



Article

Changes in Plantar Pressure While Running with a Jogging Stroller

Christoph Mickel ^{1,*}, Antonia Baltrusch ¹, Fabian Holzgreve ¹, Laura Maltry ¹, Hagen Hartmann ¹, Michael Keiner ² and Klaus Wirth ³

¹ Department of Human Movement Science and Athletic Training, Institute of Sports Sciences, Goethe University, 60487 Frankfurt am Main, Germany; antonia-baltrusch@gmx.de (A.B.); fabian.holzgreve@outlook.com (F.H.); laura.maltry@web.de (L.M.); hagen-hartmann@online.de (H.H.)

² Swimming Federation of the State Lower Saxony, 30169 Hannover, Germany; michael.keiner@landesschwimmverband-niedersachsen.de

³ Department of Sport and Exercise Sciences, University of Applied Sciences Wiener Neustadt, 2700 Wiener Neustadt, Austria; k.wirth@fhwn.ac.at

* Correspondence: c.mickel@sport.uni-frankfurt.de; Tel.: +49-69-798-24533

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Abstract: Despite the common use of jogging strollers, only a few studies cover their influence on running patterns. Kinematic studies have shown differences in the upper body movement, while potential changes in plantar pressure remain unclear. Therefore, 30 healthy sport students were asked to run at a self-selected speed with and without a jogging stroller on a treadmill. Via bilateral insole pressure measurements, the plantar pressure distribution and the stride length were quantified. A significantly decreased pressure for running with a jogging stroller was found in the forefoot, metatarsus, inner edge, outer edge and for the total pressure of the left foot. The right foot showed similar significances for all foot areas except the metatarsus. Stride length was significantly shorter when running with a jogging stroller. As stride length and plantar pressure are known to correlate, the reduced stride length in running with a jogging stroller can partially explain the measured decrease in plantar pressure. Further, the partial weight-bearing, which is needed to keep the jogging stroller in line, can also contribute to the decrease in plantar pressure. Moreover, the unilateral weight-bearing enlarges the base of support and could also be a reason for the decrease in plantar pressure. In conclusion, our results show statistically significant changes in plantar pressure, but these are not of clinical importance as the effect sizes are very low. Therefore, no specific training recommendations for running with a stroller have to be made.

Keywords: plantar pressure; jogging stroller; running

1. Introduction

Running is a modern sport. It requires little equipment and can easily be integrated into everyday life. Therefore unsurprisingly, parents have also discovered running as a leisure sport which has led to the development of jogging strollers to enable a combination of child care and running. Although such strollers are a common sight in parks and city centers, differences in biomechanics while running with one may be expected, but only very few studies on the topic exist [1–5]. Most available studies have examined physiological parameters (e.g., heart rate or oxygen uptake), explaining the rise in self-reported exertion [1–4]. Information on kinematic changes is sparse and partly contradictory. It has been described that the use of a stroller induces adaptations in stride length and cadence, while others did not find any changes. Brown [1] reported shortened stride lengths and therefore an increase in cadence (running speed was not significantly altered, but the number of steps (measured

via pedometer) and step length (measurement is not described in the publication) were), but neither Smith [2] nor O'Sullivan and Kieran [5] could confirm these results. The latter recently published complementary kinematic data. Via 3D movement analysis, a decline in trunk rotation in the sagittal plane, which had to be expected as at least one arm is fixed while running with a stroller, has been shown [5]. Moreover, they have reported an increase in the forward lean of the trunk, in pelvic tilt and in hip flexion at initial contact as well as a limited hip extension. Nevertheless, they did not find significant changes in knee or ankle joint movements. The authors postulated that this is due to a forward shift of the center of pressure (COP), which is needed to set the stroller in motion [5].

Because of the limited number of studies on running with a stroller, we have also looked for similar tasks. Even though the movement speed is slower, walking with a walker seems to be the best approximation. Obviously, the elderly tend to use their walker for partial weight-bearing while runners can be expected to almost exclusively push the stroller. Nevertheless, there are still some similarities: The movement of the upper limb(s) is limited, which reduces trunk rotation, and the device has to be moved forward. Studies analyzing walker-assisted walking have reported altered movement patterns. Alkjaer [6] found partly unloaded ankle and knee joints due to reduced knee extension and plantar flexion. These findings agree with a significant reduction in lower-limb muscle activity [7]. This effect was stronger if weight-bearing was increased. As the trunk sway remained unchanged, it was concluded that stability was gained through forces of the upper limbs [7]. This matches Ishikura's findings [8], which show the weight-bearing force being determined by the flexion angle of the hip joint. Given that O' Sullivan and Kieran [5] also showed an increase in hip flexion for running with a stroller, the similarities in movement patterns become obvious.

