que se presenta, se han obtenido una serie de resultados relacionados con la misma, a modo de proyectos financiados, becas obtenidas, artículos científicos publicados, estancias de investigación y premios recibidos. La producción obtenida se detalla a continuación:

1.1 Becas obtenidas

- Ayuda a la Enseñanza Práctica dirigidas a estudiantes de Másteres y Programas de Doctorado de la UGR-CEI BioTic. Universidad de Granada, con el título “Efecto del peso de la mochila escolar sobre la locomoción en niños de educación primaria”.
- Ayuda para la Formación del Profesorado Universitario (FPU) convocada por el Ministerio de Educación, Cultura y Deporte (ref. FPU13/00162).
- Ayuda para la realización de Estancias Breves para beneficiarios FPU (ref. EST15/00019), del Ministerio de Educación, Cultura y Deporte.
- Ayuda para movilidad internacional de estudiantes de doctorado convocada por la Universidad de Granada.

1.2 Proyectos de investigación financiados

Relacionado con la presente Tesis Doctoral Internacional se ha obtenido financiación con el siguiente proyecto:

- Efecto de la carga de la mochila sobre los parámetros de locomoción en escolares de primaria. Financiado por el Campus de Excelencia Internacional BioTic, Universidad de Granada (ref. CEI2014-MPBS18). Con una duración desde el 28 de mayo al 31 de diciembre de 2014. El investigador principal es el Dr. D. José Mª Heredia Jiménez, y se recibió una financiación de 3.000€.

1.3 Artículos científicos publicados

A continuación, se detallan los artículos científicos publicados relacionados con la presente Tesis Doctoral Internacional:

- Orantes-Gonzalez, E., Heredia-Jimenez, J., Soto-Hermoso, VM. The effect of school trolley load on spatiotemporal gait parameters of children. Gait and Posture. 2015; 42 (3): 390-393.
  DOI: 10.1016/j.gaitpost.2015.06.004.
  Factor de impacto: 2.286 en ISI-JCR (2015).
  Posición de la revista dentro del área: 20/82. Q1 área Sport Sciences.
- Orantes-Gonzalez, E., Heredia-Jimenez, J. Mochila y carro escolar: análisis cinemático usando distintas cargas. Biomecánica. 2016; 24 (1): 7-13.
  DOI: 10.5821/sibb.24.1.4870
  Factor de impacto: Indexada en Latindex. Área de Ciencias Sociales.
- Orantes-Gonzalez, E., Heredia-Jimenez, J., Beneck, G. Children required less gait kinematic adaptations to pull a trolley than to carry a backpack. Gait and Posture. 2017; 52: 189-193.
  DOI: 10.1016/j.gaitpost.2016.11.041
  Factor de impacto: 2.273 en ISI-JCR (2017).
  Posición de la revista dentro del área: 31/81. Q2 área Sport Sciences.
- Orantes-Gonzalez, E., Heredia-Jimenez, J. Pulling a school trolley: a good kinematic option for children. Gait and Posture. 2017;53: 61-66.
  DOI: 10.1016/j.gaitpost.2017.01.012
  Factor de impacto: 2.273 en ISI-JCR (2017).
  Posición de la revista dentro del área: 31/81. Q2 área Sport Sciences.

- Orantes-Gonzalez, E., Heredia-Jimenez, J., Robinson, M. A kinematic comparison of gait with a backpack versus a trolley for load carriage in children. Gait and Posture. 2018. Under review.
  Factor de impacto: 2.273 en ISI-JCR (2017).
  Posición de la revista dentro del área: 31/81. Q2 área Sport Sciences.
- Orantes-Gonzalez, E., Heredia-Jimenez, J. Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley? Work Journal. 2018. Under review.
  Factor de impacto: 0.902 (2017 JCR Impact Factor).
  Posición de la revista dentro del área: 131/156. Q4 área Public, Environmental & Occupational Health.

1.4 Resúmenes de congresos publicados

Los siguientes resúmenes de congresos en relación con la Tesis que se presenta, fueron publicados:

- Heredia-Jimenez, J., Orantes-Gonzalez, E., Rowley, K. M., & Kulig, K. Pulling, pushing and lateral use of a trolley vs. carrying a backpack. A pilot study. 2016. Gait and Posture; 49: 43-44. DOI: 10.1016/j.gaitpost.2016.07.108.
- Orantes-Gonzalez, E., & Heredia-Jimenez, J. Pulling a school trolley with different loads: A kinematic analysis in children. Gait and Posture. 2016; 49: 203-204. DOI: 10.1016/j.gaitpost.2016.07.255.

1.5 Capítulos de libro

También se ha realizado un capítulo de libro vinculado a esta Tesis, tal y como se detalla a continuación:

- Escabias M., Aguilera A.M., Heredia-Jiménez J.M., Orantes-González E. (2017) Functional data analysis in kinematics of children going to school. En: Aneiros G., G. Bongiorno E., Cao R., Vieu P. (eds) Functional Statistics and Related Fields. Contributions to Statistics. Springer, Cham.

1.6 Estancias de investigación

- University of Southern California. Division of Biokinesiology and Physical Therapy (Los Angeles, EEUU) de 3 meses de duración (marzo-mayo 2016), financiado por el Ministerio de Educación, Cultura y Deporte (Ref. EST15/00019). Se encuentra en el puesto 49 a nivel Mundial según el Ranking Académico de las Universidades del Mundo (ARWU-Shanghai) en 2016.
- University of Central Lancashire. Allied Health Research unit (Preston, Reino Unido). Duración de la estancia de 3 meses (junio a agosto 2018), financiado por la Universidad de Granada.

1.7 Premios recibidos

- Premio a la mejor comunicación del Congreso de la Sociedad Ibérica de Biomecánica y Biomateriales (2016). Con la comunicación oral presentada: ¿Podría ser el carro escolar una buena opción para los niños? León, 21-23 de octubre 2016.

Abbreviations

2. ABBREVIATIONS

AC: Acromioclavicular marker

ASIS: Anterior superior iliac spine

BW: Body weight

CAST: Calibrated anatomical systems techniques

FAL: Fibula apex of lateral malleolus

FCC: Posterior surface of calcaneus

FLE: Femur lateral epicondyle

FME: Femur medial epicondyle

FM1: First metatarsal head

FM2: Second metatarsophalangeal

FM5: fifth metatarsal head

GA: Gait asymmetry

GC: Gait cycle

GCS: Global coordinate system

HJC: Hip joint center

ISB: International Society of Biomechanics

LCS: Local coordinate system

LM7: Left costal cartilage of the seventh rib

PSIS: Posterior Superior Iliac Spine

RM7: Right costal cartilage of the seventh rib

ROM: Range of motion

RPE: Rating of perceived exertion

SJN: Sternum jugular notch

SPM: Statistical parametric mapping

SXS: Sternum Xiphisternal

TAM: Tibia Apex of Medial Malleolus

WT: Without trolley

Resumen

3. Resumen

Los escolares usan diariamente el carro o la mochila escolar para transportar sus útiles al colegio. En la presente Tesis Doctoral Internacional que se presenta se han evaluado los cambios en los parámetros espaciotemporales y cinemáticos de la locomoción que el uso del carro escolar y la mochila producen en los escolares de Educación Primaria mientras transportan distintas cargas.

Para ello se muestra en primer lugar un análisis de los **datos descriptivos** relativos al peso medio absoluto (en kilogramos) y relativo (como % BW) de la mochila y del carro escolar de los participantes en el estudio. También se realizó un análisis del número y porcentaje de niños y de niñas que se encontraban en cada uno de los rangos establecidos en función del peso de su mochila o carro escolar, así como atendiendo al tipo de equipo que usaban para ir al colegio (carro o mochila). Por otro lado, se analizó la opinión de los participantes sobre el peso y la fatiga al llevar su mochila o carro, la forma de desplazamiento al colegio, y la prevalencia de dolor de espalda relacionada con el transporte de su mochila o carro escolar.

En lo que respecta a los estudios realizados, en el **primer estudio** participaron 14 escolares entre 6 y 12 años. En este trabajo se realizó una evaluación de los parámetros espaciotemporales de la locomoción en las siguientes condiciones: caminando sin carga y transportando un carro escolar con el 10%, 15% y 20% del peso corporal del escolar (% BW). En cada una de las condiciones fueron registradas, al menos, cinco pasadas de cada participante caminando por un pasillo de locomoción de 15 metros en el que se había colocado, en el centro del mismo, una plataforma de presiones plantares (GAITRite system; CIR Systems Inc., Clifton, EEUU). Las condiciones de carga analizadas fueron realizadas en orden aleatorio para casa sujeto.

Las variables obtenidas fueron velocidad (m/s), cadencia (pasos/s) y longitud de zancada (m). Además, fueron analizadas la fase de apoyo monopodal, fase de apoyo bipodal, fase de apoyo total y fase de oscilación, expresadas como porcentaje del ciclo de marcha (% GC). El test de Shapiro Wilk fue utilizado para analizar la normalidad de las variables estudiadas, y el test ANOVA de un factor, utilizando la carga como variable independiente fue utilizado para comparar las distintas condiciones experimentales, aplicando después la corrección de Bonferroni en las comparaciones múltiples. El nivel de significación fue $p<0.05$.

Los resultados obtenidos mostraron que, comparado con la condición sin carga, tirar del carro con el 10%, 15% y 20% BW produjo una disminución significativa de la fase de oscilación y de la fase de apoyo monopodal ($p<0.001$), mientras que la cadencia ($p=0.019$), fase de apoyo total ($p<0.001$) y fase de apoyo bipodal ($p<0.001$) aumentó de forma significativa en esas mismas condiciones experimentales. No se obtuvieron diferencias significativas en ninguna de las variables analizadas entre las tres condiciones de carga.

Como conclusión, se destacó que el uso del carro escolar produce cambios en la cadencia, fase de oscilación, fase de apoyo total, fase de apoyo monopodal y fase de apoyo bipodal, pudiendo estar estos cambios relacionados con la influencia de la carga sobre el equilibrio y la estabilidad corporal. Aunque el uso del carro produjo una alteración de la locomoción independientemente de la carga transportada dentro del rango de 10-20% BW.

Posteriormente, se llevaron a cabo los estudios II y III, para los cuales se realizó la evaluación de 53 escolares con edades comprendidas entre 6 y 12 años. En ambos estudios se utilizó un sistema de captura 3D (Qualisys AB, Gotemburgo, Suecia) para analizar las variables cinemáticas de la locomoción. Para ello se empleó un set de 48 marcadores reflectantes colocados en las extremidades inferiores y el tronco. Dichos marcadores fueron capturados con nueve cámaras infrarrojas grabando a 250 Hz.

En el **estudio II** se analizaron las adaptaciones cinemáticas de la locomoción cuando se transporta un carro escolar y una mochila, ambas con el 15% BW, comparado con caminar sin carga.

Las variables analizadas fueron las siguientes: velocidad, cadencia y longitud de zancada, que fueron normalizadas siguiendo las ecuaciones propuestas por Hof (1996); y además se analizó la fase de apoyo monopodal, fase de apoyo bipodal, fase de apoyo total y fase de oscilación, expresadas como % GC. También fueron obtenidas la media y desviación estándar (en grados) del plano sagital, frontal y transversal del tórax, pelvis, cadera, rodilla y tobillo.

Para el análisis de los datos se llevó a cabo el test de normalidad de Kolmogorov-Smirnov, y para la comparación entre las variables cinemáticas en las tres condiciones experimentales se utilizó un ANOVA de medidas repetidas, con la posterior comparación por pares de Bonferroni. El nivel significación se fijó en $p<0.05$.

Los resultados obtenidos al comparar carros y mochilas con el 15% BW, mostraron que el uso del carro no producía diferencias significativas en los parámetros espaciotemporales de la locomoción, mientras que el uso de la mochila escolar provocaba mayores alteraciones cinemáticas. Se destaca como conclusión que el uso del carro con el 15% BW requiere menos adaptaciones de la locomoción y posturales que el uso de la mochila con la misma carga.

En el **estudio III** se analizaron los cambios cinemáticos de la locomoción provocados por el uso del carro escolar con distintas cargas, y evaluando el hemicuerpo lateral sobre el que recaía la carga del carro para valorar la asimetría que provoca al transportarse con una sola mano. También se analizó si el tipo de equipo que el escolar usaba diariamente para transportar sus útiles al colegio (carro vs. mochila) podía afectar a los posibles cambios cinemáticos mientras se usaba el carro.

Para ello se obtuvo la media y desviación típica de los parámetros espaciotemporales de la locomoción, así como las variables cinemáticas 3D del tórax, pelvis, cadera, rodilla y tobillo cuando los escolares caminaban sin carga, o tirando del carro escolar con el 10%, 15% y 20% BW, diferenciando además el lado dominante (brazo con el que transportan el carro) del lado no dominante.

El análisis de las variables se realizó utilizando el test de Kolmogorov-Smirnov para estudiar la normalidad de las variables, el test de Levene para comprobar la homogeneidad de la varianza y el test de Mauchly como medida de la esfericidad. Un ANOVA de dos factores fue aplicado para comparar el efecto de las distintas cargas (0%, 10%, 15% y 20% BW) en el tipo de equipo que los escolares solían utilizar diariamente para transportar sus materiales al colegio (usuarios de mochila vs. usuarios de carro), y entre ambos lados del cuerpo (cargado vs. no cargado). Se aplicó el ajuste por Bonferroni para todas las comparaciones realizadas. El nivel significación se fijó en $p<0.05$.

Tras el análisis espaciotemporal de la locomoción, los resultados mostraron que tirar del carro con el 20% BW produce una disminución de la velocidad, de la amplitud de zancada, y del apoyo monopodal, junto con el aumento del apoyo bipodal, aunque estos cambios fueron relativamente pequeños, ya que supusieron una disminución de 0.02 unidades en la velocidad y longitud de zancada, una disminución del 0.32% en el apoyo monopodal y aumento del 0.31% en el apoyo bipodal. En relación a las variables cinemáticas, el carro produjo adaptaciones en el tórax, con un aumento de la flexión conforme la carga aumenta, y en la pelvis, con un aumento de la flexión transportando la carga con el 10% y 15% BW. No se encontró una interacción significativa entre los parámetros cinemáticos y el tipo de equipo que los escolares suelen usar diariamente para transportar sus útiles (carro o mochila). Cuando se compara la cinemática diferenciando el lado dominante del no dominante, el plano transversal del tórax fue el que muestra más diferencias entre ambos lados.

Como conclusión se destacó que, aunque los parámetros cinemáticos fueron influenciados por el uso del carro escolar, las adaptaciones provocadas fueron mínimas, pudiendo considerar el carro escolar una buena opción para el transporte de material escolar.

En el **estudio IV** que se presenta para esta tesis doctoral, se realizó un análisis de los parámetros cinemáticos de la locomoción del tórax, pelvis, cadera, rodilla y tobillo, analizando cada curva de forma completa, durante el ciclo completo de marcha, y no como un único valor, expresado como la media del ciclo de marcha. Para ello, se analizó a 49 escolares mientras transportaban una mochila y un carro escolar cargado con el 10%, 15% y 20% BW con el fin de proponer unas recomendaciones sobre la carga adecuada cuando se utiliza un carro escolar o una mochila basándose en las adaptaciones cinemáticas.

En cada una de las condiciones analizadas, se obtuvieron, en grados, la flexión/extensión, aducción/abducción y la rotación interna/externa del tórax, pelvis, cadera, rodillas y tobillo. Para su análisis se llevó a cabo un test de mapeo estadístico paramétrico (Statistical parametric mapping "SPM") para evaluar los diferentes segmentos en cada plano y en las distintas cargas durante el ciclo completo de marcha.

Los resultados mostraron que cuando se transporta la mochila cargada con distintas cargas (desde 10% hasta 20% BW), la magnitud de las diferencias aumentaba desde los segmentos distales a los proximales comparado con la condición sin carga. Además, cuando se utilizaba el carro escolar con las distintas cargas propuestas, sólo se obtuvieron algunas adaptaciones cinemáticas de menor magnitud comparado con la condición sin carga.

Como conclusión, tirar de un carro escolar permite a los escolares mantener una postura muy similar a la locomoción sin carga. Por lo tanto, desde el punto de vista cinemático, se recomienda evitar cargas mayores del 10% BW cuando se usa una mochila escolar, y para el carro escolar, estas cargas recomendadas podrían fijarse por debajo del 20% BW.

Para el **estudio V** se analizó si llevar una mochila o tirar de un carro escolar con diferentes cargas provoca cambios en la percepción subjetiva del esfuerzo (RPE) y la asimetría de la locomoción (GA) de los escolares.

Las variables espaciotemporales de la locomoción fueron obtenidas utilizando un sistema de captura 3D mientras el escolar caminaba en las distintas condiciones propuestas: tirando de un carro y de una mochila, ambas con el 10%, 15% y 20% BW. De cada una de las condiciones experimentales, fueron obtenidas las siguientes variables espaciotemporales: longitud de paso, tiempo de oscilación y tiempo de apoyo total. A partir de las cuales fueron calculados y analizados los ratios, angulos de simetría y GA de cada una de las variables propuestas. Además, se obtuvo el RPE que los escolares reportaban al finalizar cada una de las condiciones experimentales.

Los resultados obtenidos indicaron que no existían diferencias significativas en ninguno de los parámetros de asimetría analizados mientras se usaba la mochila escolar y el carro con las distintas cargas propuestas. En lo que respecta al RPE, los valores aumentaron llevando una mochila con el 20% BW comparado con la condición sin carga y también con la condición 10% BW ($p<0.05$ para ambas comparaciones). En las distintas condiciones de carga en las que el carro escolar fue utilizado, no se obtuvieron diferencias significativas en los valores de RPE obtenidos.

Como conclusión, ni el uso del carro escolar ni de la mochila con cargas entre el 10% y el 20% BW produjo un aumento de la asimetría de la locomoción en escolares de educación primaria. Además, el uso del carro escolar con una carga entre el 10 y el 20% BW no supuso para el escolar un aumento del esfuerzo subjetivo.

A modo de **conclusión global**, se encontró que más de la mitad de los escolares (56.9%) transportan más del 15% BW, siendo el carro escolar la opción elegida por el 64% de las niñas analizadas. Además, los usuarios de carro escolar parecen tener una percepción más positiva en la percepción de fatiga y de peso del equipo que los usuarios de mochila. En lo que respecta a las adaptaciones cinemáticas, el uso del carro escolar entre el 10% y el 20% BW permite mantener a los escolares una postura más próxima a la locomoción sin carga y una menor percepción de esfuerzo que el uso de la mochila escolar con las mismas cargas. En lo que respecta a las cargas recomendadas, el análisis cinemático realizado en los estudios llevados a cabo parece indicar que se evite transportar una mochila transportando cargas mayores del 10% BW, y en el caso del carro escolar con cargas por debajo del 20% BW.

Abstract

4. Abstract

Every day, children carry a backpack full of books to school. This International Doctoral Thesis evaluates the kinematics changes whilst carrying a backpack or pulling a trolley with different loads, in elementary school students.

In order to do this, **descriptive data** were obtained for absolute (in kilograms) and relative (% BW) weight of a school bag for boys and girls. Further data included the number and percentage of participants for the range of weights of the school bag load and the method of carriage by gender. The opinion of participants was collected, including the school bag weight and fatigue during carriage, the mode of commuting to and from school and the prevalence of back pain related to school bag carriage. They were shown as the number and percentage of participants by backpack and trolley users.

With respect to the studies carried out, **study I** was evaluating the spatiotemporal gait parameters in 14 children (from 6 to 12 years old) when they carried a school trolley with different weights. The experimental conditions analysed were walking without a trolley, and pulling a trolley with 10%, 15% and 20% of the % BW. The load conditions were completed in a randomized order, and children walked for 5 trials per condition along 15 meters of walkway. A

pressure platform was placed in the middle of the walkway (GAITRite system; CIR Systems Inc., Clifton, USA) so as not to measure the non-stabilized walking periods at the beginning and end of each trial.

The variables analysed were velocity (m/s), cadence (steps/s) and stride length (m), that were normalized. In addition, swing phase, stance phase, single support phase and double support phase were measured and expressed as a % GC.

The Shapiro Wilk's test was used to test normal samples. Gait parameters were analysed using one-way ANOVA with Bonferroni confidence interval adjustment, since there was only one independent variable (load). The level of statistical significance was set at $p<0.05$.

Compared with unloaded walking, the three load conditions analysed produced a significant decrease in swing phase ($p<0.001$) and single support phase ($p<0.001$), and a significant increase in cadence ($p=0.019$), stance phase ($p<0.001$) and double support phase ($p<0.001$). No statistically significant differences were found between the three load conditions.

In conclusion, compared with unloaded walking, pulling a trolley produced significant changes in most of the spatiotemporal gait parameters measured, perhaps due to the load-mediated changes in stability and balance. The spatiotemporal gait parameters were similar between the load conditions, indicating that the amount of load from 10%-20% BW did not affect gait.

Subsequently, in the following studies carried out for this Doctoral Thesis, **studies II, III, IV**, performed an evaluation of the kinematics of gait using a 3D motion capture system (Qualisys AB, Göteborg, Sweden). **Study V** used this same procedure to analyse the GA of spatiotemporal gait parameters. For that, a full body marker set model without head and upper extremities formed by 48 reflective markers was used and captured by 9 infrared cameras recording to 250 Hz.

Study II was focused on comparing the effects of carrying a backpack and pulling a trolley, both with the 15% BW on gait kinematics for 53 students. The variables analysed were; velocity (m/s), cadence (steps/s) and stride length (m), that were normalized. In addition, swing phase, stance phase, single support phase and double support phase were measured and expressed as a % GC. In addition, average and standard deviation (in degrees) of sagittal, frontal and transverse planes were computed for thorax, pelvis, hip, knee and ankle.

Normality was determined using the Kolmogorov-Smirnov test. The comparison of the kinematics gait varies between the three experimental conditions (control, carrying a backpack and pulling a trolley, as independent variables). These were analysed using repeated measures ANOVA. When significant differences across carrier types were determined, a Bonferroni adjustment was computed to perform the pairwise comparisons. The level of statistical significance was set at $p<0.05$.

No significant differences were obtained in spatiotemporal gait parameters between pulling a trolley and control. Carrying a backpack resulted in larger kinematic gait alterations than when pulling the trolley compared to control. In conclusion, pulling a school trolley (15% BW) was more like not carrying a bag than carrying a backpack of the same load during level walking.

Study III analysed the kinematic gait adaptations associated with pulling a school trolley with different loads and the effects of the type of packing device user (backpack vs. trolley) and body side (loaded vs. unloaded) in a group of 53 students from an elementary school. Averages and standard deviations of spatiotemporal gait parameters and 3D kinematics of the lower limbs and thorax were obtained for the loaded and unloaded sides of the body while children pulled the trolley with 10%, 15% y 20% BW.

The normal distribution was confirmed using the Kolmogorov-Smirnov test. The homogeneity of variance was tested with the Levene test. The Mauchly test was used to assess sphericity. Two-way ANOVA was performed under two conditions: for the comparison between trolley weight (0%, 10%, 15% and 20% BW) and the type of packing device used (backpack vs. trolley users) and for the comparison between trolley weight and body side (loaded vs. unloaded side). Bonferroni's confidence interval adjustment was performed for all comparisons. The level of statistical significance was set at $p<0.05$.

Spatiotemporal gait parameters were affected by pulling a trolley with a load of 20% BW, although the changes were not important (decrease of 0.02 units in velocity and stride length, decrease of 0.32% in single support and increase of 0.31% in double support). In the 3D kinematics analysis, the main effects of trolley load were observed in the thorax, with increased flexion as the load increased, and in the pelvis between baseline and 10%–15% BW. No interaction was found between kinematic parameters and the type of packing device used (trolley or backpack). Considering the loaded and unloaded sides of the body, the transverse plane of the thorax was the main site affected by the asymmetrical task.

In conclusion, although some of the analysed kinematic parameters were influenced by the use of a school trolley, the adaptations were minimal, and trolleys could be considered a good option for use in the transportation of school supplies.

In **study IV** presented for this International Doctoral Thesis, the complete gait kinematic waveforms of the thorax, pelvis, hip, knee and ankle of the 49 participants were analysed while carrying a backpack and a trolley loaded with 10, 15 and 20% BW to clarify recommendations for appropriate load carriage in children.

The variables obtained in each condition were the degrees of flexion/extension, adduction/abduction and internal/external rotation of thorax, pelvis, hip, knee and ankle. Statistical parametric mapping (SPM) was used to evaluate differences between conditions and loads throughout the gait cycle.

The results from the analysis of the different backpack conditions showed that the magnitude of the differences decreased from proximal to distal joints compared to the control condition. While the increased load in the school trolley only required minor kinematic adaptations compared to unloaded walking.

In conclusion, pulling a school trolley allows children to maintain the closest posture to natural walking. From kinematic analysis, avoiding loads above 10% BW if using a backpack is recommended, whilst below 20% BW was deemed a safe load for children using a trolley.

Study V was aimed at determining whether carrying a backpack and pulling a trolley with different loads influenced the variability in the rating of perceived exertion (RPE) and gait asymmetry (GA) that children reported.

A 3D motion capture system was used to analyse the spatiotemporal gait variables. The ratios, symmetry angles and gait asymmetry of the step length, swing time, and stance time were subsequently analysed. Furthermore, the RPE was recorded at the end of each walking trial.

The results demonstrated that none of the asymmetry parameters showed significant differences while carrying the backpack and pulling the trolley. The RPE data increased from the control to the 20% BW ($p<0.05$) and from the 10% BW to the 20% BW backpack condition ($p<0.05$). Pulling the trolley did not produce a significant increase in the RPE.

In conclusion, carrying a backpack and pulling a trolley from 10% to 20% BW did not induce gait asymmetry in children. The use of the school trolley required less subjective effort than carrying a backpack with the same loads.

As a **general conclusion**, more than half of the schoolchildren (56.9%) were found to carry more than 15% BW, school trolleys being the chosen option by 64% of girls. Besides, school trolley users seem to feel a higher positive perception of fatigue and weight perception than backpack users. With respect to the kinematic adaptations, the use of the school trolley between 10% and 20% BW seems to let schoolchildren maintain a closer posture to unloaded walking with a lower perception of effort than the use of the school

backpack. The results of the kinematic analysis suggest children avoid loads greater than 10% when carried in a backpack, or greater than 20% if using a trolley, to maintain unloaded over ground walking kinematics.

Introduction

5. Introduction

5.1 Recommended loads for school backpacks.

Children routinely use either a backpack or trolley to carry books and other supplies when traveling to and from school. Recommendations for backpack loads range generally from 10% to 15% of children´s body weight (BW) (2,3). Other institutions such as the American Occupational Therapy Association (4), state the recommended load to be no more than 10% BW, while the American Academy of Pediatrics (5) widen this recommendation up to 20% BW.

Previous research studies have established a specific maximum load while carrying a backpack, based on spatiotemporal gait analysis, kinematics and kinetics data, oxygen consumption and electromyography data. In fact, previous studies that analysed the spatiotemporal gait parameters and kinematics variables have concluded that the recommended load for the backpack should not exceed 10% BW (6–9). That percentage of load was also considered as the amount of weight which meant children avoid postural disorders in their back (10), also carrying a backpack where 10% BW was the load, produced the lowest disturbance in the metabolic process of the schoolchildren (11) and was considered as healthy behaviour for students (12).

Other previous studies have recommended that the load for backpack carriage is around 15% BW based on gait and posture analysis (13) and EMG analysis (14,15). Another study established that pupils carrying up to 11% BW seem not to suffer the negative effects of overweight backpack carriage, while pupils that carry higher loads than 14% BW in their backpacks will have increased the negative effects over the musculoskeletal system (16).