In total, our literature search revealed that, despite the existing studies on physiological and kinematic changes, kinetic data on running with a stroller has not yet been reported to our knowledge. O' Sullivan and Kiernan [5] only refer to movement analysis data when concluding that the decline in rotation and the additional weight of the stroller is completely compensated for by the trunk and the pelvis. Whether this further influences the loading of the joints in the lower extremities is still an open question. As studies on walker-assisted walking have indicated a reduction in plantar pressure, valid data for running with a stroller is missing. Since our study is the first of its kind, we have decided to account for its explorative nature by choosing an open hypothesis: The plantar pressure shows significant differences between running with a stroller and normal running at the same, self-selected running speed.

2. Materials and Methods

2.1. Participants

Fifteen male and 15 female healthy physical education students (experienced recreational runners) (age (in years) 24.9 ± 2.40 ; height (in cm) 174 ± 8 ; weight (in kg) 68.16 ± 9.85) volunteered to participate in the study. All participants gave informed written consent and the study was approved by the institutional review board. Further, volunteers were only allowed to participate if they had not had any injury of the lower extremities in the last six months. Prior to data collection, all participants completed a self-made anamnesis questionnaire which amongst others assessed running experience in general, on a treadmill, and with a stroller. All of them reported to be recreational runners, but none of them had experience in running on a treadmill, which is why we included a habituation period, and with a stroller. Furthermore, they were asked if orthopedic aids (e.g., specific, orthopedic insoles) have usually been used while running (=one participant).

2.2. Bilateral Insole Pressure Measurement

In order to measure changes in pressure distribution on the plantar surface while running with the jogging stroller we used a bilateral insole measurement system (T&T Medilogic, Schönefeld, Germany). The company amounts the measurement error with $\pm 1\%$. Insoles were provided in different shoe

sizes. In order to maintain running comfort, these were positioned above (individual sports specific) insoles if in use. Each insole includes 64 pressure sensors which empower the system to calculate mean pressure results for five foot areas and the whole foot (forefoot, metatarsus, heel, inner edge, outer edge and total; see Figure 1). Furthermore, the double stride length was obtained in order to calculate changes in cadence while running with and without the jogging stroller.

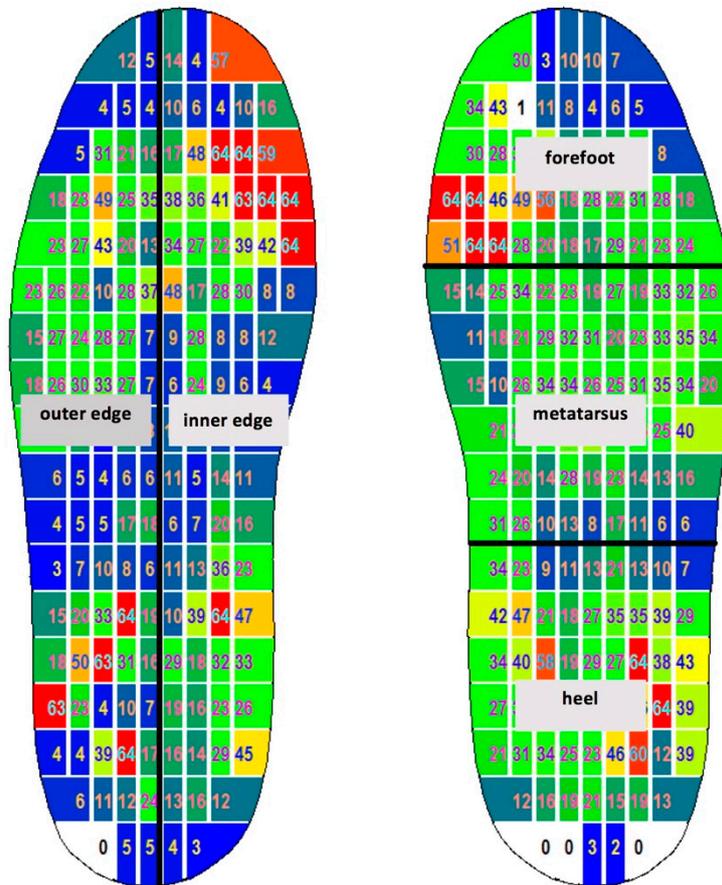


Figure 1. Schematic presentation of the five foot areas of the used pressure-sensitive insoles.