In spite of recommendations for a safer backpack carriage, studies all over the world have shown that students carry a heavier backpack than recommended loads. For example, studies carried out with a European sample, have reported overweight student´ backpacks. For example, 34% of Italian students carried a load heavier than 30% BW at least once per week, obtaining an average backpack load of 22% BW (17). Greek students also carried a higher load than recommended, obtaining an average trolley weight of 18.6% BW and 15.1% BW for an average backpack weight (18). Another previous study reported that 70% of Irish students, between 9 to 11 years old, used to carry heavier loads than 10% BW (19,20).

In Spain, the average backpack load was not as high as previous countries mentioned, reporting an average backpack load of 13.4% BW (21) and 10.2% BW (22). Although considering the percentage of students above the load recommendations, the results indicated that 50% of students between 9 and 12 years old used to carry higher loads than 10% BW in their backpacks (23), and even 61% of students from 8 to 10 years old carried more than 15% BW in their backpacks (24).

Similar results were found in countries such as Israel, where between 30 and 54% of elementary students used to carry more than 15% BW in their backpacks (25); and India, where the average school backpack weight for students between 11 and 14 years old was nearly 16% BW (16).

In previous studies carried out in America, they reported an average backpack weight closer to the recommended loads. In this way, the average weight of the backpack found in Californian students represented 10.7% BW (12), and in Texas the average backpack load was 8.2% BW, with the additional information that 26% of pupils carry more than 10% BW in their backpacks (26). Although in Brazil, a higher percentage of students were found to carry an increased load to 10% BW compared to North American results; this being 71.7% of Brazilian students between 10 and 12 years old (27) and 52% of students from 6 to 13 years old (28) carrying more than 10% BW in their backpacks.

Higher than recommended backpack load has been reported in studies carried out in countries from the Arab league. It has been published that 72% of Saudi Arabian students carry more than 15% BW in their backpacks (29), in Iraq the average backpack load of students was 18.9% BW (30), while in Egypt the average bag weight was 25.3% BW in the group from 6 to 10 years old, and 21% BW in the students between 11 and 14 years old (31).

5.2 Prevalence of school trolley and backpack use in elementary students.

The school backpack is widely the favourite option for students while attending elementary school. Although in countries such as Spain and Greece, the school backpack does not dominate the elementary school period. The use of the school trolley involves a significant percentage of students that have chosen this type of bag to transport their school supplies, reporting percentages of use very similar to the backpack: 56% backpack users vs. 44% school trolley users (32), 64% backpack users vs. 31% school trolley users (22), 63% backpack users vs. 37% school trolley users (33).

Previous studies have even reported that the use of a school trolley is higher than the backpack, being the favourite option for 46% of children, while the 38% chose carrying a backpack (18). Besides, the school trolley has been reported as the favourite option for girls, being used by 56% of female students (34). In other countries, the school trolley is less popular, being used by 5% of students in Texas (26), 14.5% in Saudi Arabia (35) and 16% in Iraq or Egypt (30,31).

5.3 Has the school trolley been recommended to children?

School trolleys have been proposed as an alternative to the backpack. One of the reasons for that change, as Forjouh et al., (26) reported, is concern about the weight of the backpacks, and this has reinforced the argument for safety and/or spine care that the school trolley would provide. In fact, the study carried out by Bort et al., (32) concluded that 57% of the students´ mothers perceived that school trolleys would require their children to make less effort when transporting their school supplies and also that the school trolleys are more comfortable than the backpacks.

The use of a school trolley involves an asymmetry of effort because all the weight of the trolley has to be transported using only one arm, and the weight is not distributed between both upper limbs. Also, the average weight of a school trolley is higher than backpacks, oscillating from 4% to 30% according to previous studies (18,26,35–37). These weight differences may be due to the own structure of the school trolley with the wheels and the handle that makes it heavier in itself. However, it could be also due to the perception of safety that the school trolley provides, as it does not have to be carried on the back, which in turn may lead to it being more loaded.

In addition to that, in some situations such as ascending and descending stairs, the use of a school trolley could raise some concerns about the potential for excessive stresses in the arm-shoulder complex (38). In reference to the recommendations provided about the use of school trolleys, they have been suggested for situations in which school children have to carry a high load (3,5); and a previous study about the use of the school trolley suggested it as an option for achieving healthy habits in students (12).

5.4 Is there a relationship between the weight of a backpack and the weight of a school trolley with those who suffer from back pain?

The relationship between the weight of the backpack and those suffering from back pain has generated controversy that continues today. Previous studies have not found a relationship between the weight of the backpack and back pain or discomfort (19–22). In fact, the use of a backpack within the recommended ranges has not been considered a risk factor to suffering from back pain as was supported by previous studies (39). But carrying a heavy backpack was associated with back pain as previous studies supported (16,40,41). A previous study has considered psychosomatic factors and not the % BW which was strongly correlated with suffer shoulder and neck discomfort (42). In accordance with that, Parma et al., (43) concluded that although school bag use does not appear to be an important risk factor for back pain, there is evidence that perception of heaviness is associated with back pain.

In exploring the possible relationship between the weight of the backpack and suffering from back pain other variables have to be included that might influence the outcome. The way in which the backpack is carried (31), the subjective perception of backpack weight, carriage duration and the commute to school (44) have been highlighted as complementary risk factors to back pain.

Complementary to those variables, gender has been another factor related to back pain as previous studies reported (45,46). The gender, together with the design of the backpack and % BW were factor related with back, neck and shoulder pain (30). Aprile et al., (47) found that variables such as weight of the backpack, carriage duration and gender is related to suffering from back pain. In the study by Pires et al., (48) the weight of the backpack did not have a relationship with suffering from back pain, although this changed when carriage time was including in the analysis. And in the study of Siambanes et al., (46) it was concluded that % BW was a predictor of back pain when the analysis was adjusted by age, economical level, walking to the school and the type of backpack carriage, and this study concluded that girls and those who walk to and from school were more likely to report back pain.

Being a woman, young, walking to school for a long period of time and carrying a heavy backpack seems to be a combination that leads to suffering from back pain. On the opposite side, the use of lockers at school seem to be an alternative to minimize the risk of suffer back pain (41).

In the analysis of the relationship between the use of a school trolley and suffering from back pain, the studies have been less numerous. Rontogiannis et al., (18) reported that in spite of school trolleys being heavier than backpacks, the percentage of students who reported back pain was lower in trolley users (43% vs. 65%). Although contrary to those results, a previous study found that being female, older, normal weight and using a trolley conferred a higher risk of scoliosis development (33).

5.5 Analysis of the spatiotemporal gait variables while carrying a backpack and pulling a school trolley.

Walking requires a repetitious sequence of limb motions to simultaneously move the body forward while also maintaining stance stability (49). With the objective of analysing how the use of a backpack or a trolley could influence the gait pattern (**Figure 1**), previous studies have focussed on the adjustments in gait that carrying a loaded backpack or a school trolley produce in children and adolescents.

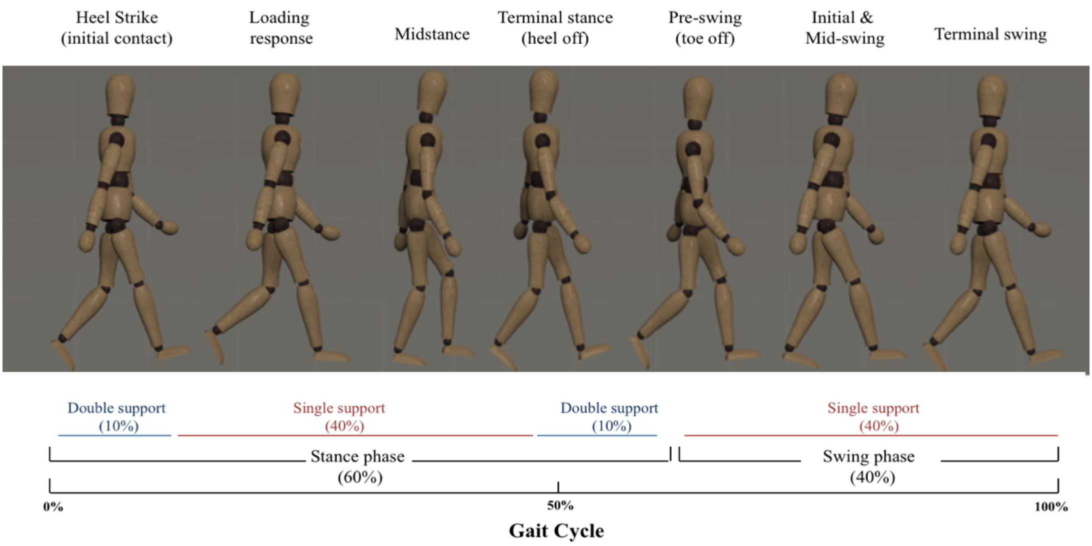

Figure 1. Gait phases for a right gait cycle according to the gait phases categorization proposed by Perry and Burnfield (2010).

In this way, Chow et al., (7) obtained that the increase in backpack load (7.5%, 10%, 12.5% and 15% BW) resulted in a significant decrease of step length, cadence, walking speed and single support, while the double support and stride time increased with backpack load. Most of the previous studies are in accordance with those results. Kellis and Arampatzi (50) obtained that carrying a loaded backpack with 17% BW produced a decrease of stride length and an increase of stance phase and double support phase. Pascoe et al., (51), who also analysed carrying a loaded backpack of 17% BW, concluded that walking with the loaded backpack decreased the stride length, although the stride frequency increased being contrary to the results obtained in previous other studies. Sing et al., (52) obtained carrying a backpack with 20% BW produced a significant decrease in the velocity and an increase of double support time, while the lightest load (10% and 15% BW) did not produce any significant gait adaptations in normalized velocity, cadence, stride length and double support time compared to unloaded.

Connolly et al., (53) did not find significant differences in velocity, however the study found that an increase of load to 15% BW produced a slight increase of double limb support, suggesting that carrying a backpack over one or two shoulders can create problems with balance. In this way, in previous studies where velocity was fixed, as in the study of Cottalorda et al., (54) where children walked at 3.5 km/h, carrying a backpack with 10 kg (that represent 25% BW) produced an increase of stance phase and double support phase compared to walking without a backpack. In the study of Hong and Brueggeman (8) where velocity was fixed at 1.1 m/s, the double support phase increased, and the swing phase decreased carrying a backpack with 20% BW compared to an unloaded condition and 10% BW. In that study, the authors reported that the increase of the backpack load would raise the subject's centre of gravity making the subject more unstable, which was compensated by reducing their swing phase, and therefore minimising the duration of the unsteady single-limb stance.

Those conclusions were also supported by Wang et al., (55) where a decrease of velocity, single and double support time, together with an increased stance time were obtained while carrying a loaded backpack of 15% BW in young adults, compared to unloaded. In the study of Lehnen et al., (56) done also with young adults, carrying a backpack with 10% BW did not affect the spatiotemporal gait parameters, although a higher load (20% BW) produced an increase of stride length, double support and stance phase, while the swing phase decreased compared to the unloaded.

Although in other previous studies, the spatiotemporal gait parameters were not affected when children carried the backpack loaded with the school supplies when compared to the no bag condition (57), and neither was it affected when carrying a backpack loaded up to 20% BW (13). However, in some of the studies carried out with young adults, the spatiotemporal parameters were not influenced by carrying a backpack with 15% BW whilst walking at a fixed speed of 1.5 km/h (58), or walking at a self-selected velocity carrying a backpack loaded with 5%, 10% and 15% BW (6). In the study of Yoon et al., (59) where participants were young adults, carrying a backpack with 10% BW did not produce changes in walking speed, stride length and single support time.

To sum up, the increase of the double support phase and the decrease of the swing phase that carrying a loaded backpack produces, could be an adjustment of the gait pattern as an answer to an increase of load in the backpack to supply the instability that carrying a backpack produces together with the reduction in the demands of the musculoskeletal system because when both the feet are in contact with the ground, the mechanical demand on the whole system would be lesser compared to when only one foot remains in contact with the ground (56). So, the increase of the double support phase to provide a higher base of support during a higher gait cycle with the aims of increased stability and to distribute the implemented load over both feet (55).

In a previous systematic review about the effect of carrying a loaded backpack it was highlighted that the increase of load has a small effect over the stride length and cadence, while over the double support and single support phase, the effect of load was moderate (60). Although, in general, the effect of load increase did not show stable adaptations on the spatiotemporal gait parameters. In this way, a previous study highlighted that disparity in gait results could be due to the different methodologies and sample characterists used in the studies (50). For example, some of the spatiotemporal gait parameters could be influenced by the type of instruments used, as the double support phase was higher while walking over level ground compared to walking on a treadmill (61,62).

Therefore, the main adaptations while carrying a loaded backpack seem to be related to an increase of double support as the load was higher, while in others, variables such us velocity, cadence and stride length, the increase of load did not show large significant effects. In addition to this, to the authors knowledge, there are no previous studies that produce an analysis about the spatiotemporal gait adaptations of children while pulling a school trolley, until the studies carried out in this doctoral thesis.

5.6 Kinematics adaptations while pulling the trolley and carrying the backpack under static and dynamic conditions.

Until a person reaches full body development at near thirty years old, children and adolescents are experiencing periods of continuous growth, especially between the ages of 5 to 18 years old (63,64) **(Figure 2).** Although the strategies for postural control mature as children grow up, it is considered that around the age of 7-10 years old, they already have mature postural control comparable to that of an adult resolving sensory conflict (65).

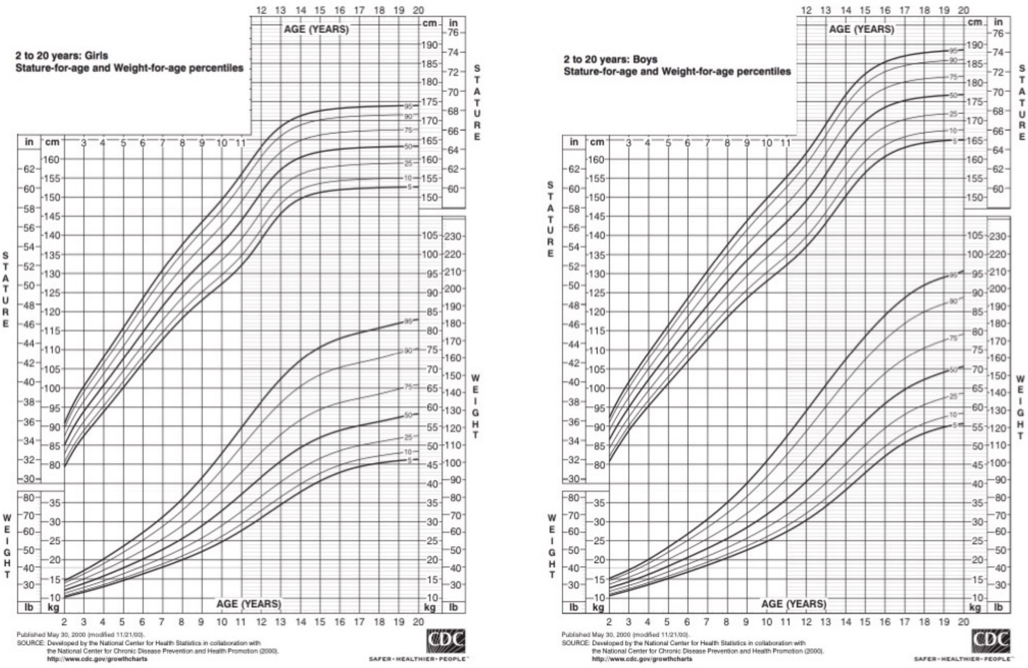

Figure 2. The clinical growth charts in girls and boys from 2 to 20 years old.

It is between 11 and 13 years old when children also acquire the same balance control strategies as adults in both static and dynamic situations (66).

Carrying a backpack has been related to some kinematic adaptations in both static and dynamic situations. Previous studies that have analysed the main kinematic adaptations under static conditions have obtained a significant increase in trunk flexion supporting loads between 7.5% and 20% BW (67,68). Applying these same loads, Al-Khabbaz et al., (69) obtained an increase in trunk extension compared to unloaded standing. So, in static conditions, children reported some postural compensations to backpack load leaning forward, protracting their heads and increasing their lordosis to compensate the weight of the backpack carried (70). In static conditions, no differences have been found in the pelvis joint supporting loads between 10 and 20% BW compared to an unloaded condition (68).

In walking conditions, previous studies have analysed the postural adaptations while carrying a backpack and pulling a school trolley with different loads. Besides, most of the previous studies that have analysed the kinematics parameters of children or young adults while walking carrying a backpack, have been focused on the analysis of the trunk segment, obtaining an increase in its flexion when a backpack was carried loaded with 15% and 20% BW. Although non-significant differences were found when a lighter load (10% BW) was carried compared to unloaded walking (8,52). Supporting those results, Li and Hong (71) obtained from a group of children of 6 years old a significant increase of trunk flexion while carrying a backpack with 15% and 20% BW compared to unloaded; while in the group of children of 12 years old, increased of trunk flexion was also obtained carrying the backpack with a load of 10% BW.

In previous studies where young adults were included as participants, only the highest load tested (20% BW) produced a significant increase of trunk flexion (13). Devroey et al., (6) did not obtain significant differences in the thorax joint (computed as the absolute angle referred to a global coordinate system) while carrying 5%, 10% and 15% BW in young adults. Although in this same study, computing the spine angle as the angle between the thorax and pelvis, carrying a backpack loaded with 15% BW produced an increase of spine flexion; and even resulted in a significant increase of spine flexion carrying the backpack in a lumbar position loaded with 10% BW compared to no load.

That increase of thorax flexion as a loading response was justified by the previous studies as an adaptation to counterbalance the extra-load on the back while a loaded backpack is being carried. In this way, the increased of load on the back would bring the centre of gravity of the body closer to the rear limit of the base of support reducing stability in this direction. And because one of the main functions of motor control is to orient the body with respect to the external world, children have to move their trunk forward to bring the centre of gravity over their base of support, maintaining their posture to minimise the disturbance of balance and to maintain their walking stability. In addition to this, the combination of load and trunk flexion could promote an additional stress on the vertebral column and consequently, an increase on the intra-discal pressure on the child´s spine (71).

As well as the thorax, the pelvis also plays an important role in load carriage, being responsible for supporting the weight from the spine to the lower limbs during standing (72). So, the pelvis segment adapts its movements under load conditions, reducing the rotation and obliquity movements as supported by previous studies (7). In a previous study where young adults carried a load of 5%, 10% and 15% BW, neither the pelvis or the hip showed significant differences compared to unloaded walking (6). In agreement with this study, Hyung et al., (73) obtained that the pelvic tilt tended to increase as backpack weight was higher in a sample of young adults, although the differences were not significant; while the rotation of pelvis significantly decreased when carrying 10% and 15% BW compared to unloaded. Smith et al., (74) showed an increase of pelvic tilt, and a decrease of rotation and obliquity ROM, although non-significant differences in the angular analysis of these two planes were obtained when carrying a backpack with 15% BW in young adults.

The effect of backpack carriage using a load of 10% and 15% BW has been linked to an alteration of lumbo-pelvic coordination in young female adults because of the changes from normal contraction patterns of the back muscles during carriage, affirming that the acquisition of this abnormal contraction pattern for the back muscles could produce an increase in the risk of spinal injury (75). These postural adaptations of pelvis segment while carrying a backpack compared to unloaded walking has been related to an increase in the trunk muscle co-contraction to continue to provide both static and dynamic stability and consequently produces a decrease in the pelvic rotation (7,74).

So as has been previously reported, the proximal segment, such us the trunk and pelvis, showed some kinematics adaptations due to the implementation of an additional load. In this way, the distal joints, such us the knee or ankle has showed a limited change with an increased load. In the study of Chow et al., (7), carrying a backpack with 12.5% BW showed an increase of the knee peak flexion during loading response for shock absorption, while non-significant differences were found in the ankle joint carrying a backpack from 7.5% to 15% BW.

In respect to previous studies about trolleys and their kinematic effects while pulling, they have been focussed on the work environment. In this way, a previous study has analysed the effect of pulling or pushing a four wheel trolley (wheelbarrow) with different loads on different surfaces (76), and the kinematic adaptations of flight attendants performing trolley manoeuvres during a flight have been analysed (77).

Focussing on the school environment, only one previous study has looked at the effect of pulling a school trolley loaded with 3 kg (that represented approximately 11% BW) compared to unloaded and also with carrying a backpack with the same load using an ultrasound device for trunk postural measures (78). In this study, carrying the backpack produced an increase in thoracic extension and right lateral flexion of the lumbar spine, with a decrease in lumbar flexion compared to unloaded walking. The trolley group was characterised by a significant increase in extension, right lateral flexion, right rotation in the thoracic spine and an increase in left rotation in the lumbar spine when compared to walking without a trolley.

Furthermore, the study resulted in the backpack group displaying a greater degree of thoracic extension and right lateral flexion in the lumbar spine, while the trolley group had more rotation in both the right thoracic and left lumbar regions. So, the conclusion of Schmidt et al., (78) was that it is better to carrying an appropriate weight of backpack rather than use trolleys.

In conclusion, walking carrying a loaded backpack produced an increase of thorax flexion and decrease in pelvis rotation movements compared to unloaded walking, while walking pulling a school trolley seem to be related to an increase of thoracic and lumbar rotations.

Aims

6. Aims

The main objective of this Doctoral Thesis was the biomechanical assessment of the changes produced in kinematic and spatiotemporal gait variables while carrying different loads using a school trolley and a backpack in elementary school students.

In addition, secondary objectives were defined as the following:

- To analyse the gait asymmetry carrying different loads using the backpack or the school trolley.
- To report the rating of perceived exertion pulling a school trolley or carrying a backpack with different loads.
- To assess the average weight children carry to school in their backpacks and school trolleys (absolute and relative).
- To analyse the habits related to the type of school bag used to transport the school supplies in schoolchildren (backpack or school trolley).
- To establish recommendations about the maximum recommended weight of the school trolley and backpack based on kinematics and spatiotemporal gait parameters.
- To analyse the mode of commuting to school in school children.

- To analyse the prevalence of back pain related to school bag carriage, and the subjective perceptions of fatigue and weight during school bag carriage.

The achievement of the proposed objectives were carried out in the different studies shown in **Figure 3.** These also indicate the main aim of each study:

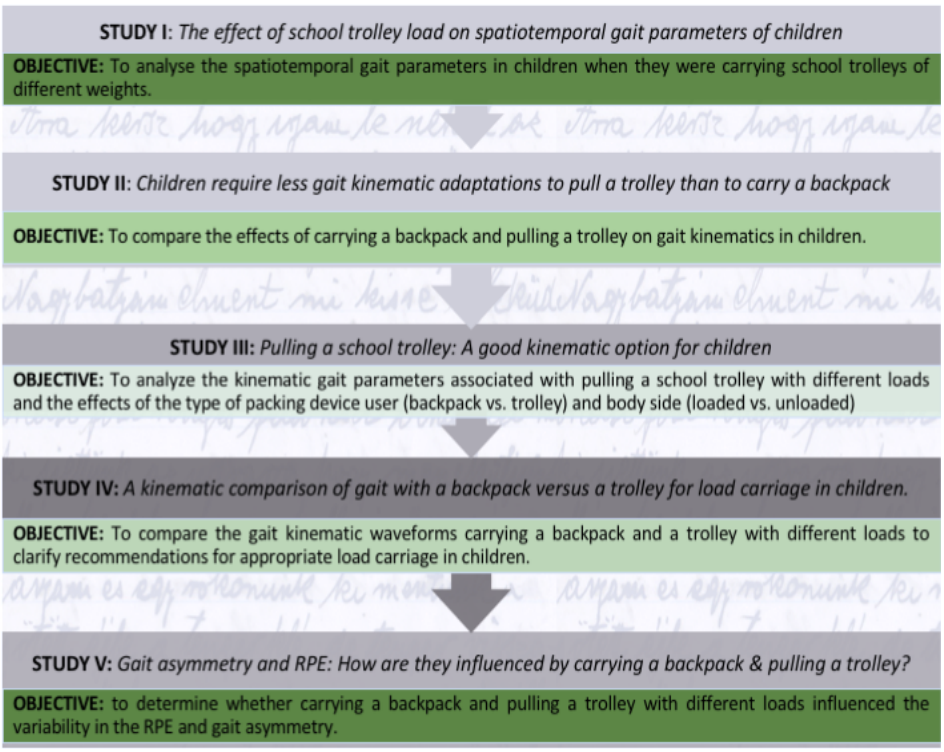

Figure 3. The aims set out in each study carried out for the Doctoral Thesis.

Below is a description of the journal, impact factor, position and area where each study was published:

- **STUDY 1:**

Orantes-Gonzalez, E., Heredia-Jimenez, J., Soto-Hermoso, VM.
The effect of school trolley load on spatiotemporal gait parameters of children.
Gait and Posture. 2015; 42 (3): 390-393.
Impact Factor: 2.286 (2015 JCR Impact Factor).
Journal rank: 20/82. Q1 in Sport Sciences.

- **STUDY 2:**

Orantes-Gonzalez, E., Heredia-Jimenez, J., Beneck, G.
Children require less gait kinematic adaptations to pull a trolley than to carry a backpack.
Gait and Posture. 2017; 52: 189-193.
Impact Factor: 2.273 (2017 JCR Impact Factor).
Journal rank: 31/81. Q2 in Sport Sciences.

- **STUDY 3:**

Orantes-Gonzalez, E., Heredia-Jimenez, J.
Pulling a school trolley: a good kinematic option for children.
Gait and Posture. 2017; 53: 61-66.
Impact Factor: 2.273 (2017 JCR Impact Factor).
Journal rank: 31/81. Q2 in Sport Sciences.

- **STUDY 4:**

Orantes-Gonzalez, E., Heredia-Jimenez, J., Robinson, M.
A kinematic comparison of gait with a backpack versus a trolley for load carriage in children.
Gait and Posture. 2018. Under review.
Impact Factor: 2.273 (2017 JCR Impact Factor).
Journal rank: 31/81. Q2 in Sport Sciences.

- **STUDY 5:**

Orantes-Gonzalez, E., Heredia-Jimenez, J.
Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley?
Work Journal. 2018. Under review
Impact Factor: 0.902 (2017 JCR Impact Factor).
Journal rank: 131/156. Q4 in Public, Environmental & Occupational Health.

Objetivos

7. OBJETIVOS

En la Tesis Doctoral que se presenta se destaca como objetivo principal la evaluación biomecánica a través de los cambios producidos en las variables espaciotemporales y cinemáticas de la locomoción mientras se transportan distintas cargas usando el carro escolar y la mochila en escolares de educación primaria.

Además, como otros objetivos secundarios se definieron los siguientes:

- Analizar cómo afecta el transporte de distintas cargas en la mochila y en el carro escolar a la asimetría de la locomoción.
- Analizar la percepción subjetiva del esfuerzo tras el uso del carro escolar y de la mochila con distintas cargas.
- Conocer el peso medio del carro y de la mochila que transportan los escolares al colegio (absoluto y relativo).
- Conocer los hábitos relativos al tipo de equipo que utilizan los escolares para el transporte del material escolar (carro escolar o mochila).
- Establecer el peso máximo recomendado para el uso del carro y la mochila basándose en parámetros cinemáticos de la locomoción.
- Analizar los medios de transporte que utilizan los escolares para ir y volver del colegio.

- Conocer la prevalencia de dolor de espalda relacionado con el transporte de la mochila o el carro escolar y la percepción de los escolares sobre la fatiga y el peso de su carro o mochila al transportarla.

Para la consecución de los objetivos propuestos se llevaron a cabo los estudios que se detallan en la figura siguiente (**Figure 4**), en la que también se destacan los principales objetivos planteados para cada uno de los estudios:

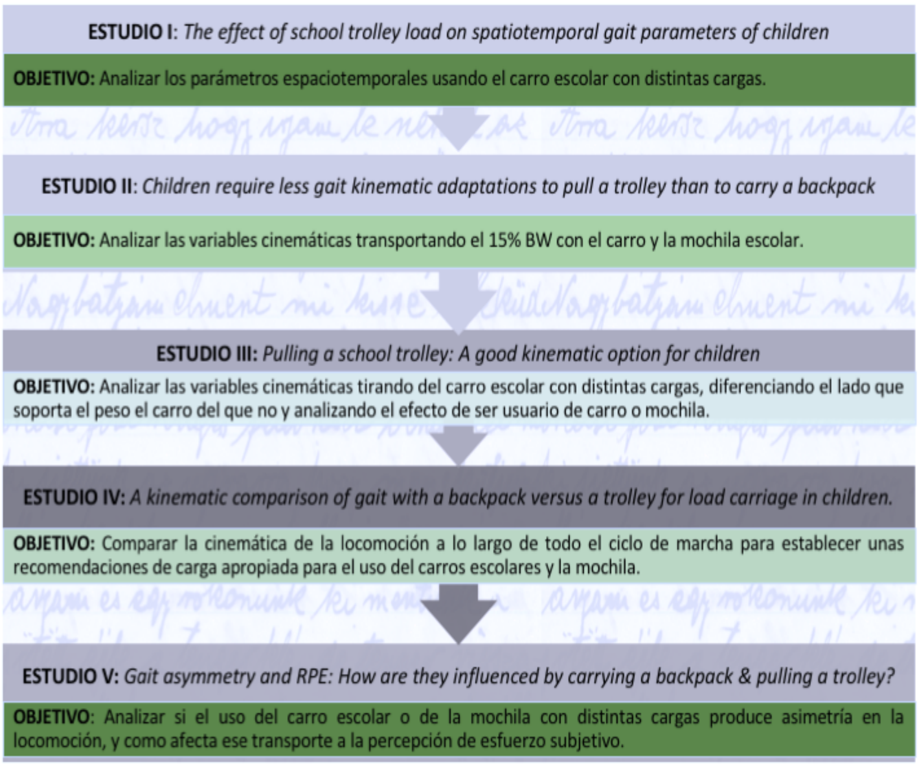

Figure 4. Objetivos planteados para cada estudio realizado relativo a la Tesis Doctoral.

A continuación, se detalla la revista, así como el factor de impacto, posición y área donde se publicaron cada uno de ellos:

- **ESTUDIO 1:**

Orantes-Gonzalez, E., Heredia-Jimenez, J., Soto-Hermoso, VM.
The effect of school trolley load on spatiotemporal gait parameters of children.
Gait and Posture. 2015; 42 (3): 390-393.
Factor de impacto: 2.286 (2015 JCR Impact Factor).
Posición de la revista dentro del área: 20/82. Q1 área Sport Sciences.

- **ESTUDIO 2:**

Orantes-Gonzalez, E., Heredia-Jimenez, J., Beneck, G.
Children required less gait kinematic adaptations to pull a trolley than to carry a backpack.
Gait and Posture. 2017; 52: 189-193.
Factor de impacto: 2.273 (2017 JCR Impact Factor).
Posición de la revista dentro del área: 31/81. Q2 área Sport Sciences.

- **ESTUDIO 3:**

Orantes-Gonzalez, E., Heredia-Jimenez, J.
Pulling a school trolley: a good kinematic option for children.
Gait and Posture. 2017; 53: 61-66.
Factor de impacto: 2.273 (2017 JCR Impact Factor).
Posición de la revista dentro del área: 31/81. Q2 área Sport Sciences.

- **ESTUDIO 4:**

Orantes-Gonzalez, E., Heredia-Jimenez, J., Robinson, M.
A kinematic comparison of gait with a backpack versus a trolley for load carriage in children.
Gait and Posture. 2018. En revisión.
Factor de impacto: 2.273 (2017 JCR Impact Factor).
Posición de la revista dentro del área: 31/81. Q2 área Sport Sciences.

- **ESTUDIO 5:**

Orantes-Gonzalez, E., Heredia-Jimenez, J.
Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley?
Work Journal. 2018. En revision.
Factor de impacto: 0.902 (2017 JCR Impact Factor).
Posición de la revista dentro del área: 131/156. Q4 área Public, Environmental & Occupational Health.

Method

8. Method

8.1 Descriptive data of backpack and trolley weight, general habits when travelling to school and opinions about their backpacks or school trolleys.

Participants

Seventy-eight students from an elementary school were evaluated for this Doctoral Thesis. Thirty-five of the participants were male, while 43 were female. The average body mass of the males was 41.9 (11.8) kg and for the females was 37.3 (10.6) kg; the average height for males was 1.47 (0.1) m and for females was 1.39 (0.2) m; and the average age was 10.5 (1.5) years old, and for females was 9.8 (1.7) years old. The participants did not report any history of orthopedic trauma or neurological problems. All of the participants were volunteers, and their parents completed informed consent forms (see **Annexe I**). The Ethics Committee of the University of Granada approved this study.

Descriptive data about the weight of the schoolbag for each participant was obtained by weighing the schoolbag that children transported to school on the evaluation day (SECA769, Hamburg, Germany). The participants and their parents were informed that they had to take to the evaluation laboratory the same schoolbag that the participants carried to the school that day. They were also asked if that was a representative day related to the number of books and supplies that children normally carry. This weight was obtained in kilograms and was also relativized considering the weight of each child, expressed as percentage of each child´s body weight (% BW).

To analyse the mode of commuting to and from school, the participants completed a self-report questionnaire **(Annexe 2)** regarding the latest weekly patterns of commuting to and from school (Monday to Friday) (79).

In addition to this, general questions about the type of schoolbag the participants use to go to school and the subjective perception of weight and fatigue while they carrying the schoolbag was completed by the participants **(Annexe 3).** The questions used to analyse the type of schoolbag the children carried, was: "What type of schoolbag do you use to carry things to school?", using the categories of Backpack, School Trolley or Other option. To analyse the load and fatigue perception of carrying the schoolbag the following questions were asked: “Do you feel your schoolbag is too heavy?” and “Do you feel tired carrying your schoolbag?”, in categories of Yes, always; Yes, sometimes; or No, never. The presence of back pain related to school bag carriage in the last 6 months was evaluated with the question: ‘‘In the past 6 months, did you usually suffer back pain while or after the use of your school bag?’’, in categories of Yes or No.

Statistical Analysis

Descriptive analysis (means and standard deviation) were performed for absolute (in kilograms) and relative (% BW) weight of the school bag. Facts were also gathered about the number and percentage of participants for the range of school bag load and method of carriage by gender. The subjective opinion about the school bag weight and fatigue during carriage, the mode of commuting to and from school and the prevalence of back pain related to school bag carriage was showed as the number and percentage of participants by backpack and trolley users.

8.2 Study I: The effect of school trolley load on spatiotemporal gait parameters of children.

Participants

For this study, fourteen students (4 boys and 10 girls) from a primary school, aged 11.43 (0.51) years, were evaluated. The average body weight was 35.1 (10.1) kg and the average height was 1.4 (0.1) m. All of the students were volunteers and their parents completed informed consent forms. The Ethics Committee of the University of Granada approved this study. Participants were healthy and did not report any history of orthopaedic trauma or neurological problems.

Protocol and Instruments

At first, each child was measured with a scale and measuring rod (SECA769, Hamburg, Germany). To analyse the effects of increased loading of school trolleys on gait, four conditions were used: walking without a trolley (WT), and walking with a trolley loaded with 10, 15, and 20% BW. The different loads were achieved by filling the trolley with books of different weights. The children pulled the trolley using only the dominant hand, and all of the participants were right-handed.

Each child walked at his comfortable speed along a 15m walkway. The GaitRite system (GAITRite system; CIRSystems Inc., Clifton, USA) was located in the middle of the walkway so as not to measure the non-stabilised walking periods at the beginning and end of the test **(Figure 5).**

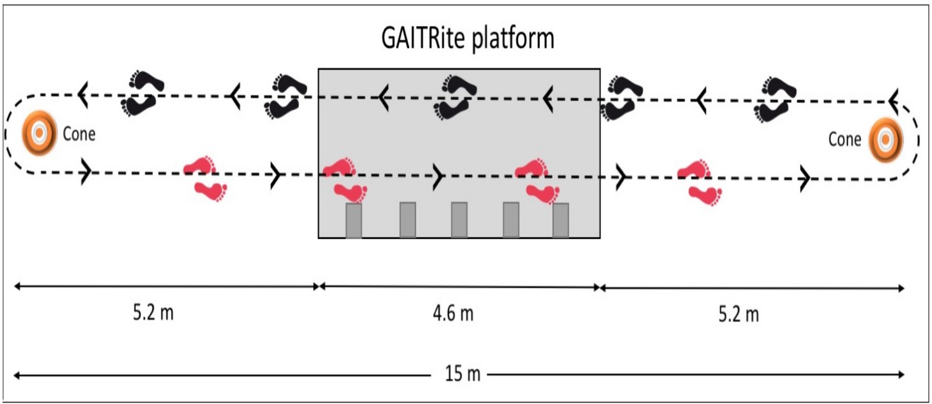

Figure 5. Walkway used for spatiotemporal gait analysis.

First, the children walked without a load for five times to familiarise themselves with the protocol. Then the children walked WT, and afterwards they completed the three load conditions (10%, 15% and 20% BW) in a randomised order. Five trials were recorded for each walking condition to be analysed. Researchers discarded the first two trials for each condition to ensure that the children were adapted to the conditions, and then recorded the five trials which were then analysed.

Outcome Variables

Spatiotemporal gait parameters were analysed: velocity (m/s), cadence (steps/s) and stride length (m). These parameters were normalised using the subject's height by following the equations proposed by Hof (1):

$$\text{Normalized velocity} = \frac{\text{velocity}}{\sqrt{(g \times l_0)}} \quad \text{(Equation 1)}$$

$$\text{Normalized cadence} = \frac{\text{cadence}}{\sqrt{(g / l_0)}} \quad \text{(Equation 2)}$$

$$\text{Normalized stride length} = \frac{\text{stride length}}{l_0} \quad \text{(Equation 3)}$$

Where g was acceleration due to gravity (9.81 m/s^2) and l_0 was the stature of the subject (m). In addition, swing phase, stance phase, single support phase and double support phase were measured and expressed as a % GC.

Statistical analysis

The data were analysed with SPSS software v.20 (SPSS Inc., Chicago IL). The Shapiro Wilk's test was used to test normal samples. The homogeneity of variance was tested with the Levene test. The Mauchly test was used to assess sphericity. Gait parameters were analysed using one-way repeated measures ANOVA with Bonferroni confidence interval adjustment, since there was only one independent variable (load). The level of statistical significance was set at $p<0.05$.

8.3 Study II: Children require less gait kinematic adaptations to pull a trolley than to carry a backpack.

Participants

Fifty-three subjects (24 boys and 29 girls) from an elementary school, aged 9.94 (1.74) years, participated in this study. The average body weight was 39.75 (12.14) kg and the average height was 1.45 (0.13) m. The daily backpack weight that children transport to the school represented an average of 15.1% BW. The proportion of participants that routinely used the school trolley to transport their school supplies was 47%. Children were excluded if they had recent orthopaedic trauma, neurologic problems, or were unable to carry a backpack or trolley.

Protocol and instruments

- **Data recording and processing**

Each child walked with the marker set at a comfortable speed along a 15m walkway. Infrared cameras were orientated to the 3 center meters of the walkway to discard the acceleration or deceleration phases of gait. First, children walked without a bag to familiarize themselves with the protocol. Then, children walked under the next experimental conditions in a randomized order: control (unloaded walking); and carrying a backpack and pulling a trolley loaded with 15% BW (**Figure 6**).

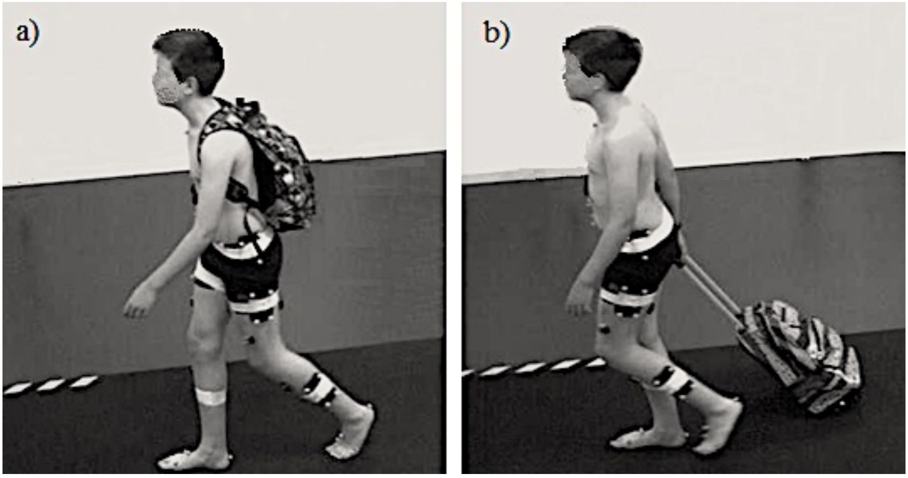

Figure 6. A participant carrying the backpack over two shoulders (a), and pulling a school trolley using the dominant hand (b).

Children walked for one minute in each of the conditions. Three minutes of rest was given between each of the experimental conditions to avoid fatigue. The different loads were achieved by filling the backpack and trolley with books of different weights. Each participant carried the backpack over the two shoulders aligning the bottom of the backpack with the waist. The school trolley was pulled using the dominant hand.

A system of nine infrared high-speed cameras (Qualisys AB, Göteborg, Sweden) at a rate of 250 Hz, collected the reflective marker locations. The calibration of the space was done with a wand (length of 751.1 mm) before each data collection and the standard deviation of the wand’s length measures were below 0.2 mm.

Visual3D v.5.0 software (C-Motion Inc., Germantown, USA) was used to compute the gait kinematics.

The calibrated anatomical systems technique (CAST) was used to model each body segment in six degrees of freedom (80). The CAST technique involves the identification of anatomical landmarks through external palpation of the proximal and distal areas of the body segments which are then calibrated with respect to corresponding arrays of tracking clusters for the calculi of an anatomical coordinate system axes of each segments (81). This technique is currently considered to be the gold standard for 3D kinematic analysis (82,83). The anatomical model created in the current Doctoral Thesis to analyse the human locomotion of children, is a full body model marker set without head or upper extremities. The reflective markers were placed with adhesive tape on the children's skin to both sides of the lower body and trunk.

Initially a static trial of the subjects was recorded in a stationary anatomical position to compute the locations of the markers. The anatomical model (**Figure 7**) was shaped by a total of 48 markers, of which 26 were anatomical markers placed at anatomically relevant locations according to the recommendations of Van (84).

A total of 22 tracking markers were placed at convenient locations for tracking the segments during gait (dynamic trials) following the rules for marker placement on rigid clusters described by Cappozzo et al., (85), markers were used as both anatomical and tracking markers.

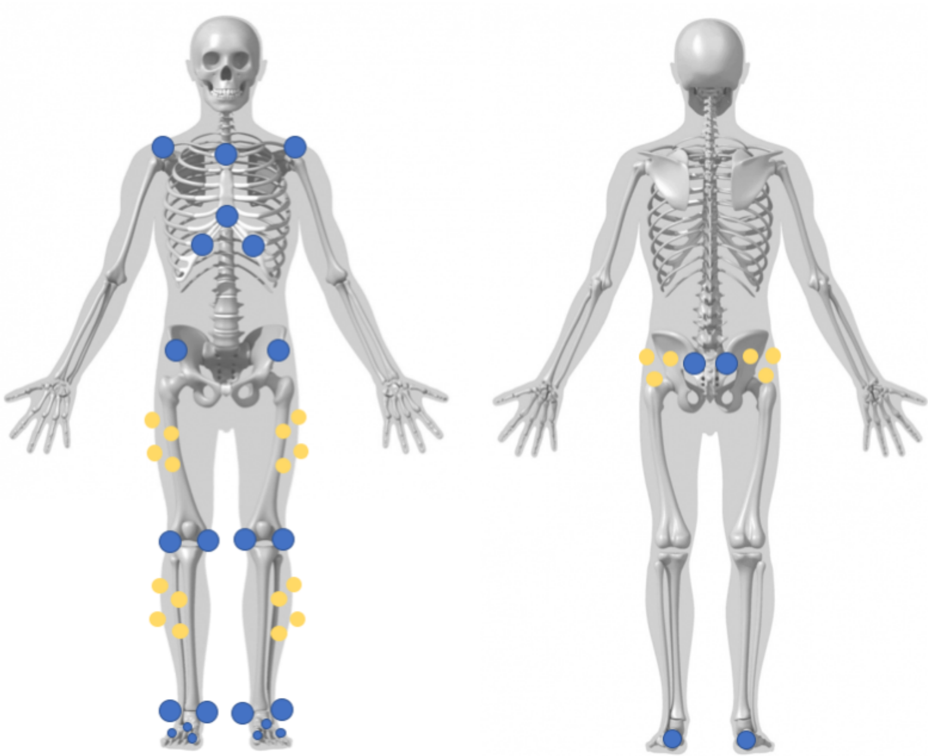

Figure 7. Marker set model. Blue markers represent anatomical markers while the yellow markers were used as clusters.

In order to define the anatomical reference frames of the thorax, pelvis, thigh, shank and foot segments, retro-reflective markers were attached to the following: first and fifth metatarsal head, second metatarsophalangeal, medial and lateral malleolus, large posterior surface of calcaneus, lateral and medial femoral epicondyle, anterior and posterior superior iliac spine, acromio-clavicular joints, jugular notch, xiphisternal joint and costal cartilage of the seventh ribs.

Besides these, a cluster with four markers were placed in the lateral of the shank and tight of both legs. Because carrying a backpack could cover the markers on the hip, two further clusters with three markers each were placed on the lateral hips **(Figure 7).** For the dynamic conditions, the malleolus, epicondyles, posterior superior iliac spines and acromioclavicular joints markers were removed from the subject.

The marker trajectories were filled using a spline interpolation (3^{rd} order polynomial) and filtered using a second order bidirectional low-pass Butterworth Filter (6 Hz cutoff frequency). A lower limb model with 8 segments were built, allowing six degrees of freedom per segment.

- **Defining anatomic terms and planes**

This International Doctoral Thesis uses the standard medical terminology and common anatomical terms used for the International Society Biomechanics (ISB) convention and in the previous literature (84,86).

Starting from the anatomical position, in which a person is standing upright, with the feet together and the arms by the sides of the body, with the palms forwards, we describe 6 terms for the directions: the umbilicus is anterior, the buttocks are posterior, the head is superior, the feet are inferior and the 2 sides are right and left (**Figure 8**).

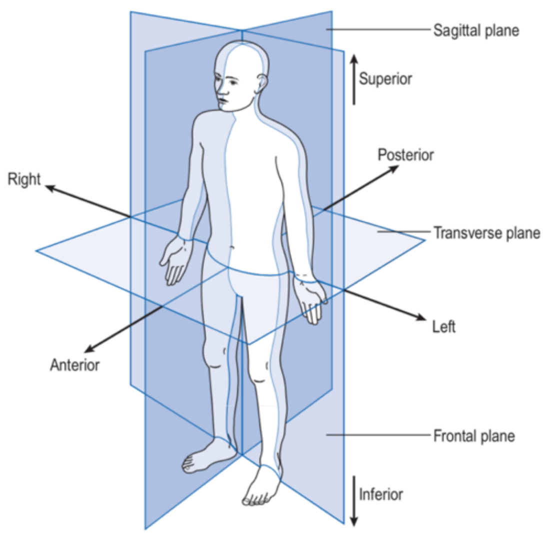

Figure 8. Anatomic terms and planes (extracted from Levine, Richards & Whittle, 2012)

Within a single part of the body, four additional terms are used to describe relationships: medial means towards the midline of the body, lateral means away from the midline of the body, proximal means towards the rest of the body, and distal means away from the rest of the body (**Figure 8**). The motion of the limbs is described using three reference planes: a sagittal plane is any plane which divides part of the body into right and left portions; a frontal or coronal plane divides a body part into front and back portions; and a transverse plane divides a body part into upper and lower portions (**Figure 8**).

- **Biomechanical model**

A biomechanical model is a collection of rigid segments. A segment's interaction with other segments is described by joint constraints permitting zero to six degrees of freedom, and subject-specific scaling is defined using palpable anatomical landmarks, and those rigid segments represent skeletal structures (87). An 8-segment full body model was created from the static pose. The 8 segments were: thorax, pelvis, and both (right and left) thighs, shanks and feet. The pelvis and thorax reference frames were aligned to the laboratory reference frame in the static pose.

Extremities were aligned with the segment's long axis and medial/lateral joint markers creating the frontal plane. The model was applied to each walking trial, tracking each segment with all of its associated markers. The lower limb model with thorax segment was created as follows:

- **PELVIS**

To create the pelvis model, marker setup is in agreement with the suggestion of CODA protocols (Charnwood Dynamics Ltd, Leicestershire, United Kingdom) for the model of pelvis segment. The pelvis segment is defined using the anatomical locations of the right (R_) and left (L_) anterior superior iliac spines (ASIS) and the posterior superior iliac spines (PSIS). These landmarks are bony protuberances on the pelvis bones that can be palpated on all subjects.

The origin of the pelvis segment coordinate system is defined as the mid-point between the ASIS markers. The pelvis orientation was defined as the (x-y) plane of the segment coordinate system, defined as the plane passing through the right and left ASIS markers, and the mid-point of the right and left PSIS markers. The x-axis is defined from the ORIGIN towards the R_ASIS. The z-axis is perpendicular to the (x-y) plane. The y-axis is then the cross product of the x-axis and z-axis (**Figure 9**). The right and left hip joint centers are defined according to Bell et al equation (88,89) defined as:

Right Hip Joint Center (RHJC): (0.36*ASIS_Distance,-0.19*ASIS_Distance,-0.3*ASIS_Distance) Left Hip Joint Center (LHJC): (-0.36*ASIS_Distance,-0.19*ASIS_Distance,-0.3*ASIS_Distance)

For gait trials, right and left lateral clusters of the pelvis with 3 markers per cluster were placed to track the pelvis in dynamic trials without the need to use the PSIS markers due to backpack occlusion (**Figure 9**).

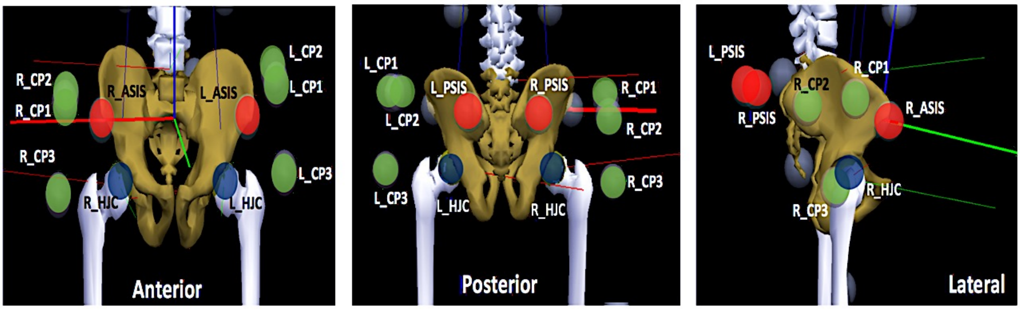

Figure 9. Representation of pelvis marker model. Red markers were anatomical markers; Green markers were cluster markers; Blue markers were virtual landmarks.

- **THIGH**

To create the thighs, the proximal joint was computed in Visual 3D as Hip Joint Center (HCJ), and the distal joint as the midpoint between the markers placed at femur lateral epicondyle (FLE) and femur medial epicondyle (FME) (**Figure 10**). A cluster of 4 markers were placed in the right and left lateral side of the thigh (**Figure 10**).

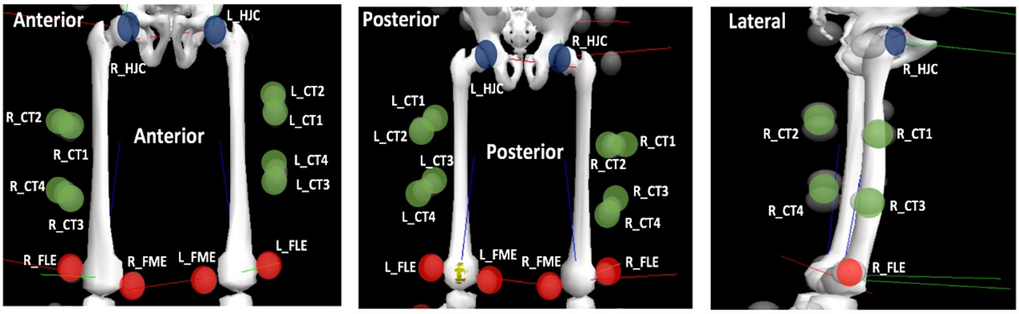

Figure 10. Representation of thighs marker model. Red markers were anatomical markers; Green markers were cluster markers; Blue markers were virtual landmarks

- **SHANK**

To define the shanks, the proximal joint was calculated as the midpoint between the markers placed at FLE and FME and the distal joint was defined as the midpoint between the markers placed at Fibula ankle lateral (FAL) and talus ankle media (TAM) (**Figure 11**).

A cluster of 4 markers were placed in the right and left lateral side of the shank (**Figure 11**).

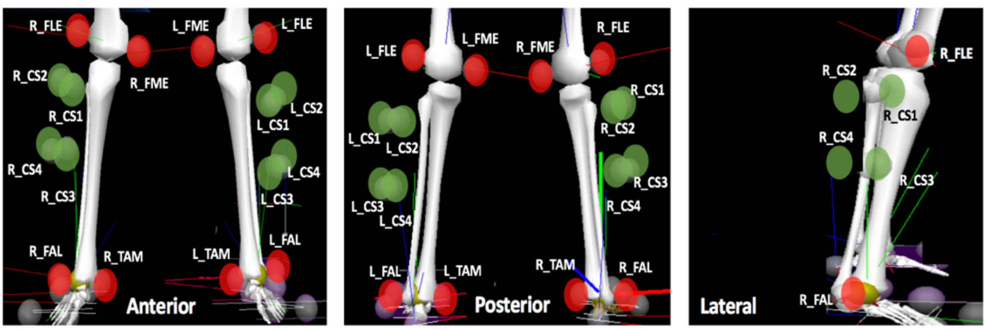

Figure 11. Representation of shank marker model. Red markers were anatomical markers and green markers were cluster markers.

- **FOOT**

To define the foot, the proximal joint was calculated as the midpoint between the markers placed at FAL and TAM and the distal joint was defined as a landmark between the large posterior surface of calcaneus (FCC) and the metatarsophalangeal joint of the big toe (FM1). The FM1, prolongation of second (FM2) and fifth toe (FM5) and FCC markers were used as tracking markers (**Figure 12**). This representation of the foot is adequate for many of the kinematic and kinetic calculations in Visual3D. It is not, however, adequate for the calculation of the ankle joint angle.

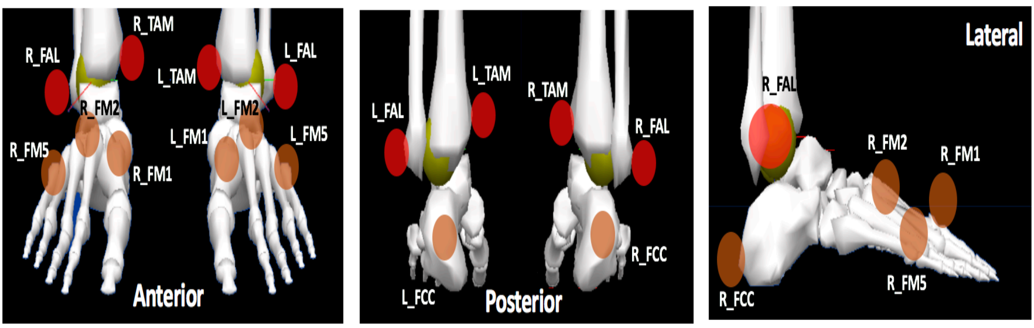

Figure 12. Representation of foot marker model. Red markers were anatomical markers and orange markers were anatomical and cluster markers.