2.3. Procedures

After the pressure-sensitive insoles had been positioned and calibrated in the running shoes of the participant, she or he was asked to warm up running on the treadmill (Woodway, ProXL, Weil am Rhein, Germany) for 7.5 min without and another 7.5 min with the jogging stroller (Naturkind, Varius Pro, Engerwitzdorf, Austria). Meanwhile, self-selected running of the participant was determined by asking them to “select a running speed for a comfortable 30 min run”. Average running speed was determined to be 8 ± 1.37 km/h. Following this familiarization period and a pause of approximately 1 min, the first condition was tested. Again, followed by a pause of approximately 1 min, the second condition was tested. The order of conditions was randomized (—participant A’s first condition was without the stroller, followed by the second condition with the stroller; for participant B the conditions order was reversed and so forth). In each condition, participants ran for five consecutive minutes at their self-selected running speed. Plantar pressure was measured for 30 s starting after 3 to 3.5 min. In the “with stroller” condition, participants were further asked to push the stroller with their right hand continuously. To account for an infant’s weight a 10 kg barbell disc was put in the jogging stroller. After each data acquisition, participants were asked to rate their level of effort via a 6–20 Borg scale to get a superficial overview to their perceived fatigueability [9]. Figure 2 shows the experimental set-up with one participant pushing the stroller.

Statistical analysis was performed using SPSS 15.0 (SPSS Inc., Chicago, IL, USA) and Excel (2010; Microsoft, Santa Clara Valley, CA, USA). Data was tested for normal distribution via the Kolmogorov-Smirnov test. As this test revealed significant results, the non-parametric equivalent of the paired *t*-test, the Wilcoxon test, was used to test for significant differences in the parameters between the two conditions. Furthermore, the Spearman test was performed to test if the changes in plantar pressure correlate with stride length. For all statistical procedures, the level of significance was set a priori to $p < 0.05$.



Figure 2. Photo of one subject running on the treadmill pushing the stroller.

3. Results

The distribution of plantar pressure of the right and left foot compared between the two conditions without the stroller and with the stroller are shown in Figures 3 and 4, respectively. Next to the total pressure of the whole foot, data included a differentiation between the forefoot, metatarsus, heel, inner and outer edge. Statistical analysis revealed significant differences in plantar pressure between the “no stroller” (=NS) and “with stroller” (=WS) conditions in the right and left foot.

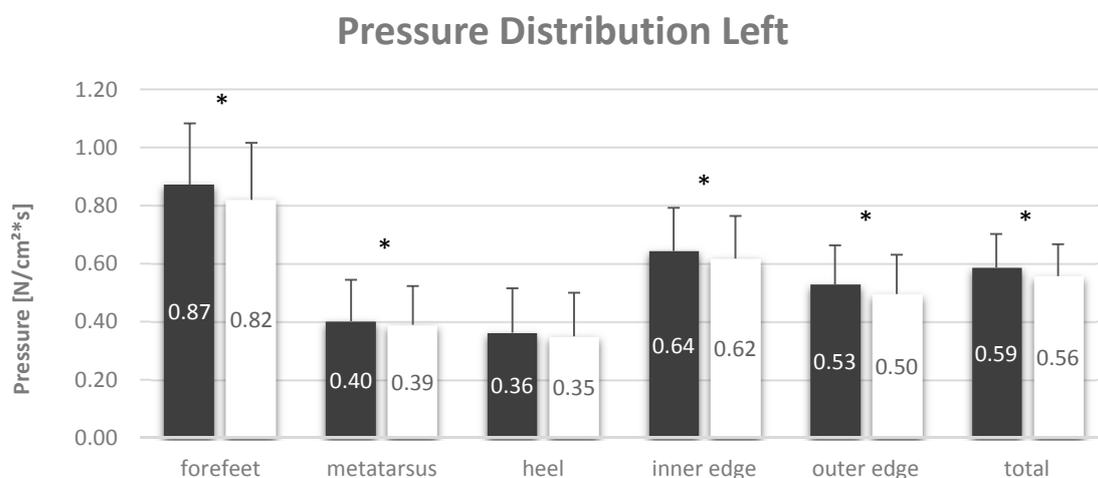


Figure 3. Pressure distribution of the left foot. * indicates statistically significant differences. Black boxes for the without stroller (=NS) and white boxes for with stroller (=WS) conditions.