For the ankle joint angle, a virtual foot segment was created using the heel to toe method defined by Visual 3D software. First, the ankle and toe joint centres were created, after that, the virtual foot was modeled with the joint centres created. For the ankle joint angle calculation, the segment coordinate system of the virtual foot segment as the X axis was rotated (red axis of **Figure 13**) representing the flexion/extension of the ankle, the Y axis (green axis of **Figure 13**) representing the inversion/eversion, and the Z axis the abduction/adduction of the ankle (blue axis of **Figure 13**).

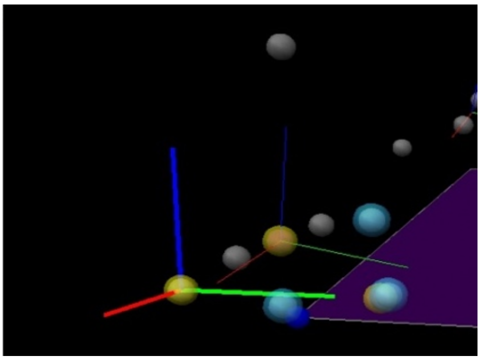

Figure 13. Axis of the virtual foot segment created in Visual 3D.

- **THORAX**

The upper extremity of the model developed by Rab et al., (90) including some modifications, were used as the thorax model in this Thesis. The distal joint was defined using the left and right acromioclavicular joint (AC) (**Figure 14**). For the distal joint, the virtual landmarks on the lateral borders of the iliac crest were defined. The iliac crest landmarks were estimated using the Terry Database (91).

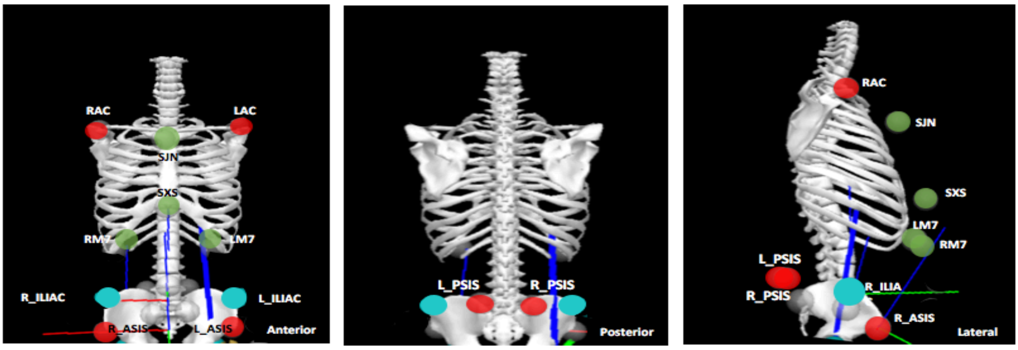

Figure 14. Representation of thorax marker model. Red markers were anatomical markers, green markers were tracking markers, and blue markers were virtual landmarks.

The medial/lateral and superior/inferior location of the right and left iliac crest landmarks were defined as the most lateral point on the superior tubercle of the Iliac crest (landmarks 43 and 44 of the Terry pelvis dataset). The anterior/posterior location of the right and left iliac crest landmarks were defined as the lateral surface of the right ilium at midpoint between the most lateral point on superior tubercle of the iliac crest and the origin of the gluteus medius posterior fibers (landmarks 43 and 44 of the Terry pelvis dataset). In summary, the right iliac crest was computed in Visual 3D as:

Existing Segment= Pelvis

ML= (114+22.332)*ASIS_DISTANCE/228

AP= (-54.477)*ASIS_SACR/143.5

AXIAL= (33.1)*ASIS_DISTANCE/228

And the left iliac crest landmark is assumed to be located symmetrically and defined as:

Existing Segment= Pelvis
ML= -(114+22.332)*ASIS_DISTANCE/228
AP= (-54.477)*ASIS_SACR/143.5
AXIAL= (33.1)*ASIS_DISTANCE/228

ASIS_SACR is the distance from the sacrum marker to the mid-point of the right and left anterior superior iliac spine markers. The sacrum landmark was computed as the mid-point of the left and right posterior superior iliac spine markers. The tracking targets for the thorax were placed on the chest of the participant to avoid the occlusion of the markers due to the backpack carriage. So, four tracking markers were placed in the middle of the jugular notch (SJN), in the xiphisternal joint (SXS), and in the right and left side of the seventh ribs (RM7 and LM7) as was shown on **Figure 14**.

- **Gait events detection**

For an easy comparison and normalization of kinematic variables across multiple strides and walking trials, joint angles, forces and moments across multiple strides and walking trials, an accurate and efficient detection of gait events is essential (92). The coordinated-based algorithm developed by Zeni et al., (92) was used for determining events based on the position of a foot marker.

First, in Visual 3D, the heel and toe markers have to be transformed into the pelvis coordinate system. Second, the maximum and minimum anterior components of right and left legs of heel and toe in the pelvis coordinate system have to be detected to find the foot strikes and toe offs (**Figure 15**).

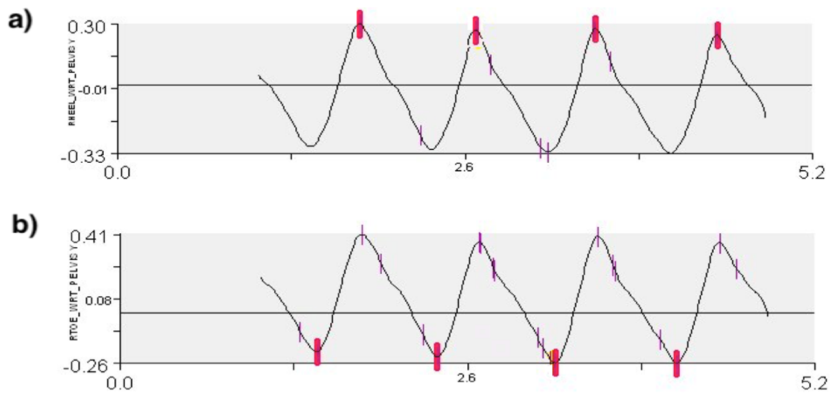

Figure 15. Detection of heel strikes (a) and toe offs (b).

Once the gait events were detected, the spatiotemporal gait variables were calculated. For the calculi and normalization of the kinematics variables of gait, the gait events must be calculated to express the data according to the subject's GC. The GC is defined, by almost universal convention, as the time that elapses between the instant that one foot makes contact with the floor (foot contact) until the next occasion when the same foot makes contact with the floor again (93). For definition, the GC is analogous and corresponds with the term stride time and the definition is taken as the time between successive foot strikes on the same side.

All kinematics variables during the gait dynamics trials were normalized based on the entire GC (100% in time of the GC, where 0% corresponds to a heel strike and 100% corresponds to the second strike of the same heel) (**Figure 1**).

The GC is conformed for 2 gait phases (**Figure 1**):

- Swing time phase: Is the weight bearing portion of each GC. It is the time elapsed between the heel contact and the toe off of the same foot. It was expressed as % of GC.
- Stance time phase: It is initiated with toe off and ends with heel strike. It is the time elapsed between the last contact of the current foot to the first contact of the next foot on the same foot. It was expressed as % of GC.

Then, the stance phase was divided in two sub-phases:

- Single support phase: It is the time from opposite foot off to opposite foot contact. This phase is analogous to the swing phase of the opposite leg. It was expressed as % of GC.
- Double support phase: Time when both feet are in contact with the floor. During GC, two double support phase periods were found: the initial double support that

occurs from heel contact of one footfall to toe-off of the opposite footfall at the beginning of the GC, and the terminal double support, that occurs from opposite footfall heel strike to support footfall toe-off at the end of the GC. The double support phase is the sum of the initial and final double support. It was expressed as % of GC.

- Step length and step time: Distance or time between the heel contact of one foot to the heel contact of the opposite foot.
- Stride length and Stride time: Distance or time between two consecutive heel contacts of the same foot. One stride is conformed for two steps (one of each foot).
- Cadence: Number of cycles taken in a specific time and expressed as steps per minute.
- Velocity: Distance walked in a given time, is related to both cadence and stride length. In this Thesis, the term "velocity" referred to "walking speed", so it was used as a similar term. Walking velocity was expressed in meters or centimeters/seconds as follows:

$$\text{Walking velocity (m/s)} = \frac{\text{Stride length (m) x Cadence (steps/ minutes)}}{120}$$

According to that, during gait, walking speed or velocity, stride length and cadence are related, so any change in one of these three variables will produce a direct effect in the other ones.

- **Joint angles**

Two coordinate systems were defined for the calculation of the different joint angles computed in the Thesis:

- A global coordinate system (GCS): The GCS refers to the capture volume in which we represent the 3D space of the motion-capture system. Recorded data are resolved into this fixed coordinate system. The y-axis is directed anteriorly, the z-axis is directly superiorly, and the x-axis is perpendicular to the other two axes (94).

- A local coordinate system (LCS): each segment is defined completely by a LCS fixed in the segment; the LCS moves correspondingly to the movements of the segment. In the same way as in the GCS, the LCS is right-handed and orthogonal. The LCS is oriented as follows: the y-axis points anteriorly, the z-axis points vertically (axially), and the x-axis is perpendicular to the plane of the other two axes with its direction defined by the right-hand rule. The orientation of the LCS with respect to the GCS defines the orientation of the body or segment in the GCS, and it changes as the body or segment moves through the 3D space (94).

In general, a joint angle is the relative orientation of one LCS with another LCS and it is independent of the position of the origin of these coordinate systems (94). In Visual 3D, joint angles are calculated as the transformation from one segment (A) to another segment (B) using the local coordinate system of segment B as the frame of reference.

For the joint angle calculi the ordered Euler/Cardan sequence of rotations (x, y, z) were selected. This Cardan rotation sequence X-Y-Z is often used in biomechanics (95). This sequence assumes that the x-axis is in a mediolateral direction, the y-axis is anterior/posterior and the z-axis is in the up/down/axial direction (96,97), where:

- X-axis represents the flexion (+) and extension (-) in the sagittal plane.
- Y-axis represents the adduction (+) and abduction (-) in the coronal plane.
- Z-axis represents the internal (+) and external rotation (-) in the transverse plane.

For the calculi of the pelvis segment angle, the GCS was used, while the LCS was used to calculate the joint angles of one segment with respect to the contiguous segment. The pelvis segment angle was computed with its orientation relative to the laboratory. The movement of the pelvis is described in equivalent terms with the pelvis considered as the distal segment and the laboratory reference system as the proximal system. The rotations about the axes embedded in the pelvis were described by Baker (93) as follow:

- Pelvis tilt: angle of rotation about the medio-lateral axis of the pelvis (anterior is positive) (**Figure 16**).
- Pelvis obliquity*:* angle of rotation of the anterior-posterior axis of the pelvis. It is the angle by which one hip joint is higher than the other (up is positive) (**Figure 16**).
- Pelvis rotation: angle of rotation of the pelvis about a vertical axis. It is the angle by which one hip joint center is anterior to the other (forward is positive) (**Figure 16**).

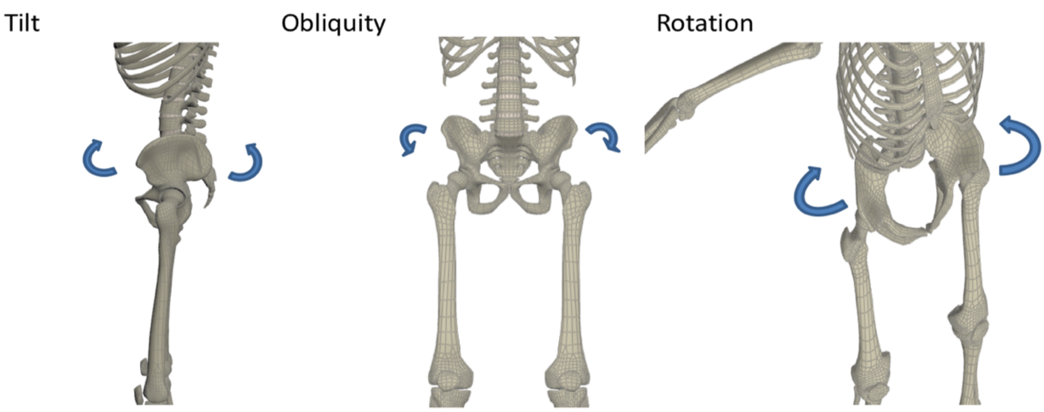

Figure 16. Pelvis movements in the sagittal, frontal and transverse planes.

The joint angles of the model were calculated for both sides of the body (right and left) and using the X-Y-Z cardan sequence described above. The joint angles were computed as:

- Hip joint angle: computed using the pelvis as a reference segment and the thigh. The angle interpretation in each axis is represented in **Figure 17**.

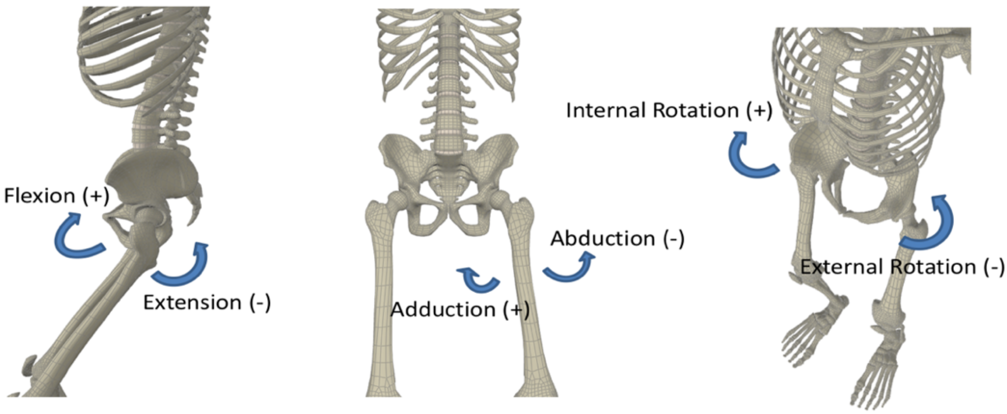

Figure 17. Hip movements in the sagittal, frontal and transverse planes.

- Knee joint angle: computed using the thigh as a reference segment and the shank. The angle interpretation in each axis is represented in **Figure 18**.

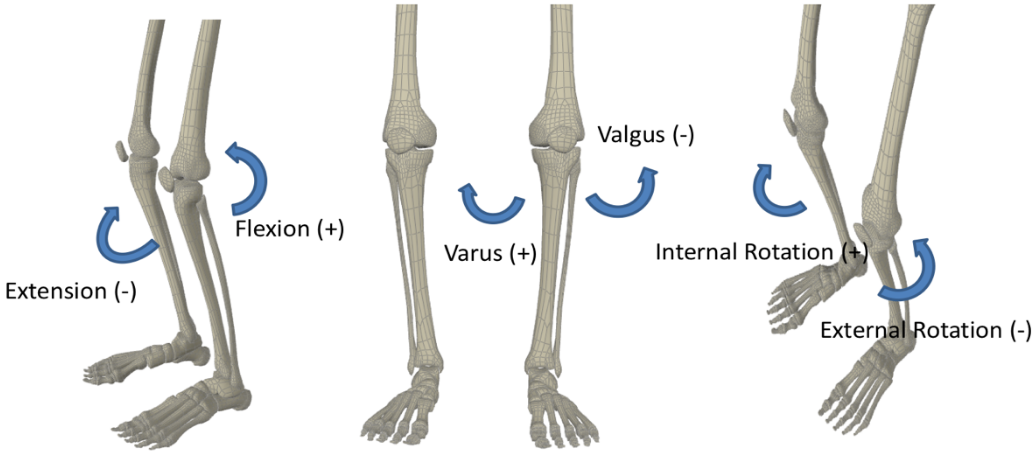

Figure 18. Knee movements in the sagittal, frontal and transverse planes.

- Ankle joint angle: computed using the shank as a reference segment and the virtual foot defined above. The angle interpretation in each axis is represented in **Figure 19**.

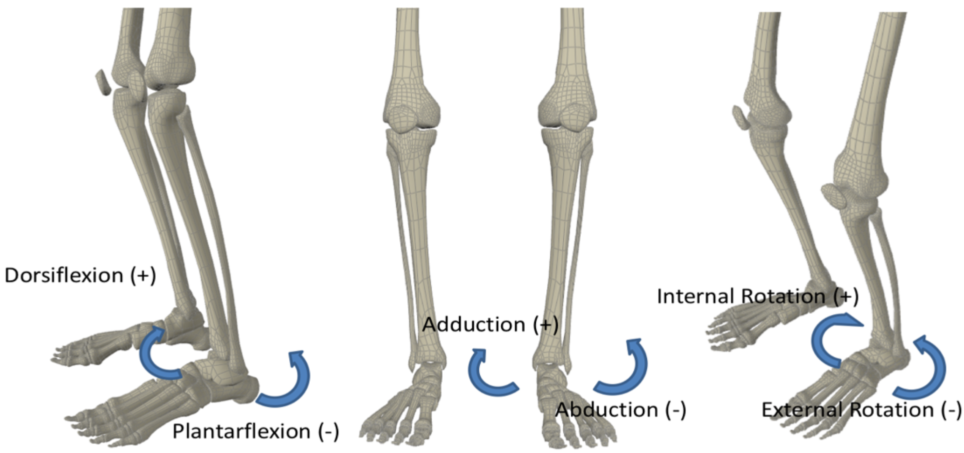

Figure 19. Ankle movements in the sagittal, frontal and transverse planes.

- Thorax: computed using the pelvis as a reference segment and the thorax. The angle interpretation in each axis is represented in **Figure 20**.

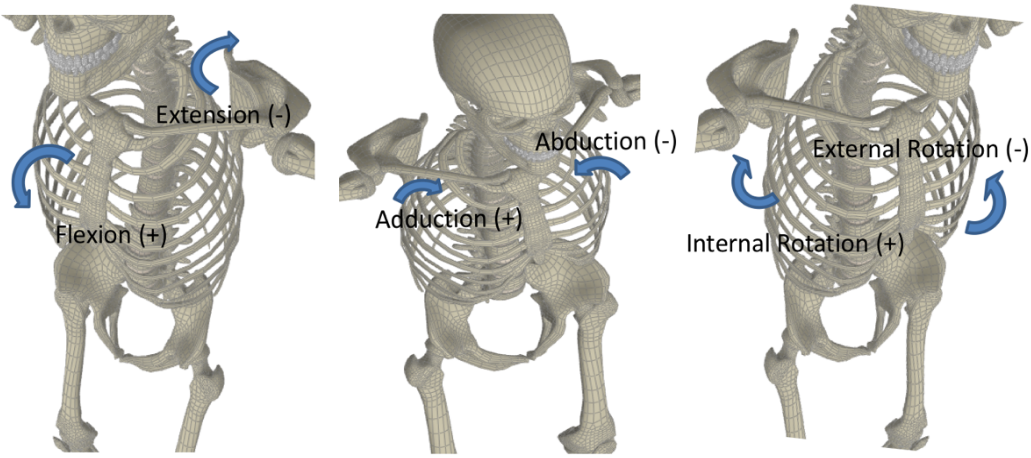

Figure 20. Thorax movements in the sagittal, frontal and transverse planes.

Outcome Variables

Spatiotemporal gait parameters were analysed: Velocity (m/s), cadence (steps/s) and stride length (m) were normalised using the subject's height by following the equations 1, 2 and 3 that were proposed by Hof (1). In addition, swing phase, stance phase, single support phase and double support phase were measured and expressed as a % GC.

Average and standard deviation (in degrees) of the flexion-extension, adduction-abduction and internal-external rotation of thorax, pelvis, hip, knee and ankle were computed. The three-dimensional kinematics parameters were obtained as the data mean of both legs and normalised relative to the duration of the walking stride cycle of each subject.

Statistical Analysis

Data was analysed with SPSS software v.23 (SPSS Inc., Chicago IL). Normality was determined by Kolmogorov-Smirnov test, the homogeneity of variance was tested with the Levene test, and the Mauchly test was used to assess sphericity. The comparison of the kinematics gait variables between the three experimental conditions (control, carrying a backpack and pulling a trolley, as independent variables) were analysed using repeated measures ANOVA. When significant differences across carrier types were determined, a Bonferroni adjustment was computed to perform the pairwise comparisons. The level of statistical significance was set at $p<0.05$.

8.4 Study III: Pulling a school trolley: A good kinematic option for children.

Participants

Fifty-three participants (25 boys and 28 girls) from an elementary school aged 10.01 (1.7) years participated in this study. The average body mass was 40.05 (11.09) kg, and the average height was 1.46 (0.09) m. All of the participants were volunteers, and their parents completed an informed consent form. The Ethics Committee of the University of Granada approved this study. The participants were healthy and did not report any history of orthopaedic trauma or neurological problems. Fifty percent of the evaluated participants used the school trolley as their daily preferred option to transport their school supplies to and from school, while the other half used backpacks.

Protocol and Instruments

In this study, four experimental conditions were tested: walking without a trolley (WT) and walking pulling a trolley with 10%, 15% and 20% BW. First, the children completed a familiarization phase while walking WT. Then, the children completed the four experimental conditions in a randomized order. The different loads were achieved by filling the trolley with books of different weights. The school trolley was pulled using the dominant hand, and for kinematic analysis, that side was considered to be the loaded side.

The protocol and instruments (data recording, processing, biomechanical model used, and calculi of gait events detection and joint angles) are presented in Study II **(Protocol and Instruments).**

Outcome Variables

See **outcome variables** section of Study II. In addition to these, the averages and standard deviations of the three-dimensional kinematic parameters were obtained based on the data for the unloaded and loaded sides of the body and normalized relative to the duration of the walking cycle for each participant.

Statistical Analysis

All data were analysed with SPSS software v.23 (IBM SPSS, Armonk, NY). The data were confirmed to conform to a normal distribution by using the Kolmogorov-Smirnov test. The homogeneity of variance was tested with the Levene test. The Mauchly test was used to assess sphericity. Two-way ANOVA was performed under two conditions: for the comparison between trolley weights (0%, 10%, 15% and 20% BW) and the type of packing device used (backpack vs. trolley users) and for the comparison between trolley weight and the different body sides (loaded vs. unloaded side). Bonferroni's confidence interval adjustment was performed for all comparisons. The level of statistical significance was set at $p<0.05$.

8.5 Study IV: A kinematic comparison of gait with a backpack versus a trolley for load carriage in children.

Participants

Forty-nine students from an elementary school participated in this study (26 girls and 23 boys). The average age for girls was 9.5 (1.8) years, average weight 36.7 (11.6) kg, and average height 1.41 (0.13) m. For boys, the average age was 10.4 (1.6) years, average weight 42.7 (12.6) kg and average height 1.47 (0.11) m. Of the total participants, 55% carried a backpack on a daily basis to and from school, while the other 45% used a trolley.

As general criteria to participate in this study the students had to have no history of orthopedic trauma or neurological problems. The participants of the present study were volunteers and their parents completed an informed consent form. All of the participants could withdraw at any time during the study. The Ethics Committee of the University approved this study.

Protocol and Instruments

To analyse the effects of transporting different loads, the children walked in the following experimental conditions: unloaded walking (as control), pulling a school trolley or carrying a backpack, both with 10, 15, and 20% BW load. The different loads were achieved by filling the backpack/school trolley with books of different weights. The backpack was a standard model (American Tourister, Samsonite, UK) and it was carried on two shoulders with the bottom of the backpack level with the waist line. The school trolley (TrainingPixel, Chamoe, Spain) had 4 wheels and the handle length was 0.38 m, it was pulled using the dominant hand, and all of the participants were right-handed.

At the beginning, each participant completed a familiarization phase that consist of walking some trials without a backpack or trolley. Then, participants completed the experimental conditions in a randomised order. The data recording, processing, biomechanical model used and joint angles followed the plan presented in Study II **(Protocol and Instruments).**

Outcome Variables

Condition mean and standard deviation curves (in degrees) for both legs were normalized to the duration of the GC for each subject (from 0 to 100% of GC) and the following variables were obtained: flexion/extension, adduction/abduction and internal/external rotation of thorax, pelvis, hip, knee and ankle. Pelvis angles were expressed as the absolute angles of the segments with relation to the global coordinate system.

Statistical Analysis

Gait kinematics were statistically compared using the open-source 1-dimensional statistical parametric mapping package "SPM1D" (98). Specifically, two main types of analyses were undertaken. First, the segment or joint level data from all backpack and school trolley conditions were separately compared to the control condition data. Segment or joint vector-fields were constructed by assembling all subjects multi-component time-series, e.g. 49 subjects x 101 data nodes x pelvis{x,y,z} and statistically compared to the control condition data using the vector-field equivalent of the paired t-test – a paired Hotelling's T^2 test (99).

Considering there were 5 kinematic segments / joints and 3 weight manipulations (10, 15 and 20% BW) for the backpack and school trolley conditions, 30 statistical tests were run in total. To avoid inflating the type I error rate, alpha was corrected for 30 comparisons. For those unfamiliar with SPM, the Hotelling's T^2 statistic is calculated at each time node to produce a statistical "map". Random field theory (100) is then used to model the behavior of random vector-fields and determine the critical threshold at which only alpha % of equivalently smooth random data would cross. If the T2 statistic crosses the critical threshold at any point in the time series, then the null hypothesis is rejected. This analysis controls the false positive rate more tightly than selecting arbitrary 0D (e.g. peak) values from the time-series (101). Second, a within-condition analysis was undertaken for the backpack and school trolley conditions.

Each weight manipulation was compared in a pairwise fashion (e.g. 10-15%, 10-20% and 15-20%) for all 5 segments/joints using a paired Hotelling's T^2 test, resulting in 15 condition comparisons. Alpha was corrected for 15 comparisons within each condition.

8.6 Study V: Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley?

Participants

Fifteen students from an elementary school aged 10.1 (1.7) years participated in this study. Six of the participants were boys. The average body mass of the participants was 42.4 (14.1) kg, and the average height was 1.5 (0.1) m. The participants did not report any history of orthopedic trauma or neurological problems. All of the participants were volunteers, and their parents completed informed consent forms. The Ethics Committee of the University of Granada approved this study.

Protocol and Instruments

The procedure for the study and data recording, processing and gait events detection follow that used in Study IV of this Doctoral Thesis (see **Protocol and Data processing**).

In addition to that, the RPE data was recorded using the Children's OMNI Scale **(Annexe II).** This scale evaluates the perceived effort. It contains pictures and verbal explanations that correspond with a numerical range from 0 to 10 (0 indicates not tired at all and 10 indicates extremely tired). The OMNI scale was validated in children (102) for walking and for running. At the end of each experimental condition, a researcher presented the OMNI Scale to the participant and asked: "How do you feel? 0 is not tired at all and 10 is extremely tired. Remember there are no right or wrong answers. You can use the pictures and words to help you to select the number."

Outcome variables

The ratios, indexes, GA and symmetry angle for the following parameters were analysed according to the equations proposed by Patterson et al., (103): step length (cm), swing time (s), stance time (s) and ratio swing/stance. In addition, the values of the RPE at the end of each experimental condition were recorded with the OMNI Scale once participants completed each of the experimental conditions.

Statistical analysis

All of the data were analysed using SPSS software v.24 (IBM SPSS, Armonk, NY). The Shapiro–Wilk test was used to determine the distribution normality of the different variables. The homogeneity of variance was tested with the Levene test. The Mauchly test was used for the sphericity assessment. To compare the GAs, a repeated-measures ANOVA was used. Bonferroni's confidence interval adjustment was performed for all of the comparisons. The level of statistical significance was set at $p<0.05$.

For the RPE analysis, a non-parametric test was performed for the significance analysis (Friedman test). Then, a Wilcoxon test for pairwise comparisons was carried out for variables that showed significance. To limit the chance of statistical error due to multiple comparisons, the alpha level (0.05) was calculated by dividing between the number of comparisons, obtaining a significance level of $p<0.008$.

Results

9. RESULTS

9.1 Descriptive data of backpack and trolley weight, general habits when going to school and opinions about their backpacks or school trolleys.

The average weight that males carried in their schoolbags was 5.9 (1.7) kg, that represented 14.7 (4.9) % BW. For females, the average weight was 6.2 (1.9) kg, that represented 17.3 (6.4) % BW. Comparing the weight of the backpack vs. the school trolley, the average backpack weight was 5.8 (1.9) kg, and the average weight of school trolley was 6.3 (1.8) kg.

The descriptive data numbers and percentages about the ranges of load and method of carriage by gender (males and females) are shown in **Table 1**. Nearly sixty percent of students carried higher loads than 15% BW, and the school trolley was the most popular option in females, reaching 64% in this group.

Table 1. Number of participants and percentage by gender carrying a schoolbag within the ranges analysed and method of carriage (backpack or school trolley).

	Males		**Females**		**Total**	
	Number	Percentage	Number	Percentage	Number	Percentage
Load range						
≤10% BW	5	16.1 %	4	9.8 %	9	12.5 %
10.1% - 15% BW	9	29%	13	31.7 %	22	30.6 %
>15% BW	17	54.9 %	24	58.5 %	41	56.9 %
Method of carriage						
Backpack	20	57.1 %	15	35.7 %	35	45.5 %
School trolley	15	42.9 %	27	64.3 %	42	54.5 %

The analysis of the mode of commute to school, the subjective perception of load and fatigue during carriage and the prevalence of back pain related with the schoolbag carriage are shown on **Table 2.** With respect to feelings about the bag being heavy and fatigue during carriage, the school trolley users seem to have a lower percentage in heaviness feeling and fatigue. In general, 90% of students feel their school bags were heavy always or sometimes and 77% used to feel fatigue during carriage.

Table 2. Number and percentage of participants for subjective perception of load and fatigue of school bag, mode of commute to school and back pain by backpack and trolley users.

	Backpack users		**Trolley users**		**Total**	
	Number	Percentage	Number	Percentage	Number	Percentage
Feeling school bag heavy						
Always	9	25.7%	7	16.7%	16	20.8%
Sometimes	25	71.4%	29	69%	54	70.1%
Never	1	2.9%	6	14.3%	7	9.1%
Feeling fatigue during carriage						
Always	4	11.4%	4	9.5%	8	10.4%
Sometimes	26	74.3%	26	61.9%	52	67.5%
Never	5	14.3%	12	28.6%	17	22.1%
Mode of commute to school						
Walk	13	37.1%	30	71.4%	43	55.8%
Car	17	48.6%	11	26.2%	28	36.4%
Bus	4	11.4%	1	2.4%	5	6.5%
Others	1	2.9%	0	0	1	1.3%
Back pain related to school bag carriage						
Yes	15	42.9%	13	31.7%	28	36.8%
No	20	57.1%	28	68.3%	48	63.2%

It needs noting that, most of the school trolley users travel to school by walking, while the common commute to school in backpack users was by car. In relation to suffering from back pain after carrying their school bag, the trolley users seem to have a lower incidence of back pain than backpack users (31.7% vs. 42.9%).

9.2 Study I: The effect of school trolley load on spatiotemporal gait parameters of children.

The ANOVA outcome showed significant results for the cadence, swing phase, stance phase, single support phase and double support phase **(Table 3).**

Table 3. Average and standard deviation of the spatiotemporal gait parameters analysed, indicating the ANOVA results.

	EXPERIMENTAL CONDITIONS				
PARAMETER	WT	10%	15%	20%	ANOVA p –value
Normalized velocity	0.33 (0.04)	0.35 (0.02)	0.35 (0.03)	0.35 (0.02)	0.156
Normalized cadence	0.74 (0.04)	0.83 (0.14)	0.80 (0.05)	0.80 (0.03)	0.021
Normalized stride length	0.89 (0.09)	0.90 (0.06)	0.88 (0.07)	0.89 (0.06)	0.743
Swing phase (%GC)	43.88 (1.7)	41.81 (1.5)	42.15 (1.5)	41.86 (1.4)	<0.001
Stance phase (%GC)	56.14 (1.7)	58.18 (1.5)	57.83 (1.5)	58.15 (1.4)	<0.001
Single support (%GC)	43.88 (1.7)	41.93 (1.6)	42.15 (1.5)	41.86 (1.4)	<0.001
Double support (%GC)	12.37 (3.1)	16.29 (3.02)	15.58 (3.0)	16.68 (2.4)	<0.001

GC: Gait cycle; WT: without trolley

The normalised cadence was lower when children walked WT than when pulling the trolley. This difference was significant when WT and either 15 or 20% BW **(Figure 21).**

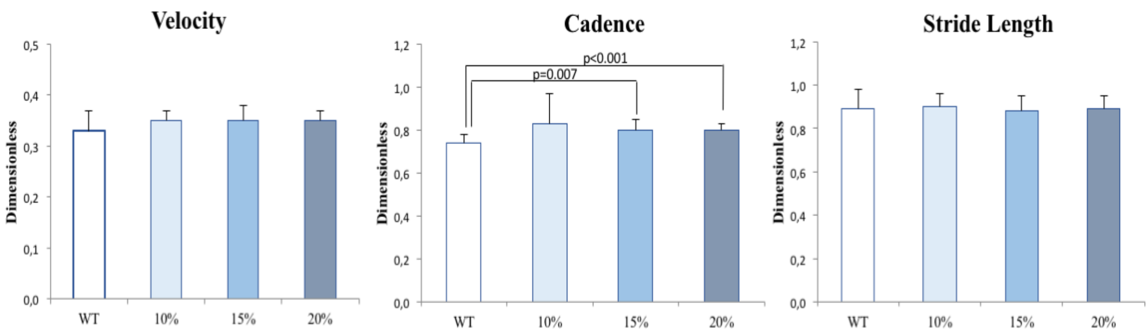

Figure 21. Normalized velocity, cadence and stride length in the different conditions analysed. WT: without school trolley.

The swing and the single support phases were significantly decreased in the 10, 15 and 20% BW conditions compared with the WT condition (**Figure 22**). Conversely, the stance and double support phases were significantly increased in the load conditions compared with the WT condition (**Figure 22**).

None of the gait parameters studied showed significant differences between the load conditions (comparing 10 and 15% BW, 10 and 20% BW, or 15 and 20% BW).

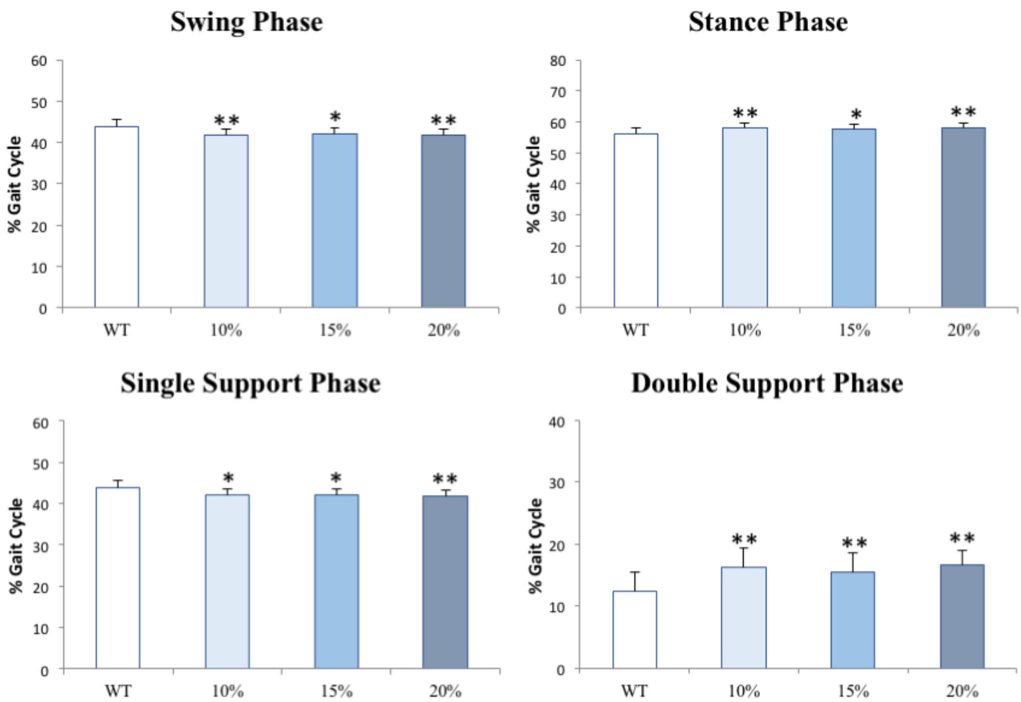

Figure 22. Swing phase, stance phase, single support phase and double support phase in the different conditions analysed. WT: without school trolley; **: p≤0.01 compared to WT; *: p<0.05 compared to WT.

9.3 Study II: Children require less gait kinematic adaptations to pull a trolley than to carry a backpack.

The results of the repeated measures ANOVA are shown on **Table 4**. In the pairwise comparisons, the results obtained showed that compared to control, carrying a backpack produced a significant decrease in stride length (p=0.009) and swing phase (p=0.002), which was similar to the findings for the stance and double support phases (p<0.05). No significant differences were obtained in the spatiotemporal gait parameters when pulling a school trolley compared to control walking.

Table 4. Spatiotemporal gait parameters analysed expressed as mean (standard deviation) and ANOVA results.

	EXPERIMENTAL CONDITIONS			
PARAMETER	No bag condition	Backpack 15% BW	Trolley 15% BW	ANOVA p–value
Normalized velocity	0.31 (0.05)	0.30 (0.05)	0.30 (0.04)	0.07
Normalized cadence	0.78 (0.07)	0.79 (0.07)	0.78 (0.07)	0.64
Normalized stride length	0.78 (0.07)	0.76 (0.07)	0.76 (0.06)	0.01
Swing phase (%GC)	34.33 (1.01)	34.04 (0.95)	34.31 (1.08)	0.01
Stance phase (%GC)	65.69 (1.02)	65.99 (0.94)	65.67 (1.28)	0.004
Double support (%GC)	15.65 (0.92)	15.90 (0.93)	15.79 (0.94)	0.001

GC: Gait cycle; BW: body weight.

Analysis of the three-dimensional kinematics, the average and standard deviation of each parameters, and ANOVA results are shown on **Table 5**.

Table 5. 3D kinematic parameters for each load condition expressed as the mean (standard deviation). In bold font are the significant ANOVA results.

3D Kinematics	LOAD CONDITIONS			ANOVA p-value
	No bag	Backpack 15%	Trolley 15%	
Thorax				
Flexion (+)/extension (-)	-13.9 (6.5)	-7.01 (7.0)	-11.9 (7.0)	**<0.001**
Adduction (+)/abduction (-)	0.04 (0.5)	0.06 (0.6)	-0.02 (0.6)	0.73
Internal (+)/external rotation (-)	-0.01 (0.6)	-0.20 (0.6)	0.25 (1.5)	0.08
Pelvis				
Flexion (+)/extension (-)	12.1 (4.9)	15.2 (5.4)	13.6 (5.1)	**<0.001**
Adduction (+)/abduction (-)	-0.05 (0.4)	-0.13 (0.5)	-0.03 (0.4)	0.29
Internal (+)/external rotation (-)	-0.15 (1.0)	-0.03 (0.9)	-0.1 (1.3)	0.75
Hip				
Flexion (+)/extension (-)	20.1 (5.7)	38.1 (6.9)	21.4 (6.2)	**<0.001**
Adduction (+)/abduction (-)	1.3 (1.6)	2.4 (1.5)	1.6 (1.5)	**<0.001**
Internal (+)/external rotation (-)	2.2 (6.5)	1.5 6.5)	2.2 (6.7)	**0.02**
Knee				
Flexion (+)/extension (-)	26.6 (3.7)	26.4 (3.9)	26.5 (4.1)	0.15
Adduction (+)/abduction (-)	-2.3 (2.6)	-2.5 (2.7)	-2.5 (2.7)	0.17
Internal (+)/external rotation (-)	-13.3 (8.9)	-12.8 (9.0)	-13.1 (9.0)	0.15
Ankle				
Flexion (+)/extension (-)	2.9 (3.2)	2.5 (3.3)	2.7 (3.2)	**0.03**
Adduction (+)/abduction (-)	13.8 (3.0)	13.5 (3.0)	13.6 (3.0)	0.27
Internal (+)/external rotation (-)	-8.3 (4.7)	-8.6 (5.0)	-8.3 (5.0)	0.3

BW: body weight.

In the pairwise comparisons, the thorax showed a significant flexion increase when carrying the backpack compared to no bag and pulling the trolley ($p<0.001$) and also when comparing the no bag condition with the trolley condition ($p<0.001$). In the frontal and transverse planes, the thorax did not show any significant differences. The 3D kinematics of the thorax during the complete GC in the different conditions analysed are shown on **Figure 23.**

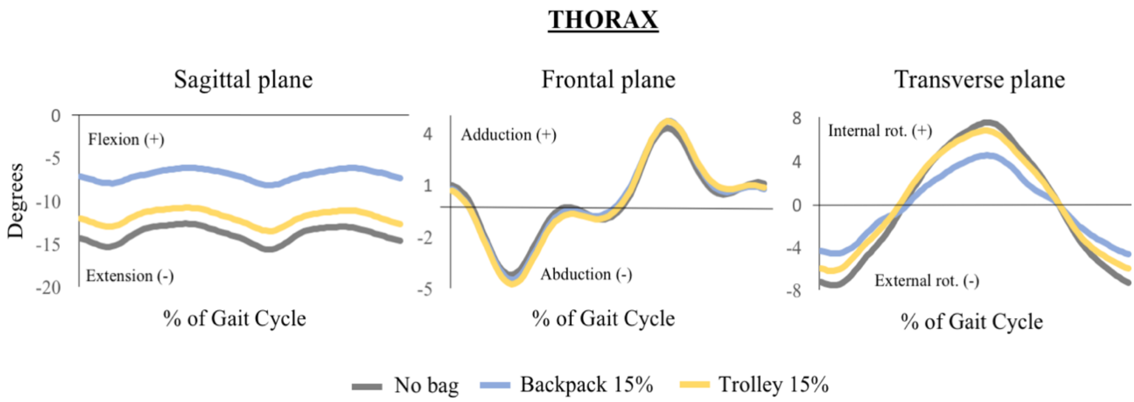

Figure 23. Three-dimensional kinematics parameters of thorax during the gait cycle in each of the conditions analysed.

In the analysis of the pelvis, a significant increase of flexion was obtained when carrying the backpack compared to no bag and pulling the trolley ($p<0.001$). Besides, the pelvis showed a significant increase of flexion comparing with pulling the trolley with no bag condition ($p<0.001$). In the frontal and transverse planes, the pelvis did not show any significant differences. The 3D kinematics of the pelvis during the GC in the different conditions are shown on **Figure 24**.

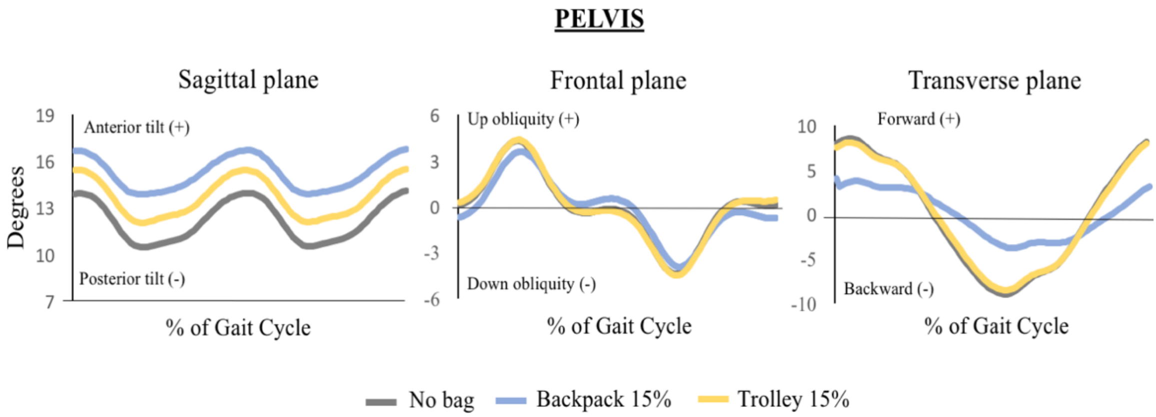

Figure 24. Three-dimensional kinematics parameters of the pelvis during the gait cycle in each of the conditions analysed.

With respect to the hip analysis, a significant increase of flexion was obtained between the backpack condition compared to no bag and the trolley condition ($p<0.001$) and also between the no bag condition and the trolley conditions ($p<0.001$). In the frontal plane, the hip showed a higher level of adduction carrying the backpack compared to no bag and the trolley ($p<0.001$). In the transverse plane, the hip showed a significant decrease of rotation in the backpack condition compared to the trolley condition ($p<0.05$). The 3D kinematics of the hip during the GC in the different conditions are shown on **Figure 25**.

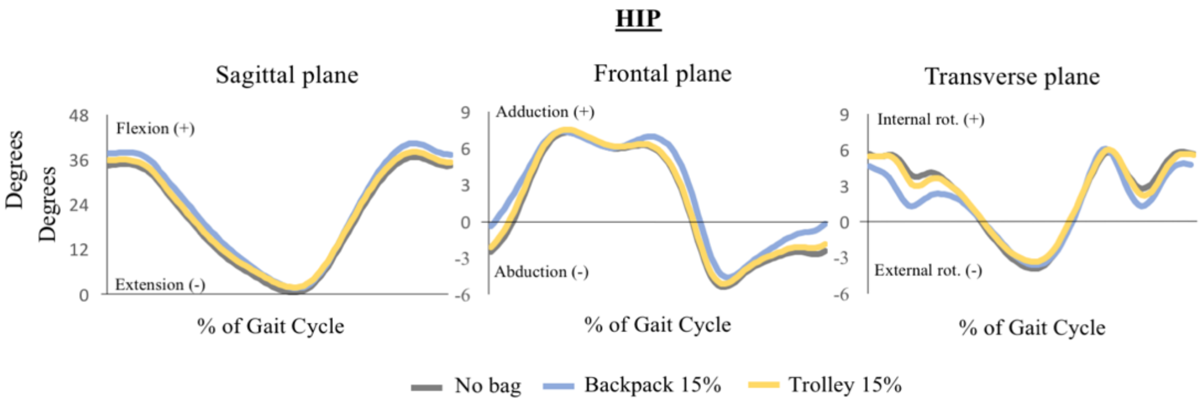

Figure 25. Three-dimensional kinematics parameters of the hip during the gait cycle in each of the conditions analysed.

In the kinematics analysis of the knee, all of the planes showed significant differences when children carried the backpack, except while pulling the school trolley. The 3D kinematics of the knee during the GC in the different conditions are shown on **Figure 26**.

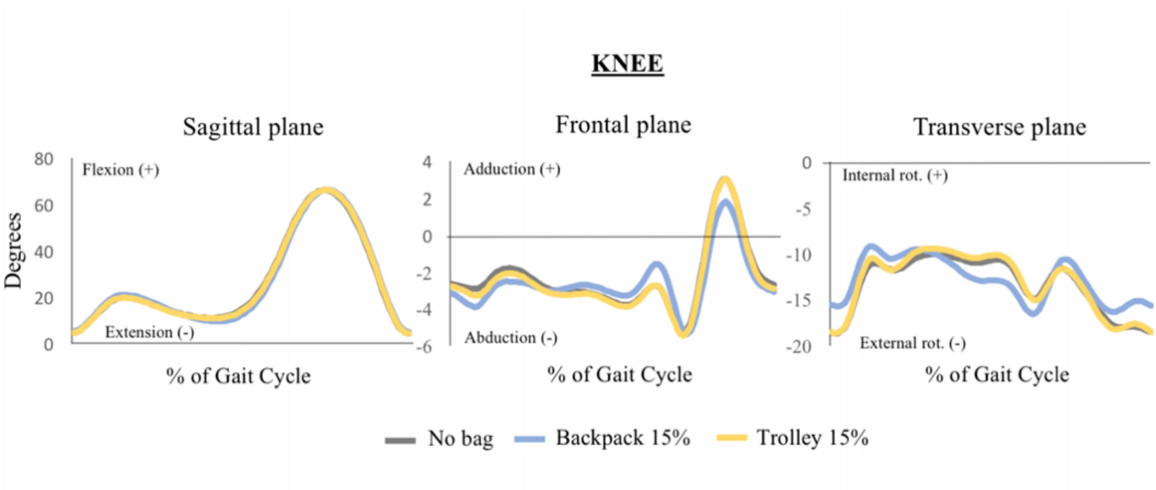

Figure 26. Three-dimensional kinematics parameters of knee during the gait cycle in each of the conditions analysed.

The ankle showed a decrease of flexion in the backpack condition compared to no bag ($p<0.05$). In the frontal and transverse planes, the ankle did not show significant adaptations. The 3D kinematics of the ankle during the GC in the different conditions are shown on **Figure 27**.

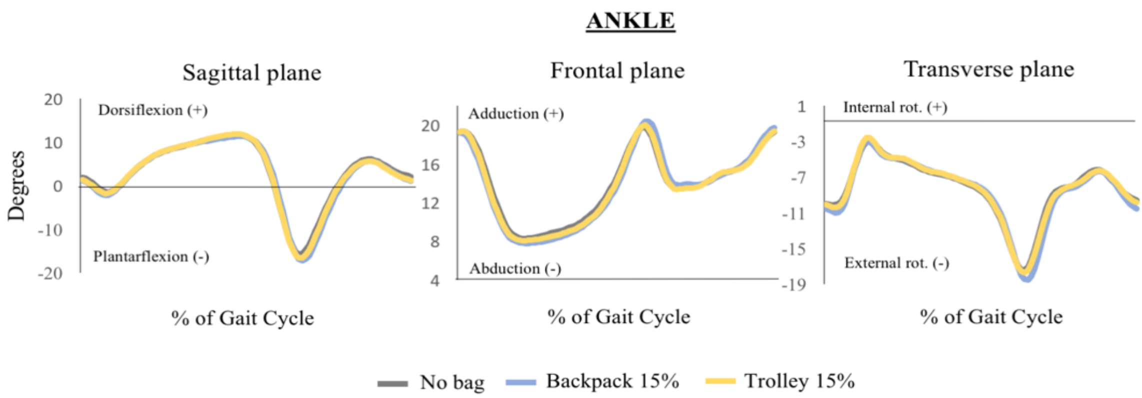

Figure 27. Three-dimensional kinematics parameters of the ankle during the gait cycle in each of the conditions analysed.

9.4 Study III: Pulling a school trolley: A good kinematic option for children.

- Spatiotemporal gait parameters

The averages and ANOVA results of spatiotemporal gait parameters are shown on Table 6. The results show that pulling the trolley with a load of 20% BW induced significant decreases in velocity, stride length and single support phase, and an increase of the double support phase in comparison to walking WT. No significant changes in cadence, step width or stance phase (**Table 6**) were obtained in any of the load conditions analysed.

Table 6. Spatiotemporal gait parameters for each load condition, expressed as the mean (standard deviation), results for ANOVA and pairwise comparisons. In bold font for significant p-value.

	LOAD CONDITIONS				
PARAMETER	WT	10%	15%	20%	ANOVA p-value
Velocity (dimens.)	0.31 (0.05)	0.30 (0.05)	0.30 (0.04)	0.29 (0.04)*	**0.03**
Cadence (dimens.)	0.78 (0.07)	0.79 (0.07)	0.78 (0.06)	0.78 (0.06)	0.7
Stride length (dimens.)	0.78 (0.07)	0.76 (0.06)	0.76 (0.06)	0.76 (0.06)*	**0.004**
Stance phase (%GC)	65.69 (1.01)	65.90 (1.13)	65.67 (1.28)	65.99 (1.01)	0.05
Single support (%GC)	34.33 (1.01)	34.16 (1.11)	34.31 (1.08)	34.01 (1.01)*	**0.01**
Double support (%GC)	15.65 (0.92)	15.75 (1.06)	15.78 (0.94)	15.96 (0.94)*	**0.002**
Step Width (m)	0.10 (0.02)	0.10 (0.02)	0.10 (0.02)	0.10 (0.02)	0.995

WT: without trolley; GC: gait cycle; dimens.: dimensionless; *: significant differences ($p<0.05$) compared to the without trolley condition.

- Effect of trolley weight by type of carrier used

There were non-significant interactions between trolley users and non-users **(Table 7).**

Table 7. Analysis of the interactions of trolley weight (10%, 15%, 20% BW), type of packing device used (trolley or backpack) and body side (loaded vs. unloaded side) with gait kinematic variables.

	Trolley weight		Trolley weight* Type of packing device		Trolley weight* Body side	
	F	p-value	F	p-value	F	p-value
THORAX						
Flexion/extension	10.47	<0.001	0.683	0.56	2.06	0.11
Adduction/abduction	1.146	0.34	0.648	0.58	0.029	0.99
Internal/external rotation	0.306	0.82	1.129	0.34	40.544	<0.001
PELVIS						
Flexion/extension	5.779	<0.01	0.474	0.70	0.602	0.61
Adduction/abduction	0.827	0.48	0.373	0.77	1.354	0.26
Internal/external rotation	1.083	0.36	0.208	0.89	8.938	<0.001
HIP						
Flexion/extension	0.665	0.57	0.859	0.46	1.175	0.33
Adduction/abduction	0.707	0.55	0.226	0.87	1.084	0.36
Internal/external rotation	1.571	0.20	0.823	0.48	1.138	0.34
KNEE						
Flexion/extension	2.082	0.11	0.087	0.96	1.103	0.35
Adduction/abduction	2.164	0.10	1.173	0.33	1.884	0.14
Internal/external rotation	2.394	0.08	1.084	0.36	8.588	<0.001
ANKLE						
Flexion/extension	1.127	0.34	1.361	0.26	2.628	0.06
Adduction/abduction	2.16	0.10	0.312	0.81	5.275	<0.01
Internal/external rotation	0.725	0.54	0.963	0.41	3.052	0.08

- Trolley weight

When analysing kinematic parameters without differentiating the two sides of the body, significant increases of thorax flexion were obtained when comparing WT with 10%, 15% and 20% BW ($p<0.001$) and when comparing the 10%–20% BW and 15%–20% BW load conditions ($p<0.05$) **(Table 8).** The pelvis showed a significant increase of flexion between WT and 10% BW ($p<0.05$) and WT and 15% BW ($p=0.001$).

In the frontal and transverse planes, the pelvis and thorax did not show significant differences. The hip, knee and ankle joints did not show differences in the three kinematic planes analysed **(Table 7).**

Table 8. Three-dimensional kinematic parameters for each load condition expressed as the mean (standard deviation).