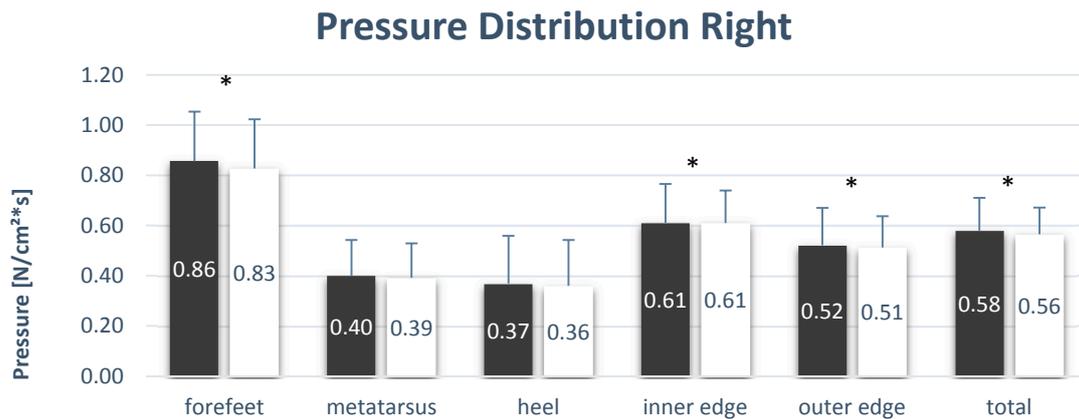


Figure 4. Pressure distribution of the right foot. * indicates statistically significant differences. Black boxes for the without stroller (=NS) and white boxes for with stroller (=WS) conditions.

With regard to the right foot, significantly decreased pressure was found in the condition with the stroller compared to the condition without the stroller for the forefoot ($0.856 \text{ N/cm}^2\cdot\text{s} \pm 0.198$ vs. $0.827 \pm 0.196 \text{ N/cm}^2\cdot\text{s}$; $p = 0.01$; $d_{\text{Cohen}} = 0.147$), outer edge ($0.52 \pm 0.135 \text{ N/cm}^2\cdot\text{s}$ vs. $0.512 \pm 0.135 \text{ N/cm}^2\cdot\text{s}$; $p = 0.01$; $d_{\text{Cohen}} = 0.059$), inner edge ($0.61 \pm 0.155 \text{ N/cm}^2\cdot\text{s}$ vs. $0.60 \pm 0.130 \text{ N/cm}^2\cdot\text{s}$; $p = 0.03$; $d_{\text{Cohen}} = 0.07$) and total pressure ($0.58 \pm 0.114 \text{ N/cm}^2\cdot\text{s}$ vs. $0.565 \pm 0.106 \text{ N/cm}^2\cdot\text{s}$; $p = 0.01$; $d_{\text{Cohen}} = 0.136$), but not for the heel ($0.37 \pm 0.189 \text{ N/cm}^2\cdot\text{s}$ vs. $0.36 \pm 0.183 \text{ N/cm}^2\cdot\text{s}$; $p = 0.27$; $d_{\text{Cohen}} = 0.054$) and metatarsus ($0.40 \pm 0.143 \text{ N/cm}^2\cdot\text{s}$ vs. $0.39 \pm 0.139 \text{ N/cm}^2\cdot\text{s}$; $p = 0.07$; $d_{\text{Cohen}} = 0.071$). The plantar pressure distributions of the left foot also showed significant decreases for the forefoot ($0.872 \pm 0.211 \text{ N/cm}^2\cdot\text{s}$ vs. $0.820 \pm 0.196 \text{ N/cm}^2\cdot\text{s}$; $p = 0.00$; $d_{\text{Cohen}} = 0.255$), inner edge ($0.643 \pm 0.149 \text{ N/cm}^2\cdot\text{s}$ vs. $0.617 \pm 0.147 \text{ N/cm}^2\cdot\text{s}$; $p = 0.01$; $d_{\text{Cohen}} = 0.176$), outer edge ($0.528 \pm 0.149 \text{ N/cm}^2\cdot\text{s}$ vs. $0.495 \pm 0.125 \text{ N/cm}^2\cdot\text{s}$; $p = 0.00$; $d_{\text{Cohen}} = 0.24$), total pressure ($0.586 \pm 0.116 \text{ N/cm}^2\cdot\text{s}$ vs. $0.557 \pm 0.110 \text{ N/cm}^2\cdot\text{s}$; $p = 0.00$; $d_{\text{Cohen}} = 0.257$), and metatarsus ($0.402 \pm 0.142 \text{ N/cm}^2\cdot\text{s}$ vs. $0.389 \pm 0.134 \text{ N/cm}^2\cdot\text{s}$; $p = 0.027$; $d_{\text{Cohen}} = 0.094$), but not for the heel ($0.643 \pm 0.149 \text{ N/cm}^2\cdot\text{s}$ vs. $0.617 \pm 0.147 \text{ N/cm}^2\cdot\text{s}$; $p = 0.28$; $d_{\text{Cohen}} = 0.176$). Furthermore, the double-step length was significantly reduced in the “with stroller” condition compared to without the stroller ($1.691 \pm 0.29 \text{ m}$ vs. $1.665 \pm 0.27 \text{ m}$; $p = 0.01$; $d_{\text{Cohen}} = 0.093$) (see Figure 5).