	LOAD CONDITIONS			
3D KINEMATICS	WT average (SD)	10% BW average (SD)	15% BW average (SD)	20% BW average (SD)
Thorax				
Flexion (+)/extension (-)	-13.9 (6.5)	-11.9 (6.8)	-11.9 (6.9)	-11.1 (6.8)
Adduction (+)/abduction (-)	0.04 (0.5)	-0.08 (0.6)	-0.02 (0.6)	0.07 (0.7)
Internal (+)/external rotation (-)	-0.1 (0.7)	0.25 (1.2)	0.25 (1.5)	0.18 (1.6)
Pelvis				
Flexion (+)/extension (-)	12.1 (4.9)	13.1 (5.1)	13.6 (5.1)	13.6 (4.9)
Adduction (+)/abduction (-)	-0.05 (0.4)	-0.07 (0.4)	-0.03 (0.4)	-0.02 (0.3)
Internal (+)/external rotation (-)	-0.15 (1.0)	-0.01 (0.9)	-0.1 (1.3)	0.2 (1.1)
Hip				
Flexion (+)/extension (-)	20.1 (5.6)	20.9 (5.8)	21.4 (6.1)	21.1 (5.8)
Adduction (+)/abduction (-)	1.3 (1.5)	1.5 (1.7)	1.6 (1.5)	1.7 (1.4)
Internal (+)/external rotation (-)	2.2 (6.5)	2.3 (6.7)	2.2 (6.7)	2.3 (6.8)
Knee				
Flexion (+)/extension (-)	26.6 (3.7)	26.6 (3.8)	26.5 (4.1)	26.2 (3.8)
Adduction (+)/abduction (-)	-2.3 (2.6)	-2.5 (2.9)	-2.5 (2.7)	-2.5 (2.8)
Internal (+)/external rotation (-)	-13.3 (8.9)	-12.9 (9.1)	-13.1 (9)	-12.9 (8.9)
Ankle				
Flexion (+)/extension (-)	2.9 (3.2)	2.8 (3.3)	2.7 (3.1)	2.8 (3.3)
Adduction (+)/abduction (-)	13.8 (3.0)	13.6 (3.2)	13.6 (3.0)	13.4 (3.2)
Internal (+)/external rotation (-)	-8.3 (4.7)	-8.4 (5.1)	-8.3 (5.0)	-8.3 (5.1)

WT: without trolley

- Effect of trolley weight by body side

The thorax and knee showed significant interactions in the transverse plane (p<0.001) **(Table 7).** Comparing WT with the other trolley weight conditions, the loaded side of the thorax showed a significant increase of external rotation, while the unloaded side exhibited increased internal rotation (p<0.001). In the thorax sides comparison (loaded vs. unloaded side), significant differences were obtained in all conditions in the transverse plane (p<0.001) (**Figure 28**). A significant reduction of the external rotation of the knee was reported on the loaded side between WT and the loaded conditions (**Figure 28**).

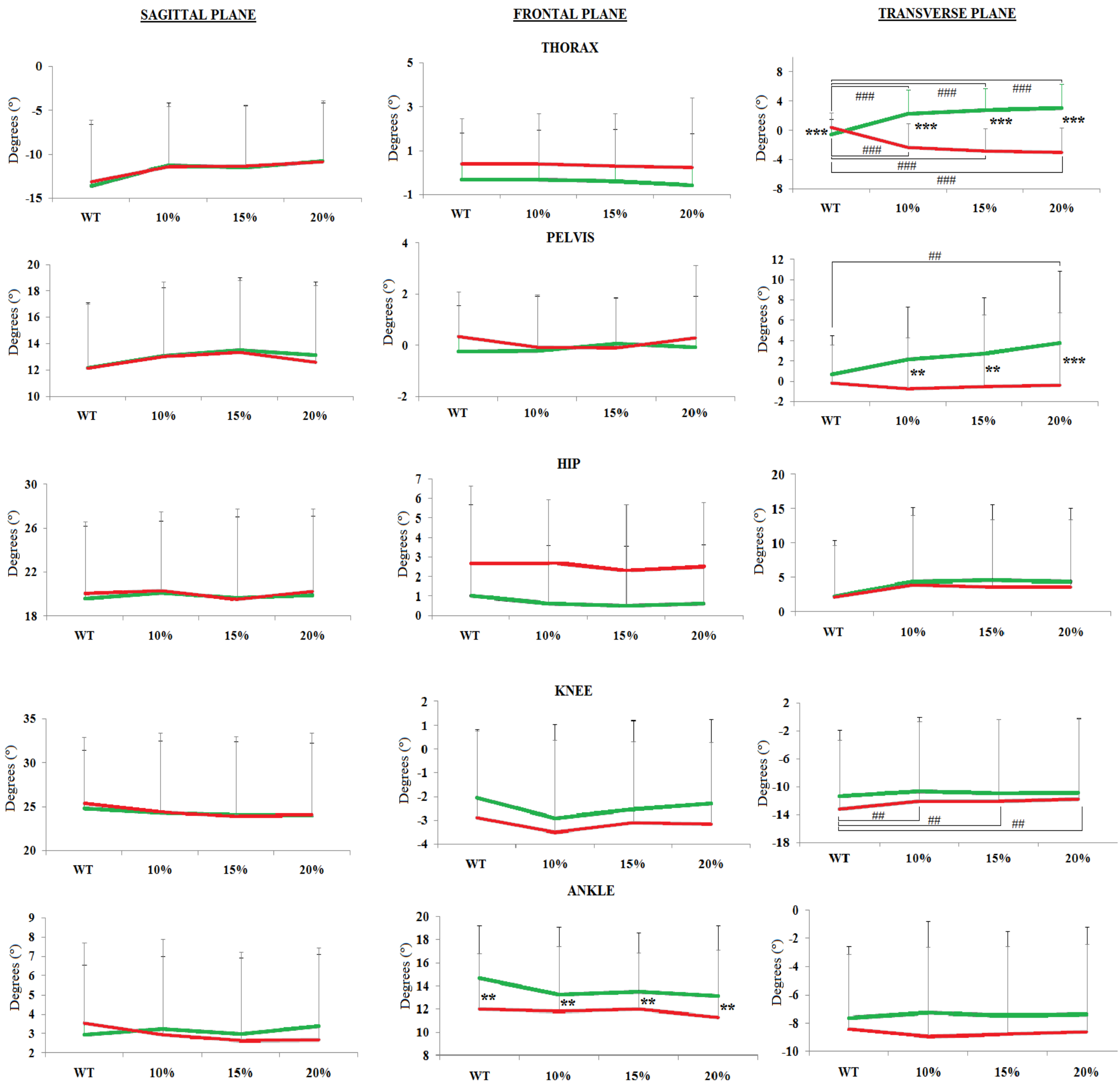

Figure 28. Average and standard deviation of kinematic data collected in the experimental conditions. Between-side analysis (***: p<0.001, **: p<0.05), within-side analysis (###:p<0.001, ##: p<0.05).

WT: without trolley. ▬: loaded side; ▬: unloaded side.

In the pelvis, significant differences were obtained in the transverse plane ($p<0.001$) **(Table 7).** The unloaded side of the pelvis showed an internal rotation increase between WT and 20% BW ($p<0.05$). Within the pelvis sides comparison, significant differences were observed among the three loaded conditions in the transverse plane (**Figure 28**).

Significant differences were obtained in the frontal plane of the ankle **(Table 7).** The within ankle side comparison was significant between the loaded and unloaded sides in all conditions ($p<0.01$) (**Figure 28**).

9.5 Study IV: A kinematic comparison of gait with a backpack versus a trolley for load carriage in children.

The 3D kinematic waveforms of thorax, pelvis, hip, knee and ankle showed some substantial differences between conditions, joints/segments and between loads (**Figure 29**, **Figure 30**).

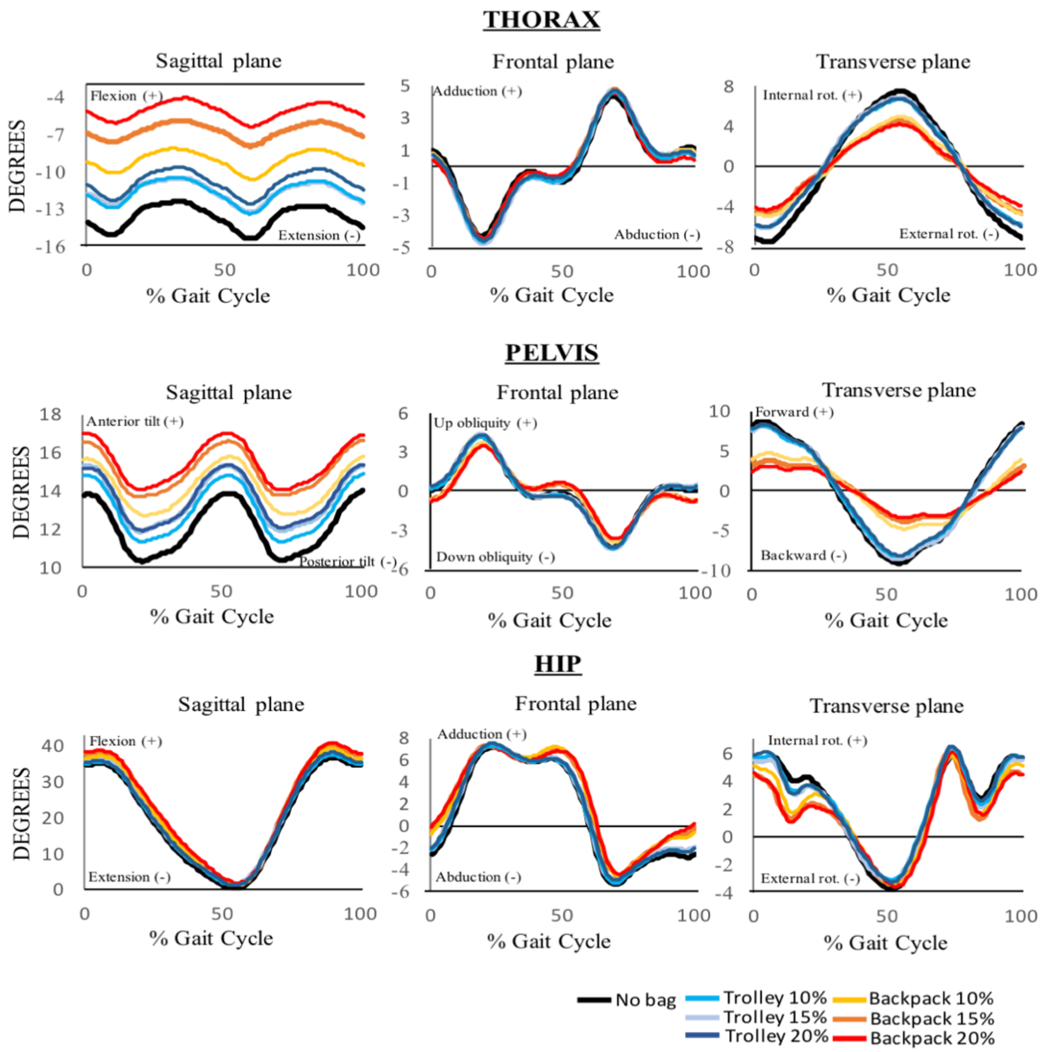

Figure 29. Multi-planar kinematic waveforms for proximal joints (thorax, pelvis, hip) in each of the experimental condition analysed. GC: gait cycle.

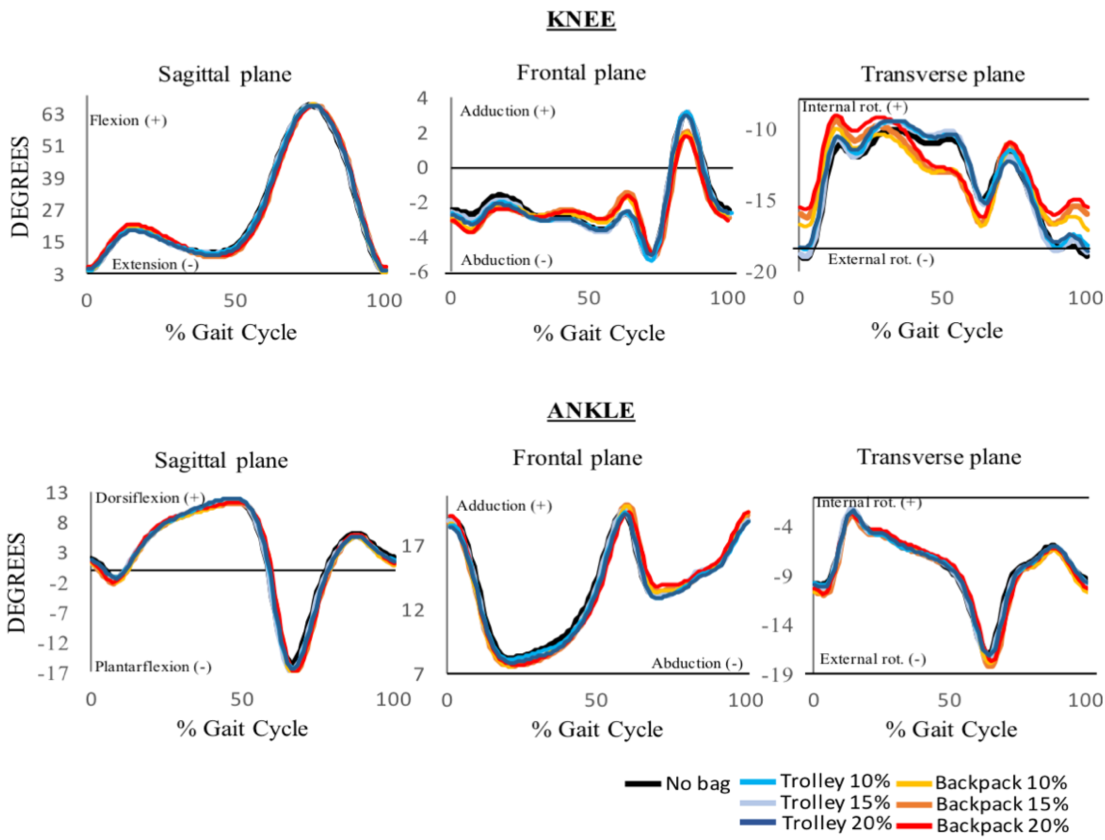

Figure 30. Multi-planar kinematic waveforms for distal joints (knee and ankle) in each of the experimental condition analysed. GC: gait cycle.

Following with the kinematic curves, the thorax, pelvis and hip showed significant differences in the backpack conditions throughout the gait cycle (**Figure 31**). Comparing the school trolley condition to the control condition, identified significant differences in the thorax throughout the gait cycle except in the 10% BW condition, where no difference was observed between 68-79% of the GC, and in the 15% BW condition where no significant differences was observed from 68 to 78% of the GC. The hip showed significant differences between conditions throughout the gait cycle in the 15% BW and 20% BW school trolley conditions (**Figure 31**).

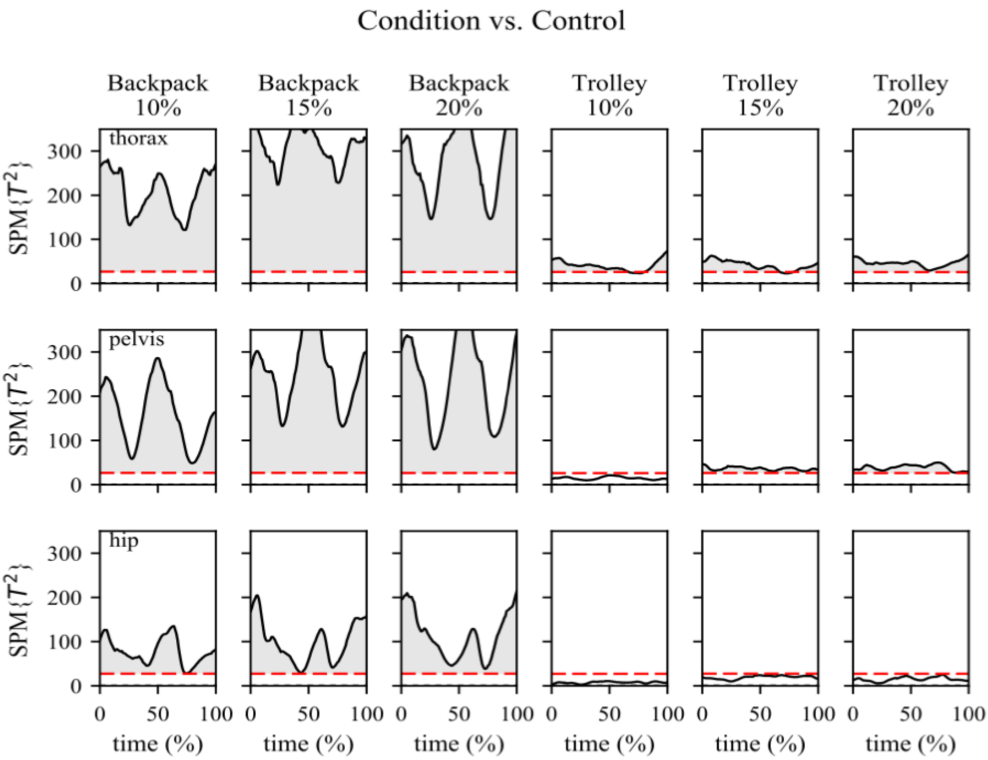

Figure 31. Results of Hotelling's T^2 test for thorax, pelvis and hip, comparing unloaded walking with carrying a backpack, and pulling a school trolley, both with 10%, 15% and 20% BW. The red dashed line indicates the critical threshold. The area of T^2 curve that crosses the critical threshold is shaded in grey and indicates the temporal location of significant kinematics differences.

Non-significant differences were found in the pelvis 10% BW school trolley condition, and also in the hip, knee and ankle in the three-school trolley loads as the T^2 statistic did not cross the critical threshold (**Figure 31**, **Figure 32**).

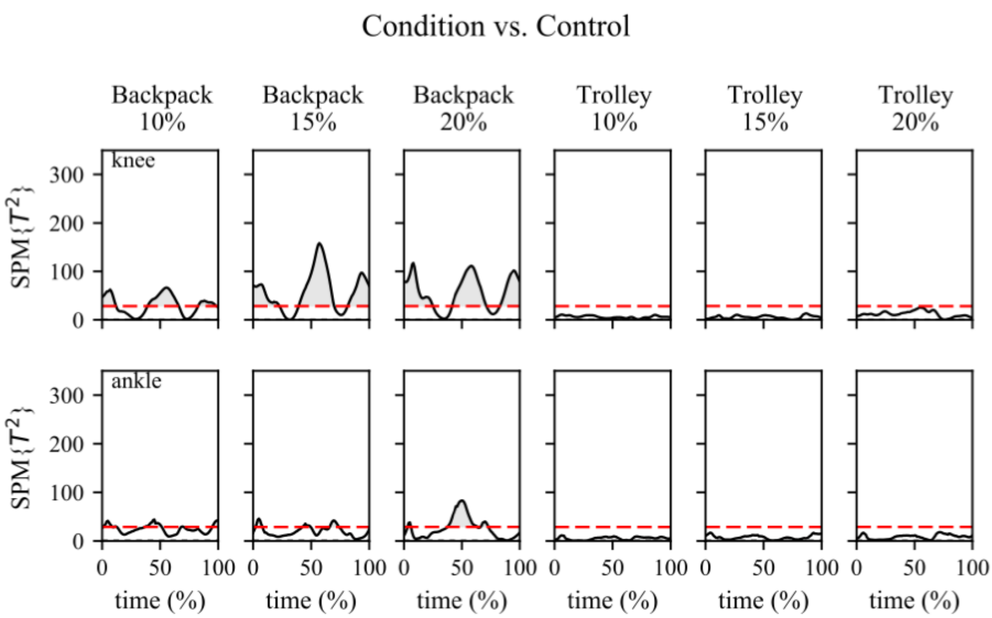

Figure 32. Results of Hotelling's T^2 test for knee and ankle comparing unloaded walking with carrying a backpack, and pulling a school trolley, both with 10%, 15% and 20% BW. The red dashed line indicates the critical threshold. The area of T^2 curve that crosses the critical threshold is shaded in grey and indicates the temporal location of significant kinematics differences.

In the within condition SPM analysis, the comparisons of the different backpack loads showed significant differences for the thorax when comparing 10-15% BW and 10-20% BW during the whole gait cycle (**Figure 33**).

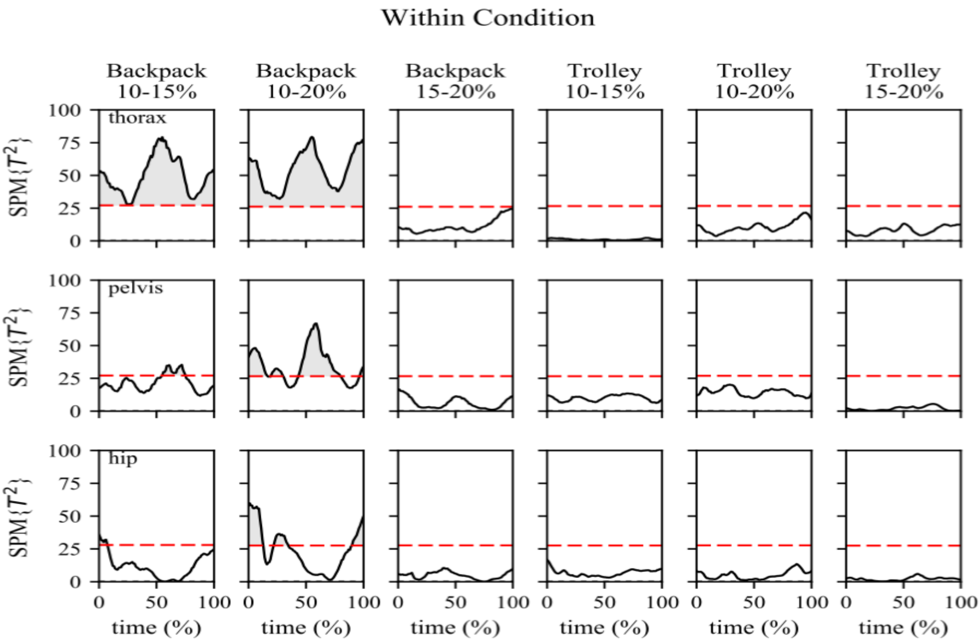

Figure 33. Results of Hotelling's T^2 test for thorax, pelvis and hip for within load comparisons, while carrying a backpack with 10-15%, 10-20% and 15-20% BW; and for school trolley conditions between 10-15%, 10-20% and 15-20% BW. The red dashed line indicates the critical threshold. The area of the T^2 curve that crosses the critical threshold is shaded in grey and indicates the temporal location of significant kinematics differences.

In the pelvis, the results showed a significant peak between 55-75% of GC in the 10-15% BW backpack comparison, and between 0-16%, 19-30%, 43-80% and 96-100% of GC in the 10-20%

BW backpack comparison. For the hip, significant differences were obtained in the 10-15% BW backpack conditions from 0 to 7% of GC, and between 10-20% BW in the following parts of the GC: 0-13%, 22-35% and 90-100%. The knee showed significant differences from 0 to 7% and from 92% to 100% of GC comparing the 10-20% BW backpack conditions. No significant differences were obtained in the knee comparing backpack at 10-15% BW. No significant differences were found in any of the joints comparing backpack at 15-20% BW and also in any of the ankle comparisons. (**Figure 33**, **Figure 34**).

With respect to the within condition analysis of school trolley loads (**Figure 33**, **Figure 34**), no significant differences were found for any of the joints in each of the load comparisons (10-15% BW, 10-20% BW and 15-20% BW).

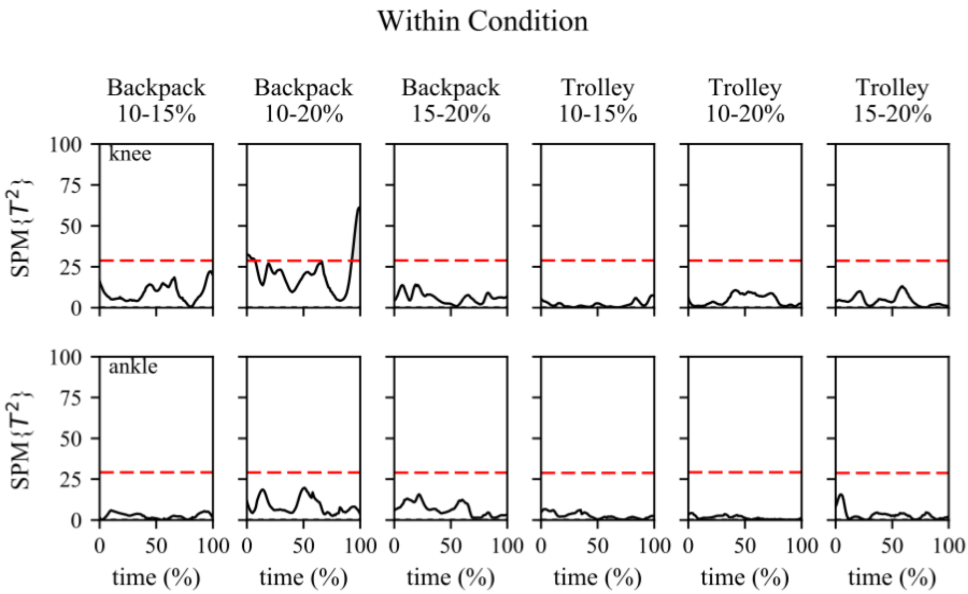

Figure 34. Results of Hotelling's T^2 test for knee and ankle for within load comparisons, while carrying backpack with 10-15%, 10-20% and 15-20% BW; and for school trolley conditions between 10-15%, 10-20% and 15-20% BW. The red dashed line indicates the critical threshold. The area of the T^2 curve that crosses the critical threshold is shaded in grey and indicates the temporal location of significant kinematics differences.

In addition to previous results, a post-hoc analysis was carried out to compare backpack vs. trolley in the different load conditions, as were shown on **Figure 35** for the comparisons in the 10% BW condition, **Figure 36** for the 15% BW condition comparisons, and **Figure 37** for the 20% BW condition comparisons.

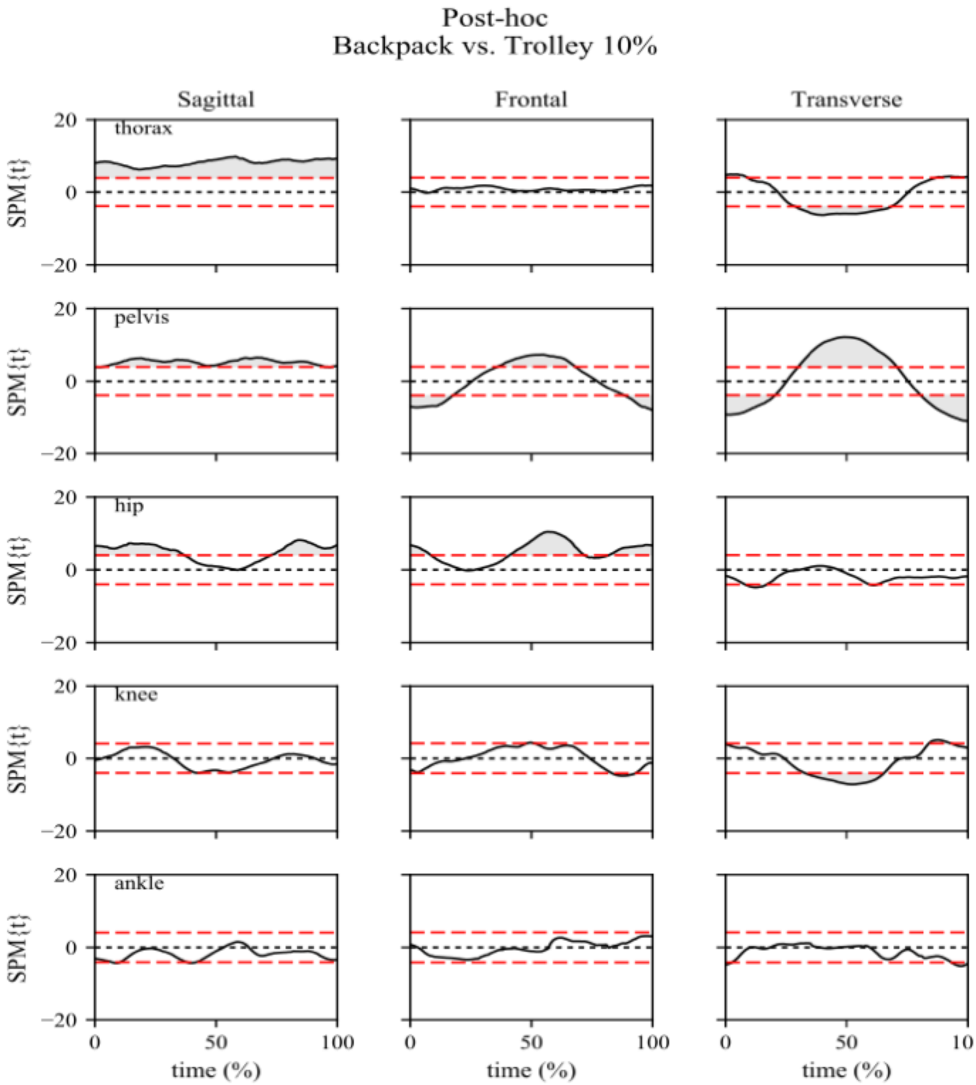

Figure 35. Post-hoc univariate spm 1d t-tests to establish joint level planar differences between backpack and trolley 10% BW condition.

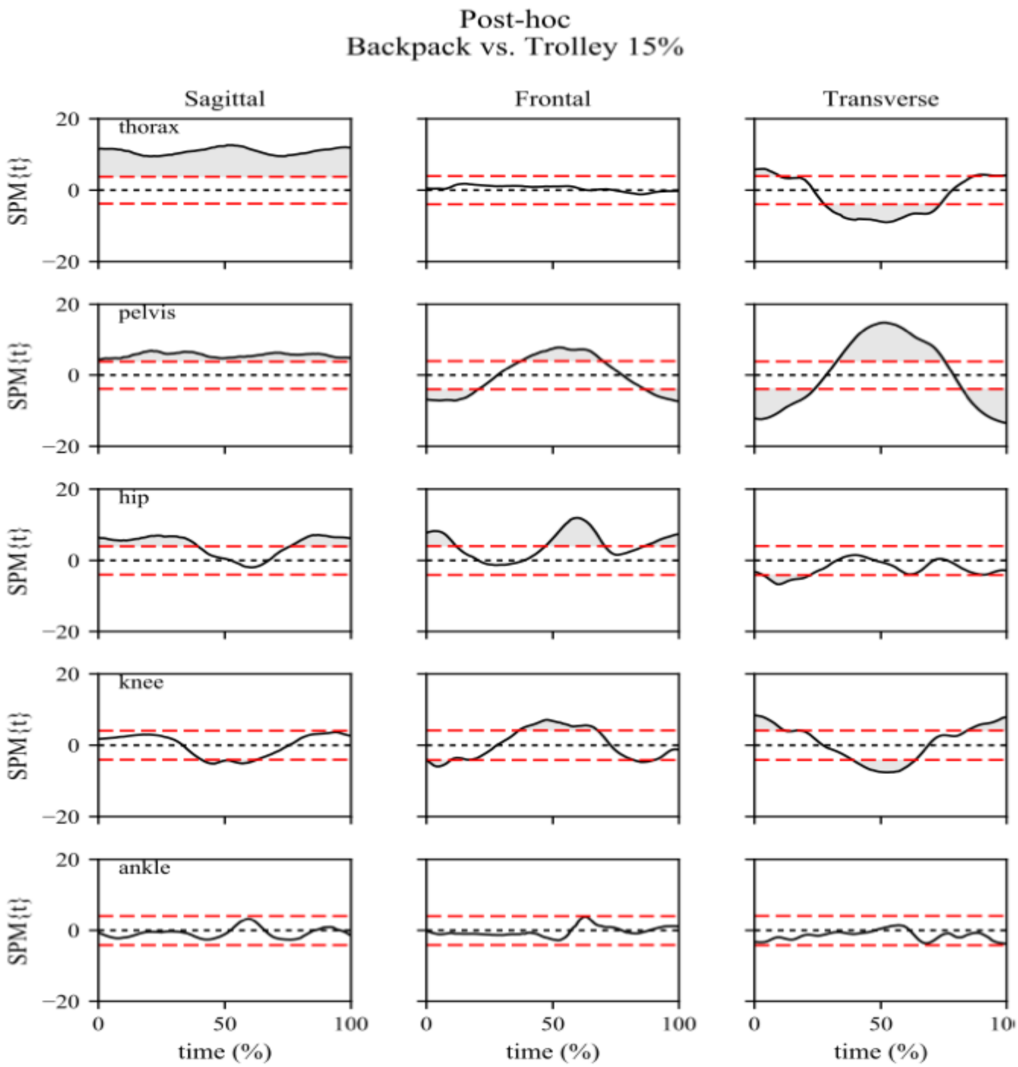

Figure 36. Post-hoc univariate spm 1d t-tests to establish joint level planar differences between backpack and trolley 15% BW condition.

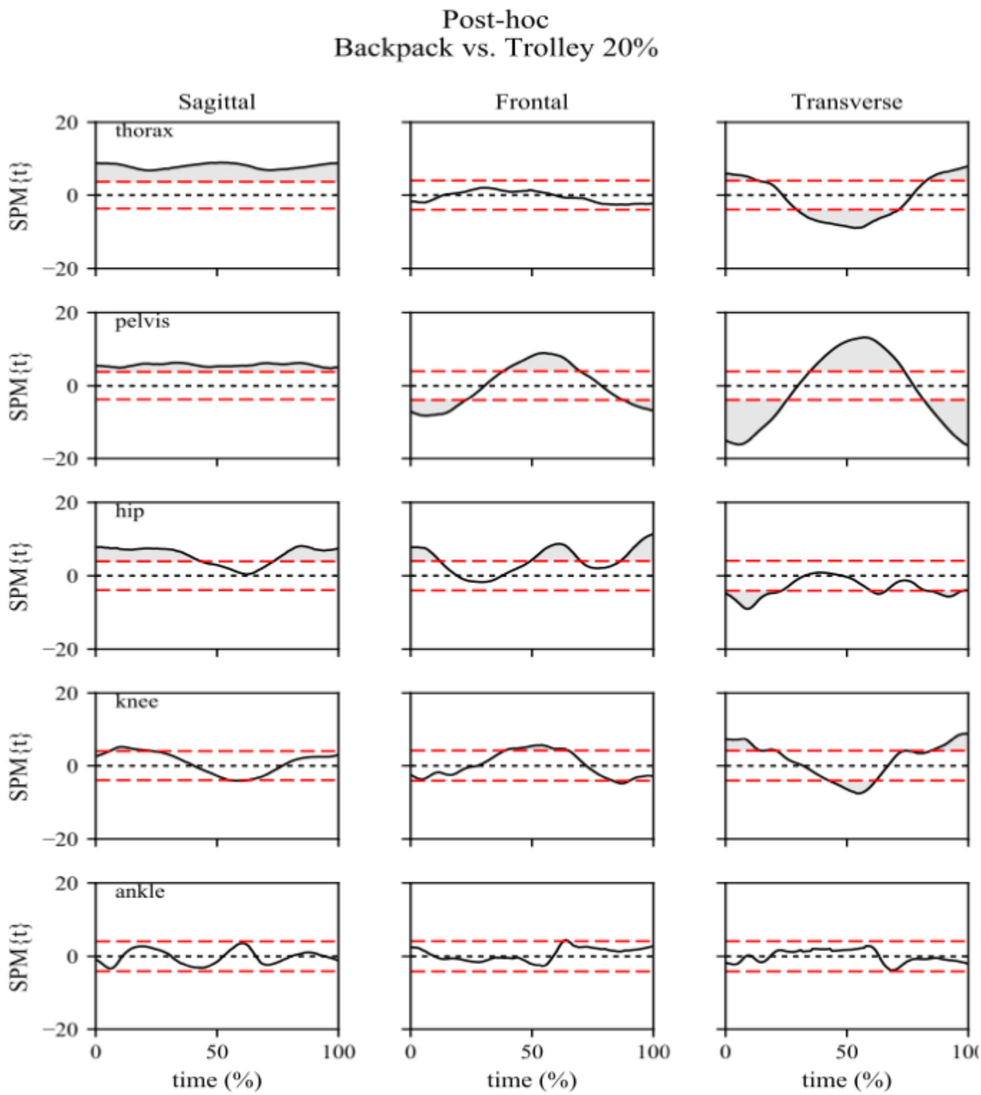

Figure 37. Post-hoc univariate spm 1d t-tests to establish joint level planar differences between backpack and trolley 20% BW condition.

9.6 Study V: Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley?

In this study where GA values were analysed carrying a backpack and pulling a trolley with different loads (10%, 15% and 20% BW), there were no significant differences between any of the GA values analysed for the different experimental conditions. The averages and standard deviations of the GA variables are shown in **Table 9**.

Table 9. Gait symmetry values, expressed as the mean (standard deviation), for the different experimental conditions.

In addition to GA parameters, the RPE was also evaluated in each of the load conditions carrying the backpack and pulling the trolley. The score of the RPE in the different experimental conditions is represented in **Figure 38**. The results indicated a significant increase of the RPE score which appeared from the control condition to the carrying a backpack with 20% BW condition and from the 10% BW and 20% BW backpack conditions (**Figure 38**).

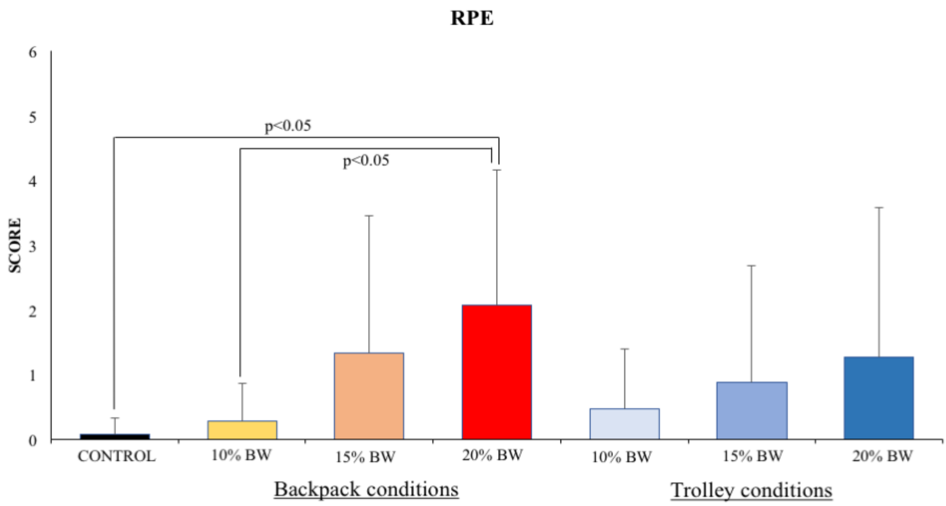

Figure 38. The averages and standard deviations of the rating perceived exertion (RPE) reported at the end of each walking condition.

Discussion

10. DISCUSSION

10.1 Study I: The effect of school trolley load on spatiotemporal gait parameters of children.

The present study shows that the increase in trolley load motivated the subjects to use a cadence adjustment mechanism to maintain their natural velocity because stride lengths were not significantly changed. This result is consistent with that of Hillman and Stansfield (104) who found that children adjust their cadence to change speed, whereas stride length is dictated by other factors particular to the individual. In addition, previous studies suggested that an increased walking cadence created a higher hip power, accentuating the importance of the hip in propulsion and stability (105).

In a previous study of children transporting asymmetrical loads, velocity did not change significantly when the children carried a backpack in one hand (17% BW), but the stride length decreased (50). In contrast, a different study on asymmetrical load transportation found significant decreases in velocity and cadence with the load (15% BW), but stride length did not change (7). Kellis and Arampatzi (50) suggested that the differences in the results between these two studies were due to differences in methodology and sample characteristics.

In this study, the stance phase and double support phase were higher when children walked with any of the three load conditions compared with walking WT. As a result, the load conditions produced a decrease in the swing phase and single support phase. These changes in gait phases are consistent with those seen in previous studies, which showed that increases in the double support phase and decreases in the swing phase occur as an adaptation to maintain a stable and balanced posture while walking with a loaded backpack (50,106).

A previous study found that pulling a school trolley could be more risky for posture than carrying a backpack within the recommended load range (78). In addition, in a study containing interviews with traumatologists (32), 50% of them affirmed that pulling a school trolley involved an asymmetric column effort and a forced posture of shoulder and spine that could cause tendinitis, joint overload and other related disorders. The other 50% of traumatologists preferred the use of school trolleys when the transport load was high.

This study did not reveal significant differences in the spatiotemporal gait parameters when the load varied between 10% BW (a recommended level) and 15 or 20% BW (higher than recommended levels). This result supports the recommendation to use school trolleys when transporting heavy loads (32). The main limitation of this work was that the children started walking without the trolley and then had randomised load conditions, and this could affect the results obtained in this study.

10.2 Study II: Children require less gait kinematic adaptations to pull a trolley than to carry a backpack.

This study set out to compare the influence of two common methods of transporting school materials, a backpack and school trolley, on the gait and posture of children with 15% BW. The kinematic data showed evidence of gait and postural adaptations by the children with each transportation method. However, the type and amount of adaptation differed depending on which device was used.

Compared with control, pulling a trolley did not show significant differences in the spatiotemporal variables. However, carrying a loaded backpack resulted in four changes. Consistent with previous studies, carrying a backpack reduced stride length (50,51,107), increased double limb support and stance phase and reduced the swing phase (7,50,53,54). Those results indicated that carrying a backpack required children to increase the time spent on both feet to manage the load of the backpack during the gait cycle. Increasing the base of support results in a better distribution of the load to maintain postural stability (108) as an adaptation to the negative effect on the balance that is associated with children carrying a backpack (36).

Only our previous study reported a decrease in swing phase and an increase of stance and double support phases resulting from transporting a school trolley (109). The differences in the results between the current study and our previous study may be explained by methodological differences. First, in contrast to the 3D motion capture system used in the current study, a GAITRite system was previously used. However, this seems an unlikely explanation since good agreement between the two systems has been demonstrated (110). Secondly, in our earlier study, we did not randomize the control condition with the loaded conditions as we did in the current study. A third consideration is the proportion of students that routinely used a school trolley in the two studies (17% in our previous work and 47% in the present study). Greater familiarity with pulling a trolley would seem to reduce the likelihood of a change in the gait parameters.

The postural analysis indicated that both, carrying a backpack and pulling a trolley, significantly increased thorax flexion compared with the control condition. However, thorax flexion was significantly greater (4.9º) when carrying a backpack compared to pulling a trolley. The higher thorax flexion was an adaptation to compensate the additional load placed on the back to maintain the center of mass over the pelvis to maintain the body equilibrium

(6,8,13,51,52,69,71). Furthermore, higher flexion of the thorax may increase spinal loading as evidenced by increases in intervertebral disc pressures (111,112). Flexion of the thorax and time of spinal loading are biomechanical factors identified as predictors of musculoskeletal pain in children (113,114).

An important advantage of pulling a trolley in contrast to carrying a backpack is that due to a lack of load on the back, less adaptation of the thorax is necessary thus more closely resembling the thorax posture in the unloaded walking condition. In the frontal and transverse planes, the thorax did not show significant differences between conditions, contradicting previous theoretical analyses about school trolleys, where an asymmetrical trunk effort was one of the characteristics of this type of transportation (32,115).

The results of this study showed a significant increase in the flexion of the pelvis and hip when carrying a backpack and pulling a trolley compared with control, and also a significantly greater increase in these measures while carrying a backpack compared with trolley use. Devroey et al., (6) reported a higher pelvic flexion while carrying a backpack, although hip flexion was not significantly different. According to Chow et al., (7), the increase in backpack load promoted a greater demand of the hip joint for propulsion and braking. This study showed the important role of the hip when carrying a loaded backpack, in that the hip was the only segment that demonstrated adaptations to the three planes while carrying a loaded backpack.

In summary, the use of the school trolley seems to produce fewer adaptations in the ankle, hip, pelvis and thorax than the use of the traditional backpack over level walking. Although the use of the trolley in some situations, such as on stairs or ramps, could be more harmful to the musculoskeletal system than the use of a backpack, it likely lessens the risk of musculoskeletal injuries compared to a backpack during standing activities (waiting at the door of the school, waiting for their parents to go home, waiting for the traffic lights to cross the road, talking with the friends at the end of the classes...).

Limitations of this study consisted of the following: First, pulling the trolley was only analysed in level walking and not in more challenging circumstances for the trolleys such as stairs and steps. A previous study has reported large dynamic forces associated with these tasks in children (38). Second, a simple thorax model was used in the current study. Thus, the influence of carrier type on motion between thoracic and lumbar regions could not be determined. Third, 15% BW was used for both backpacks and trolleys in the current study. In practice, children may carry a greater load when pulling a trolley than while carrying a backpack, however the effect of pulling a higher load in a trolley was not examined.

10.3 Study III: Pulling a school trolley: A good kinematic option for children.

This study set out to determine the influence of pulling a school trolley on the kinematic gait parameters of children using loads that children typically transport to school: 10%, 15% and 20% BW.

Pulling the trolley with a 20% BW load produced significant changes in the investigated spatiotemporal parameters (except cadence, stance phase and step width). Despite the significant differences obtained for some of the spatiotemporal gait parameters while pulling the trolley with a 20% BW load, these changes did not appear to be important; we observed differences of only 0.02 units in normalised velocity and stride length, 0.32% in the single support phase and 0.31% in the double support phase. Those results are supported by previous backpack studies in which the observed changes were not clinically meaningful or not significant (6,13,52).

In the present study, the influence of the different loads on the spatiotemporal parameters was smaller than reported in a previous study of trolleys (109); this difference could be caused by the higher prevalence of trolley use in this sample (50% vs. 20% in the previously reported study). In addition, in comparison to previous backpack studies, the use of a school trolley appears to produce fewer changes in spatiotemporal gait parameters than the use of a backpack with the same load (50,53,54,58).

According to the interaction of trolley weight with the type of packing device used, children who pulled a trolley or carried a backpack daily did not exhibit altered gait kinematics in this study. Those results appear to indicate that no adaptation is required for non-trolley users to adopt the same kinematic profile as daily trolley users. In accordance with this finding, is a previous study that analysed the kinematic changes associated with carrying a backpack and pulling a trolley with a load of 15% BW (116). This demonstrated that pulling a trolley was more similar to unloaded walking than carrying a backpack, as fewer kinematic changes were needed to pull a trolley than to carry a backpack.

The main kinematic changes caused by trolley weight (without interactions) were obtained in the sagittal plane of the thorax and pelvis. Previous authors reported similar results in an unloaded walking study, concluding that the majority of the work performed while walking without a load was performed in the sagittal plane to move the body forward in the plane of progression (117). The increased thorax flexion reported as the trolley load increased was also obtained in backpack studies as an adaptation to compensate for the additional load and to maintain the center of mass over the pelvis and maintain body equilibrium (8,13,52,71).

Previous studies reported a flexion increase of 6–9º while carrying a backpack, which differs from the increases obtained in the present study while pulling the trolley, although the loads were the same (8,13,52,71). Considering that an increase of thorax flexion was previously related to a stronger compression of the intervertebral disc (111,112), the lower flexion of the thorax that is required to pull the trolley could represent an advantage for promoting childhood spine care.

Furthermore, the pelvis exhibited increased flexion as the trolley load increased; this change occurs as a compensatory mechanism to maintain a standing posture and vertical position and is supported by previous studies (118). Previous backpack studies with a 15% BW load also reported an increase of pelvis flexion (6,74). However, because there is no need to support the load on the back, pulling a trolley could require less flexion of the pelvis than carrying a backpack with the same load, as shown in previous comparative studies (116).

With respect to the effect of load increases while pulling a trolley, no significant changes in the distal joints (knee and ankle) were observed when the load was increased, as was previously reported in backpack studies in which no important changes were induced by the backpack load (7).

Comparing the effect of trolley weight by body side (loaded vs. unloaded side), the thorax exhibited increased rotation towards the loaded side in comparisons between WT and the other trolley conditions, with maximum differences in rotation of 3.5º between WT and 20% BW. Adaptations similar to those recorded for the thorax were obtained for pelvis rotation; however, these changes were only observed when the transport load was 20% BW. Kumar et al., (119) estimated that an interval of 10-15º of axial rotation towards one side of the thorax sagittal axis involved very little muscle effort, although an increase in this region would cause the osteoligamentous structures to become stiff and require increasing effort to execute axial rotation. Although the results of this study showed an increase of thorax rotation toward the direction of the load, the magnitude of that change may not require any extra muscle contraction of the subject's thorax.

The changes obtained in the knee and ankle joints were less marked than those obtained in the thorax and pelvis, as reported in a previous study (7). In addition, ankle changes were not produced by the increased load, and all differences were observed within the ankle sides comparison.

10.4 Study IV: A kinematic comparison of gait with a backpack versus a trolley for load carriage in children.

In this study, gait kinematics throughout the gait cycle were evaluated in children while carrying backpacks or school trolleys with different loads. This is the first study that compared children carrying a backpack and pulling a school trolley with different loads conditions (control, 10, 15 and 20% BW) throughout the gait cycle using SPM to analyse the kinematics changes. All of the previous studies that have analysed the effect of pulling a school trolley on gait have computed kinematic data obtaining discrete parameters (mean or peak) of the gait waveform (116,120), without completing a description of the postural adaptations to load carriage during the complete gait cycle.

The loaded backpack compared to the natural walking showed the most affected joints were the proximal joints (thorax, pelvis and hip), while the joints least affected were the distal (knee and ankle), as was reported in previous studies (7,116). Specifically, the thorax, pelvis and hip flexed more to compensate for the backward displacement of the child's center of gravity due to the load being carried on the back (74). Such adaptations would have a negative effect for spine care because the increased thorax flexion combined with the heavy backpack load add an additional stress in the spine, resulting in a high intra-disc pressure (71) and the suffering of back pain or discomfort in elementary students (12,30,31,121).

Moreover, according to the categorization of gait phases (49), this study showed maximum differences in the thorax, pelvis and hip kinematics during loading response, pre-swing and terminal swing. These results can be related to an inefficiency of weight-bearing stability (loading response phase), limb progression and limb advancement (pre-swing phase and terminal swing phases) while walking carrying a backpack. In this way, children that carry a backpack have demonstrated decreased postural stability (122), negative balance effects (36,122) and an increase in metabolic cost (58).

Besides, the reduction of thorax and pelvis rotation while carrying a backpack compared to natural walking were a consequence of a decrease in the counter-rotation between the thorax and lower body to provide a dynamic stability and reduce the effect of the increased moment of inertia of the backpack (7,73,74,123).

In the distal joints, the knee showed significant differences in the heaviest backpack conditions analysed (15% and 20% BW) compared with natural walking. In the study of Chow et al., (7), where discrete parameters were analysed (range of movement and peaks) this resulted in an increase of the knee peak flexion as load increased during loading response for shock absorption and non-significant differences in the ankle joint. However, in this study, an analysis of the knee showed three significant peaks during the gait cycle phases and the same trend for the ankle but with a lower significant effect, that corresponds to the weight stability, shock absorption, transference of load and limb progression.

The use of a school trolley resulted in kinematic patterns more closely aligned to normal walking than carrying a backpack (116,124). The thorax and pelvis showed the greatest kinematic adaptations in the sagittal and transverse plane in comparison with control walking. The increase in thorax and pelvis flexion with an increase in school trolley load was reported in previous studies as load compensation mechanics (116,120).

Apart from the thorax and pelvis there were few other differences in distal joints as the school trolley seemed to effectively redistribute weight onto the wheels and not on the back. The handle height of the school trolley could be related to the kinematic adaptations of thorax and pelvis while pulling the school trolley, and future studies will be carried out on this field. These results therefore partially validate the observations of Rontogiannis et al., (18) who reported a higher incidence of musculoskeletal symptoms in backpack users than the school trolley´ users (65% vs. 43%).

The range of recommended safe loads for backpack carriage ranges from 10-20% BW. In this study, the inclusion of three loads within this range allowed a systematic analysis to determine if substantial differences in kinematics between these loads existed. In this analysis, the increased of load up to 10% BW produced some kinematics changes, supporting previous studies which recommended avoiding loads above 10% BW for the backpack of children based on kinematics, EMG and subjective effort variables (6–8,125). In this way, El-Nagar et al., (126) obtained that school children who carrying school bags between 10.1-15% and >15% BW were more likely to suffer from back pain complaints by approximately 2.6 times and 6.1 times respectively than those carrying school bags ≤10% of their body weight.

In contrast to the differences observed between different backpack loads, the school trolley showed no significant differences in any of the within load comparisons. Kinematic adaptations were therefore independent of the load carried, in agreement with a previous study which analysed the spatiotemporal gait parameters while pulling a trolley with different loads (109).

To summerise, in this study, a load of up to 20% BW could be considered a safe load for school trolley users, because of the non-kinematic adaptations required while children are walking over ground level. Although other previous studies have reported that the use of a school trolley with 20% BW produced an increase of 6.7% thorax flexion compared to 10 and 15% BW (120), and also Pau et al., (38) found that during the ascent and descent of stairs with the school trolley loaded at 20% BW, large dynamic forces could raise some concerns about the potential for excessive stresses in the arm-shoulder complex.

Taking those results into consideration and as there are currently no recommended "safe" loads for school trolley users, pulling a school trolley over ground below 20% BW could be recommended and considered a "safe" load for children to manage.

10.5 Study V: Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley?

Carrying a loaded backpack and pulling a school trolley make children adapt some of their spatiotemporal gait parameters when walking. The present study aims to determine whether pulling a trolley or carrying a backpack over two shoulders influences the GA in children. Although pulling a school trolley had been considered as a good option from kinematic (116,120) and spatiotemporal gait analyzes (109), it entails an asymmetric task that could influence the GA of children. However, there was no previous data about this. In addition, in the present study, the RPE of the children, which was reported in each of the experimental conditions, was analysed. This study is the first to consider the RPE of children while pulling a school trolley with different loads.

With respect to GA, the results obtained in this study demonstrate that pulling a trolley and carrying a backpack did not influence any of the parameters of GA that were analysed. In addition, none of the variables showed significant changes when the loads increased for carrying the backpack and pulling the school trolley (in the range from 10% BW to 20% BW). Previous studies about gait asymmetry and backpacks support these results, and observed no significant differences between carrying a backpack with 10 kg and unloaded walking (54).

Yoon et al., (59) analysed the effect of carrying an asymmetrical backpack (loaded with 10% BW). The results showed an asymmetrical increase of the medio-lateral GRFs. Although in the present study the analysis of GA was carried out using the spatiotemporal gait parameters and not using the GRFs. In this study the trolley supported the load via its wheels and not over the shoulders, as in the study of Yoon et al., (59), and this could have promoted the lack of an increase of asymmetry observed using the school trolleys. As a consequence, pulling a school trolley was a natural behavior for users compared to transporting items in asymmetrical bags, such as carrying a backpack over one shoulder.

As previously reported, asymmetry in stance and swing times were related to balance and gait control (103). In the present study, the differences were not significant and indicated that, with respect to GA, neither backpacks nor trolleys produced an increase of gait control perturbations. In addition, considering that GA reflects the similarity of motor function related to leg propulsion of both sides of the body (127), it could be considered that carrying a backpack or pulling a trolley did not alter it.