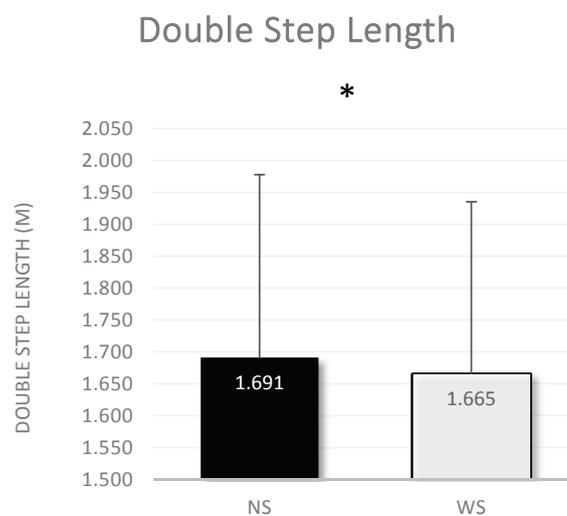


Figure 5. Double-step length for the without stroller (=NS) and with stroller (=WS) conditions. * indicates statistically significant differences.

The Spearman test revealed no correlation between the decrease in plantar pressure and the stride length for the left and right foot (0.2906 and 0.0219) (see Figure 6).

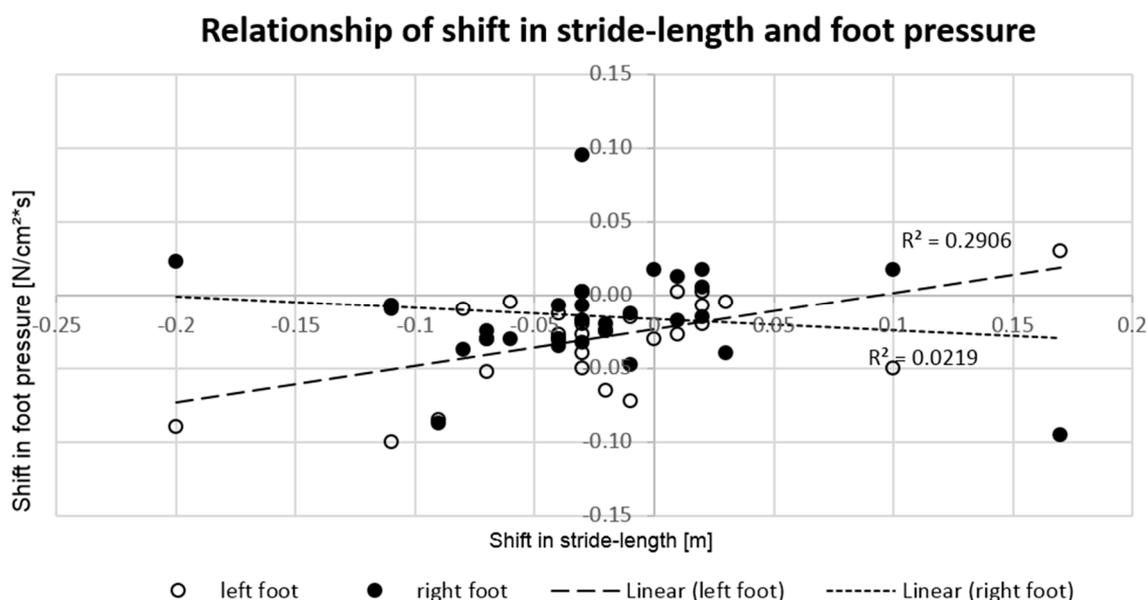


Figure 6. Relationship of the shift of running with and without a jogging stroller in stride length and foot pressure in the left and right foot. The correlation for the left foot is 0.29 and 0.022 for the right foot.

4. Discussion

As stated previously, there has been no study—to our knowledge—which had determined changes in plantar pressure when running with a stroller. Before we discuss our findings, we want to describe the limitations of our study. (1) The tests were carried out on a treadmill. As several studies have shown, treadmill walking [10] and running [11,12] are not identical to the normal over ground situation. We still decided to use a treadmill, as it offers the possibility to set the running speed. Therefore, only the combination of cadence and step length may be altered if subjects do not move forward or backward on the treadmill, which was controlled for in the tests; (2) The time of data collection was limited to 30 s as the measurement devices used do not support longer time periods.

Our results show significantly lower total plantar pressure for both left and right feet, with larger decreases for the left feet. Moreover, stride length was significantly reduced while running with a jogging stroller. As the literature reveals, several studies have suggested an inverse relationship between the stride frequency, center of mass (COM) vertical excursion and ground reaction force (GRF), respectively [13–15]. Schubert and Kempf [13] published a systematic review on the influence of stride frequency and length on running mechanics, in which they reported a significantly inverse relationship of reduced peak vertical GRF and COM vertical excursion when the cadence was increased while running over ground as well as on a treadmill. Thompson and Gutman [14] were able to show a significant main effect of stride length on the anterior-posterior and vertical GRFs during running over ground. Moreover, Heiderscheit and Chumanov [15] reported similar results for running on a treadmill concerning the inversely related COM to the stride length. Furthermore, statistically significant lower peak pressure for the heel, toes and midfoot have been reported [16,17]. However, even though a correlation between a decrease in stride length and total foot pressure could have been expected, it is very low to non-existent (see Figure 6) in our data. Therefore, we conclude that there must be other influences besides a reduction in step length which result in the decrease of plantar pressure when running with a stroller.