In relation to the RPE values, all of the participants reported how they felt, from tired to not tired and from 1 to 10, at the end of each experimental condition. The results presented in this study showed higher RPE values as the load increased in the backpack and trolley conditions, compared with the control condition. However, the increase in the RPE was only significant between the 20% BW backpack condition and the control and 10% BW backpack conditions. These results support the results from previous studies, which also observed an increase in the RPE values.

In this way, Devroey et al., (6) showed an increase in the RPE while carrying the backpack with 10% BW and 15% BW compared with the unloaded condition. Bauer (125) also observed a significant increase in the RPE values from the control and 10% BW conditions to the 20% BW condition in boys, while this increase was significant between the control and 10% BW conditions and between 10% and 15% BW conditions in girls. Kistner (68) reported the RPE data after the participants completed the 6 Minute Walking Test and observed an increase in the RPE from the unloaded conditions to the 10% BW, 15% BW and 20% BW conditions. The increase in the RPE while walking with a loaded backpack would support the conclusions of

Alberola et al., (21), who found that 59% of students felt tired carrying their backpacks.

Considering the trolley conditions, the increase in the load did not produce a significant increase in the RPE values. Although there are no previous references about the effect of pulling a trolley on the RPE values, these results seem to support the conclusions proposed in previous kinematics studies about trolleys (116,120), which affirmed that school trolleys could be considered a good option for children, supporting the conclusions provided from biomechanic results with subjective perceptions of children.

The main limitation of this study is that only the asymmetry of the lower limbs was analysed, using variables such as swing and stance times and step length, while the asymmetry of the upper extremities and thorax was not studied.

Conclusions

11. CONCLUSIONS

The main conclusions found in this International Doctoral Thesis are:

- A high percentage of students (55% of boys and 58.5% of girls) carried higher loads than 15% BW in their school bags. The school trolley was the favorite option for girls (64.3% of girls used school trolleys).

- Users of school trolleys seem to have better feelings about the perception of weight, fatigue and back pain while pulling their school trolley than backpack users.

- The increase of backpack load produced greater kinematics changes in the proximal joints (thorax and pelvis) compared to the distal joints (knee and ankle), while the use of a school trolley resulted in comparatively minor kinematic adaptations for children.

- The use of the school trolley loaded up to 20% BW required fewer kinematics adaptations than the use of the traditional backpack. In addition to that, the use of the school trolley allowed children to maintain a closer posture to unloaded walking than carrying a backpack.

- Pulling a trolley with loads between 10% to 20% BW produced a lower rating of perceived exertion and was closer to unloaded walking than the use of the backpack with the same loads.

- Kinematic analysis leads to recommending avoiding loads above 10% BW if carrying a backpack, however if using a school trolley, below 20% BW maintains acceptable natural over ground walking kinematics.

- As a final conclusion, school trolleys should be considered to be a good option for the transportation of school supplies.

Conclusiones

12. CONCLUSIONES

Las principales conclusiones de esta Tesis Doctoral se describen a continuación:

- El 55% de los niños y el 58.5% de las niñas transportan más del 15% BW en su mochila o carro escolar. Además, el carro escolar fue la opción elegida por el 64% de las niñas.

- Los usuarios de carro escolar parecen tener una percepción más positiva en lo que se refiere a sensación de peso, fatiga y dolor de espalda tras el uso de este equipo, que los que son usuarios de mochila.

- El aumento del peso de la mochila produce mayores cambios cinemáticos en los segmentos proximales (tórax y pelvis) comparado con los distales (rodilla y tobillo), mientras que el uso del carro escolar requiere, en comparación con la mochila, de menos adaptaciones cinemáticas para los escolares.

- El uso de un carro escolar con cargas de hasta el 20% BW requiere de menores cambios cinemáticos que el uso de la mochila tradicional. Además, el uso del carro escolar permite a los escolares mantener una postura más próxima a la condición sin carga que el llevar una mochila.

- Tirar de un carro con un peso de entre el 10% y el 20% BW requiere de un menor índice de esfuerzo percibido que el uso de la mochila escolar con las mismas cargas, y muy cercano a la locomoción sin carga.

- El análisis cinemático realizado en los estudios presentados sugiere que cuando se transporta una mochila se evite hacerlo transportando cargas mayores del 10% BW. Sin embargo, cuando se usa un carro escolar, el uso de cargas por debajo del 20% BW permite mantener una postura natural y similar a la de sin carga cuando se utiliza a nivel de suelo.

- Como conclusión final, se destaca que el uso del carro escolar podría ser considerado una buena opción para que los escolares transporten sus materiales al colegio.

Future research directions

13. FUTURE RESEARCH DIRECTIONS

Future research directions proposed in the different studies presented for this Doctoral Thesis, have highlighted some areas for future research that could be carried out.

In **Study I**, it was proposed that a future research direction could be the integration of 3D gait analysis and the joint loading of both sides of the body, and the comparison of the effects of pulling and pushing school trolleys using the recommended loads. Further study could be made of the daily loads that children transport to school, and the associations of asymmetric load transportation with musculoskeletal disorders, back pain, and quality of life in children.

In **Study II**, a proposal for further studies suggested the needed to analyse the frequency of the situations where children have to climbing stairs or ramps; and to compare and analyse the risk of musculoskeletal injuries when carrying a backpack during standing activities (waiting in the door of the school, waiting for their parents to go home, waiting at the traffic lights to cross the road, talking with the friends at the end of the classes...) and obstacle situations where children are using a school trolley.

In **Study III**, future research directions that were proposed include the analysis of the effect of pulling a school trolley by using a multi-segment trunk model to analyse the kinematic changes of the thorax and abdominal sections and an EMG analysis of the trunk to support a global conclusion about recommendations for school trolley use by children.

In **Study IV**, future work was suggested as the quantification of lower back loads more specifically, using a musculoskeletal model which could help to estimate the loads experienced by the musculoskeletal system as a consequence of the altered kinematics. Also, the analysis of the handle height of the school trolley was proposed and the relationship with the kinematic adaptations of thorax and pelvis while pulling the school trolley.

In **Study V**, future studies indicated were the need to determine the RPE evolution after a long duration of carrying the backpack and pulling the trolley, to analyse the asymmetry of the thorax and arms while pulling a trolley, and to test the RPE in different conditions, such as incline streets, overcoming obstacles, climbing stairs and other daily situations This would help to clarify the recommendations about school trolleys and backpacks in elementary school students.

As additional and complementary to those previously described, the following future research directions are suggested:

- To analyse the energy expenditure pulling a school trolley with different loads and exploring a representative distance for children to commute.

- To analyse the upper extremity kinematics and EMG data while children are pulling a trolley over level walking and in different situations where different obstacles have to be overcoming (such us curb, stairs, ramps…).

- To analyse the prevalence of two trends that are appearing in children: On the one hand, the tendency of children to carry more to school because of the combination of the backpack with an additional case and the larger amount of school supplies children are carrying in their backpacks or trolleys. On the other hand, the development of a technological backpack or "Backpack 3.0", where children changed their books for a tablet or other technological solution that is lighter than carrying books

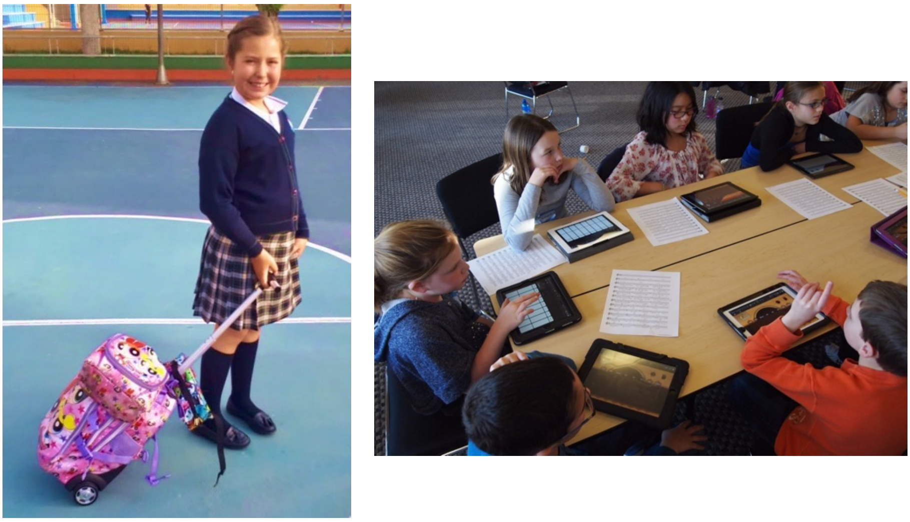

Figure 39. Two examples for future research, where the trend for a heavier backpack is leviated by technological advances in schools.

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Resumen CV

15. RESUMEN CURRICULUM VITAE

Datos personales

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Formación académica

- Diplomada en Magisterio, especialidad Educación Física

Facultad de Ciencias de la Educación (2008-2011)

Universidad de Granada

- Licenciada en Ciencias de la Actividad Física y el Deporte

Facultad de Ciencias del Deporte (2011-2013)

Universidad de Granada

- Máster de Investigación en Actividad Física y Deporte

Facultad de Ciencias del Deporte (2013-2014)

Universidad de Granada

Becas obtenidas

- Ayuda a la Enseñanza Práctica dirigidas a estudiantes de Másteres Oficiales y Programas de Doctorado de la UGR-CEI BioTic Universidad de Granada. Julio-octubre 2014.
- Ayuda para la Formación del Profesorado Universitario (FPU) convocada por el Ministerio de Educación, Cultura y Deporte (ref. FPU13/00162), octubre 2014-2018.
- Ayudas para movilidad: Estancias Breves para beneficiarios FPU (ref. EST15/00019), convocada por el Ministerio de Educación, Cultura y Deporte y Ayuda para movilidad internacional de estudiantes de doctorado convocada por la Universidad de Granada.

Participación en proyectos de investigación

- Efecto de la carga de la mochila sobre los parámetros de locomoción en escolares de primaria (ref. CEI2014-MPBS18). Investigador principal: Dr. D. Jose Maria Heredia Jiménez. Duración de mayo a diciembre 2014. Financiación: 3.000€
- Sistema ergonómico integral para la evaluación de la locomoción como predictor de la calidad de vida relacionada con la salud en mayores "ERGOLOC" (ref. DEP2012-40069). Investigador principal: Dr. D. Victor Manuel Soto Hermoso. Duración de 2012 a 2016. Financiación: 42.000€
- Informatización de Máquina Patentada para la Medición de Propiedades Viscoelásticas del Tríceps Sural (ref. CEIbioV14-2015). Investigador principal: Dr. D. Manuel Noguera García. Duración: marzo a diciembre 2015.Financiación: 2.000€

- Monitorizacion y fomento de hábitos saludables, mediante una plataforma basada en sensores portables y asesores virtuales, para la promoción del envejecimiento activo en población activa y mayor "AVISAME" (ref. DEP2015-70980-R). Investigador principal: Dr. D. Manuel Noguera García y D. Victor Manuel Soto Hermoso. Duración: Enero a Diciembre 2016. Financiación: 102.850€
- Efecto del peso de la mochila sobre parámetros biomecánicos de la locomoción en soldados de infantería, la composición corporal y el estado físico (ref. PIN 23/16). Investigador principal: Dr. D. Jose Mª Heredia Jiménez. Duración: enero a diciembre 2016. Financiación: 6.000€
- Laboratorio multidisciplinar para el análisis del movimiento y comportamiento humano en el campus de Ceuta "HUBEMA LAB" (ref. UNGR15-DE-3312). Investigador principal: Dr. D. Jose Mª Heredia Jiménez. Duración: enero a diciembre 2017. Financiación: 377.297,15€
- La carga fisica y estrés del combatiente: evaluación, análisis y prevención de lesiones por sobrecarga "FISIMEN" (ref. PIN 21/18). Investigador principal: Dr. D. Jose Mª Heredia Jiménez. Duración: abril 2018 a marzo 2019. Financiación: 6.500€

Participación proyectos de innovación docente

- Conexión entre la educación física de los centros escolares y las actividades didácticas planteadas en la asignatura de la mención de educación física. Plan FIDO UGR 2016-2018. Unidad de Calidad, Innovación y Prospectiva. Universidad de Granada. Curso académico 2017/2018.

Publicaciones científicas

- Heredia Jiménez, J., Tejada Medina, V., Ventaja Cruz, J., & Orantes González, E. (2015). Valoración de la grasa corporal: ultrasonidos frente a sistemas de bioimpedancia tetrapolar y antropometría. Estudio piloto. *Archivos de Medicina del Deporte,* 32(165), 20-24.
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- Ruiz-Zafra, A., Orantes-González, E., Noguera, M., Benghazi, K., & Heredia-Jimenez, J. (2015). A comparative study on the suitability of smartphones and IMU for mobile, unsupervised energy expenditure calculi. *Sensors*, *15*(8), 18270-18286.
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- Orantes-Gonzalez, E., Heredia-Jimenez, J., & Beneck, G. J. (2017). Children require less gait kinematic adaptations to pull a trolley than to carry a backpack. *Gait & posture*, *52*, 189-193.
- Orantes-Gonzalez, E., & Heredia-Jimenez, J. (2017). Pulling a school trolley: A good kinematic option for children. *Gait & posture*, *53*, 61-66.
- Orantes-González, E., & Heredia-Jiménez, J. (2016). Mochila y carro escolar: análisis cinemático usando distintas cargas. *Biomecánica*, 24, 7-13.
- Gil-Cosano, J.J., Orantes-Gonzalez, E., Heredia-Jimenez, J. (2018). Effect of carrying different military equipment during a fatigue test on shooting performance. *European Journal of Sport Sciences.* In press.
- Heredia-Jimenez, J. & Orantes-Gonzalez, E. (2018). Evaluation of a wearable 3d inertial measurement unit for countermovement jump height assessment. *Revista Brasileira de medicina do esporte*. Submitted to the journal.
- Orantes-González, E., & Heredia-Jiménez, J. (2018). Gait asymmetry and RPE: How are they influenced by carrying a backpack and pulling a trolley? *Work.* Submitted to the Journal.
- Orantes-Gonzalez, E., Heredia-Jimenez, J., Robinson, MA. (2018). A kinematic comparison of gait with a backpack versus a trolley for load carriage in children. *Gait & Posture.* Submitted to the Journal.

Capítulos de libro

- Ruiz-Zafra, Á., Gonzalez, E. O., Noguera, M., Benghazi, K., & Jiménez, J. M. H. (2014, December). Energy expenditure analysis: A comparative research of based on mobile accelerometers. En *International Workshop on Ambient Assisted Living* (pp. 38-45). Springer, Cham.
- Escabias, M., Aguilera, A. M., Heredia-Jiménez, J. M., & Orantes-González, E. (2017). Functional data analysis in kinematics of children going to school. In *Functional Statistics and Related Fields* (pp. 95-103). Springer, Cham.
- Orantes-González, E., Heredia-Jiménez, J., Benghazi, K., Noguera, M. (2018). Análisis de la interacción del equipo militar y el soldado de Infantería. En *Investigación e innovación en el ámbito universitario. Tendencias ante los retos actuales de la sociedad* (pp. 399-410). EOS, Madrid.

Comunicaciones y póster

- 11 comunicaciones libres presentadas en congresos internacionales.
- 4 comunicaciones libres presentadas en congresos nacionales.
- 5 póster presentados en congresos internacionales.
- 4 póster presentados en congresos nacionales o de otra índole.

Estancias de investigación

- University of Southern California. Division of Biokinesiology and Physical Therapy (Los Angeles, EEUU), año 2016. Duración de la estancia: 3 meses. Se encuentra en el puesto 49 a nivel Mundial según el ARWU-Shanghai 2016.

- University of Central Lancashire. Allied Health Research unit (Preston, Reino Unido), año 2018. Duración de la estancia: 3 meses.

Docencia impartida en Grado

- 18 créditos en el Grado de Ciencias del Deporte. Becaria FPU. Facultad de Ciencias del Deporte. Universidad de Granada.
- 7.97 créditos en el Grado de Ciencias de la Actividad Física y el Deporte. Facultad de Ciencias de la Educación. Universidad de Cádiz.

Otros méritos

- 1 comunicaciones presentadas como ponencias invitadas.
- 10 cursos/charlas/talleres prácticos impartidas en distintos organismos (colegios, empresas, congresos).
- 1.8 créditos impartidos en el Aula Permanente de Formación Abierta, con la asignatura: Calidad de vida, actividad física y nutrición.
- Más de 350 horas realizadas de cursos de formación para la mejora del desempeño docente e innovación.

Premios recibidos

- Mención al mejor expediente del Máster Universitario Oficial de Investigación en Actividad Física y Deporte de la Universidad de Granada.
- Premio a la mejor comunicación del Congreso de la Sociedad Ibérica de Biomecánica y Biomateriales. León, octubre 2016.
- Tercer Premio al proyecto "Efecto del peso de la mochila sobre parámetros biomecánicos de la locomoción en soldado de infantería y relación con fatiga, composición corporal y estado físico "WaR" en la I Jornada del Colegio Oficial de Enfermería de Granada.

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Annexes

17. ANNEXES

17.1 ANNEXE I: Informed consent and information for participants and parents.

Hoja de Consentimiento informado para el participante

PROYECTO "Efecto de la carga de la mochila sobre los parámetros de locomoción, dolor de espalda, variables biomédicas y psicosociales en escolares de primaria"

(Universidad de Granada)

Yo D/Dª…………………………………………………………………………………………..

con D.N.I. …………………………………como padre/madre/tutor legal de

D/Dª …………………………………………………….

DECLARO bajo mi juramento y responsabilidad:

- Que autorizo la participación de mi hijo/a o tutorizado en este estudio de forma libre y voluntaria.
- Que he sido informado de forma detallada de las pruebas que se van a realizar.
- Que he podido preguntar y aclarar todas las dudas acerca de las pruebas que se van a realizar y del estudio en general.
- Que puedo retirar al interesado del estudio en cualquier momento si lo deseo oportuno y sin tener que dar ninguna explicación.
- Que soy consciente y he sido informado de los posibles riesgos que conlleva la realización de las pruebas que se van a realizar.
- Que los datos obtenidos del estudio se me facilitarán para información personal y podré hacer preguntas y aclarar dudas sobre ellos.
- Que los datos obtenidos estarán protegidos y se garantiza la confidencialidad de los mismos sin que aparezca ninguna alusión que identifiquen al sujeto que las realiza en futuras publicaciones o explotación de los datos.

En Granada a ………………… de …………………… de 201_

Firma del responsable legal del participante: Firma del investigador responsable:

Fdo:………………… Fdo:………………………………

Efecto de la carga de la mochila sobre los parámetros de locomoción, dolor de espalda, variables biomédicas y psicosociales en escolares de primaria

¿Quién realiza este estudio?

Es un estudio financiado por el Ministerio de Educación, Cultura y Deporte y que lo realizan profesores e investigadores de la Universidad de Granada, del departamento de Educación Física y Deportiva.

OBJETIVO del estudio: se pretende analizar cómo afecta a los niños el peso que cada día tienen que transportar en su mochila a la locomoción, dolor de espalda y calidad de vida, para poder establecer recomendaciones saludables en cuanto al transporte de la mochila escolar.

¿Quién lo puede realizar?

Cualquier niño/a entre 6 y 14 años que no tenga problemas de salud que le impidan caminar con su mochila.

¿Tiene algún efecto negativo realizar este estudio?

NO. Este estudio no presenta ninguna consecuencia adversa para su hijo/a, ya que son pruebas muy sencillas que no suponen ningún riesgo para su salud. Además, la metodología del estudio está aprobada por el comité ético de la Universidad de Granada.

¿Qué ventajas tengo al realizar el estudio?

Los padres/madres que lo deseen podrán solicitar un informe de su hijo/a en el que aparecerán datos tan importantes como los de composición corporal (peso de su hijo, porcentaje de grasa que posee, porcentaje de masa muscular etc.), aspectos biomecánicos de la locomoción (cómo camina su hijo y recomendaciones sobre ello), recomendaciones para el transporte de la mochila, colocación correcta de la mochila, etc.…

¿Puedo retirarme cuando quiera?

Sí. Este estudio es totalmente voluntario y su hijo/a podrá retirarse cuando lo desee o no realizar las pruebas que considere.

¿Tiene algún coste?

Este estudio no tendrá ningún coste ya que se engloba dentro de un proyecto de investigación financiado por el ministerio y es totalmente gratuito para usted.

Confidencialidad y protección de los datos:

Los datos de su hijo/a nunca se harán públicos. Sólo tendrán fines científicos y los datos que se recojan estarán siempre codificados para garantizar la confidencialidad de su hijo/a. Nunca saldrán imágenes ni datos personales de su hijo/a.

Los datos de los sujetos estarán tratados según la Ley Orgánica 15/1999, de 13 de diciembre, de Protección de Datos de Carácter Personal.

¿Puedo estar presente mientras evaluan a mi hijo/a?

Sí, Usted puede estar presenta mientras su hijo/a está siendo evaluado, además estamos a su disposición para aclarar cualquier duda que surja.

¿Qué pruebas se van a realizar?

Todas las pruebas serán voluntarias. Si usted no quiere que su hijo/a realice alguna prueba concreta no importa, podrá seguir formando parte del estudio.

1) **Valoración de la composición corporal:**

Sus hijos serán pesados y medidos con una báscula y un tallímetro. También la mochila que normalmente llevan al colegio.

Después se realizará una prueba muy sencilla para determinar su composición corporal: Su hijo/a se pondrá descalzo y de pie en el aparato de la imagen durante sólo 10 segundos. El aparato calculará el porcentaje graso y magro, porcentaje de agua, porcentaje óseo de su hijo/a. Dicho aparato NO tiene ningún efecto adverso sobre su hijo/hija ni emite radiación alguna.

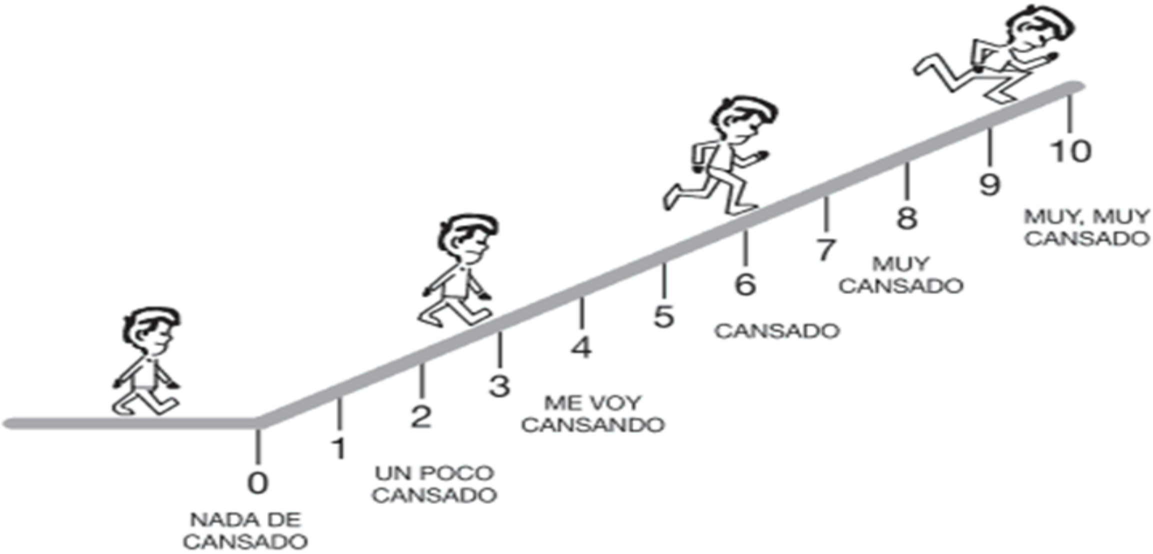
2) **Prueba de biomecánica de la locomoción:**

Se analizará la locomoción de su hijo/a cuando: camine sin mochila y cuando transporta en una mochila de dos asas el 10%, 15% y 20% del peso corporal de su hijo/a.

Esto será evaluado usando 8 cámaras de video que van a capturar la trayectoria de unos marcadores reflectantes que se colocan sobre el niño/a (ver ejemplo de esos marcadores en la imagen de la derecha). Esto permitirá realizar un análisis tridimensional posteriormente.

Por último, su hijo/a cumplimentará 3 sencillos y cortos cuestionarios sobre hábitos de desplazamiento al colegio y percepción subjetiva de fatiga y peso tras cargar con su mochila o carro escolar.

17.2 ANNEXE II: Children´s OMNI Scale of Perceived Exertion for walking/running.



17.3 ANNEXE III: Survey for mode and frequency of commuting to and from school.

Modo y frecuencia de desplazamiento hacia y desde el colegio

Nombre: ____________________ Apellidos: ____

Fecha de nacimiento : ______________________________ Teléfono: ____________________

Dirección completa: calle ____número: _____

localidad (provincia): _________________________código postal: ___________

Tu eres... ☐ Chico ☐ Chica Correo electrónico: ______________________________

Colegio: ____ Curso y grupo: _______________

¿Cómo vas habitualmente al colegio? ☐ ☐ ☐ ☐ ☐ ☐ ☐ _Otro, escríbelo_

¿Cómo vuelves habitualmente del colegio? ☐ ☐ ☐ ☐ ☐ ☐ ☐ _Otro, escríbelo_

Piensa en la última semana que has tenido clase y contesta estas preguntas

¿Cómo FUISTE al colegio cada día? Fecha de hoy: _______________

	Lunes	Martes	Miércoles	Jueves	Viernes
Andando	☐	☐	☐	☐	☐
En bici	☐	☐	☐	☐	☐
En coche	☐	☐	☐	☐	☐
En moto	☐	☐	☐	☐	☐
En autobús	☐	☐	☐	☐	☐
En metro/ tren/tranvía	☐	☐	☐	☐	☐
Otros	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_

Si señalas más de un modo de desplazamiento al día, indica al lado de cada uno el tiempo en minutos.

¿Cómo VOLVISTE del colegio a casa cada día?

	Lunes	Martes	Miércoles	Jueves	Viernes
Andando	☐	☐	☐	☐	☐
En bici	☐	☐	☐	☐	☐
En coche	☐	☐	☐	☐	☐
En moto	☐	☐	☐	☐	☐
En autobús	☐	☐	☐	☐	☐
En metro/ tren/tranvía	☐	☐	☐	☐	☐
Otros	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_	☐ _Escríbelo aquí_

Si señalas más de un modo de desplazamiento al día, indica al lado de cada uno el tiempo en minutos.

¡Gracias por tu colaboración!

17.4 ANNEXE IV: Questions about type of school bag, subjective opinion about the weight and fatigue carrying the school bag and prevalence of back pain related with school bag carriage.

CUESTIONARIO GENERAL Y BIOMÉDICO		
CÓDIGO:	Nombre y apellidos:	
Fecha de Nacimiento:	Curso Escolar:	Peso de la mochila/carro:
Nombre del colegio:		

• ¿Qué tipo de mochila sueles llevar normalmente?: ☐ Mochila con dos asas ☐ Tipo carrito ☐ Otro: ________	• ¿Cómo la sueles llevar normalmente?: ☐ Colgada sobre los dos hombros ☐ Colgada solo de un hombro ☐ En la mano • Si es carrito: Empujando ☐ Tirando ☐
• ¿Llevas tú la mochila o carro al colegio? ☐ Si, siempre ☐ Algunas veces ☐ No, nunca	• ¿Crees que tu mochila o carro es demasiado pesado? ☐ Si, siempre ☐ Algunas veces ☐ No, nunca
• ¿Te sientes cansado cuando llevas tu mochila o carro? ☐ Si, siempre ☐ Algunas veces ☐ No, nunca	
• Durante los últimos 6 meses, ¿Sueles tener dolor de espalda mientras usas la mochila o el carro escolar o justo después de usarla? ☐ Sí ☐ No	