Batani and Maki [18] published a systematic review on assistive devices for balance and mobility in which the authors have highlighted the changes induced through the assistive devices on the COM

and the base of support (BOS). The use of a crutch or cane on the contralateral side of an injured leg, for example, leads to a forward shift of COM, an increase in BOS and—as this is the purpose of using an assistive device in the first place—a reduction in plantar pressure of the injured leg. Obviously, a stroller cannot be regarded as an assistive device for balance and mobility, but the effects seem to be similar. However, in our study the participants also had to keep the stroller in a straight line. Therefore, a certain amount of pressure on the handlebar had to be applied, which explains self-reports of having to increase the activation of muscles of the right shoulder. Further, we observed a forward shift of the trunk towards the handlebar.

Moreover, Ishikura [8] reported a correlation between weight-bearing and hip joint flexion angles and O’Sullivan and Kieran [5] found an increase in hip flexion at initial contact, in pelvic tilt and in forward lean of the trunk when running with a stroller. This does not necessarily mean that these changes in kinematics induced the reduction in plantar pressure through weight-bearing, but it may be part of the explanation.

In total, our results show statistically significant changes in plantar pressure, but we do not think these are of clinical importance as the effect sizes are very low. Therefore, no specific training recommendations for running with a stroller have to be made.

We suggest for future studies to measure the force applied on the handlebar of the stroller and to determine the alterations in hip flexion, as this data might offer further insight into the underlying mechanisms of the presented alterations.

Author Contributions: All of the authors (Christoph Mickel, Antonia Baltrusch, Fabian Holzgreve, Laura Maltry, Hagen Hartmann, Michael Keiner and Klaus Wirth) worked together for research design, data analysis, and writing the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

WS	with jogging stroller
NS	no jogging stroller
COM	center of mass
GRF	ground reaction force
BOS	base of support

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