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TITLE

Changes in joint kinematics and dynamic postural stability with free and restricted arm movements in children

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Arm restriction and dynamic balance in children

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ABSTRACT

Background **A**rm movements make a substantial and functionally relevant contribution to quiet standing and dynamic balance tasks. The impact of restricted arm movements on balance control is particularly important for children as their postural control system is not fully matured, and many fundamental motor skills are still emerging. **Research question** This study investigated the effects of arm movements on lower body joint kinematics and dynamic postural stability during anterior and lateral dynamic movements in children. ***Methods*** Eighteen boys (age, 10.1 ± 1.6 years) completed an anterior and a lateral jump-landing task under two different verbally conveyed instructions of arm position; (1) arms placed flat across the chest touching the contralateral shoulder (i.e., restricted arm movement) and (2) arm movement without restriction. Lower body joint kinematics were recorded and used to calculate mean joint position, joint range of motion (ROM) and joint movement variability. ***Results*** Restricting arm movements resulted in a reduction of joint movement variability and joint ROM of the pelvis during the lateral jump ($p < 0.05$), but increased joint movement variability and joint ROM of the pelvis during the anterior jump ($p < 0.05$). ***Significance*** The reduced joint movement variability and joint ROM

with restricted arm movements during the lateral jump may represent a potential compensatory 'stiffening strategy', whilst the increase during the anterior jump suggest an exploratory strategy. These novel findings highlight that it is important for children to be introduced to different dynamic task constraints so that they can learn to control and organise the motor system degrees of freedom appropriately.

1. INTRODUCTION

It is well established that arm movements play an important role in recovery responses after unexpected perturbations of upright stance [1,2] and gait [3-5] in adults. There is also emerging evidence that arm movements make a substantial and functionally relevant contribution to quiet standing [6,7] and dynamic balance [6,8-11] tasks. The potential impact of restricted arm movements on balance control are particularly important for children as their postural control system is not fully matured. For example, refinement of postural control continues to develop throughout childhood, with adult-like postural control not observed until 12 years of age [12]. As most daily activities are dynamic in nature, it is important to investigate the potentially important role the arms may play in dynamic conditions that are essential for everyday life.

Despite the compelling evidence of a degradation in postural stability with restricted arm movements in adults [6-11], the potential contribution of arm movements to dynamic balance in children is poorly understood. This is in part due to an age bias of studying more adults than children in the literature. To our knowledge, only one experimental study has compared balance performance during free and restricted arm conditions in children. Hill et al. [9] found that restricted arm movements elicited a reduction in the performance of the Y balance test and a slower balance beam walking speed. In contrast, the ability to transition from a dynamic to a static state (i.e. dynamic postural stability index [DPSI]) following an anterior jump, was not altered with restricted arm movement [9]. These findings are surprising given that children take advantage of the action of the arms during jumps [13]. Although the study by Hill et al. [9] provides an initial first step to elucidate the role of arm movement on dynamic postural control in children, the tests employed were limited in their ability to discern different postural strategies and movement patterns related to optimal movement. Indeed, the authors hypothesised that the null effects of arm restriction on the anterior DPSI might have been a result of ankle, knee and hip postural strategies absorbing the vertical force from contact to stabilization of the vertical displacement of the centre of mass during landing. In light of these initial findings, it would seem sensible to further explore the effects of arm movements on balance control in order to move towards a better understanding of the role of the upper body on dynamic postural stability in children. Including measures which are more sensitive to subtle changes in movement, such as ankle, knee and hip joint kinematics, may provide a better understanding of the adaptive responses in lower limb postural control strategies with restricted arm movements.

Postural mechanisms controlling frontal plane dynamic balance reach maturity later than the mechanisms involved in controlling the sagittal plane [14] and restriction of arm movements affects stability in the mediolateral direction [6-9]. Thus, to ascertain the directional impact of restricted arm movements on dynamic movement control in children, it is necessary to address the limitations of prior work and expand the analysis to frontal and sagittal plane movements. For this purpose, we measured lower limb joint kinematics during an anterior and lateral jump with free and restricted arm movements in children. It was hypothesised that arm restriction would impact on lateral, but not anterior dynamic postural stability.

2. METHODS

2.1 Participants

Eighteen boys (age, 10.1 ± 1.6 years; height, 1.45 ± 0.11 m; mass, 26.7 ± 7.83 kg) who were regularly engaged in grassroots soccer participated in the study following institutional ethics approval, informed parental consent and child assent, in line with the Declaration of Helsinki (1964). Participants were recruited from their primary schools in the city of Coventry, United Kingdom. All parents completed a health screen questionnaire prior to participation. This requested information relating to any physical, cognitive or other issues that may prevent participation in physical activity. Exclusion criteria included chronic disease (e.g., diabetes), injuries, muscular deficits, cardiovascular impairments or if they were diagnosed with any form of developmental disorder likely to influence motor performance (i.e., developmental coordination disorder, dyspraxia, dyslexia, Asperger's syndrome, and autism). The pre-screening questionnaire was also used to confirm that children had normal vision and no auditory impairments which may affect their balance.

2.2 Design

Participants completed dynamic postural tasks of varying difficulty under two different verbally conveyed instructions of arm position; (1) arms placed flat across the chest touching the contralateral shoulder (i.e., restricted arm movement) and (2) arm movement without restriction (i.e., free arm movement). The order of arm conditions was randomised. The two dynamic postural tasks were an anterior and a lateral jump-landing task, in accordance with the method highlighted by Sell [15], where the participant landed on the dominant limb. To ensure familiarisation and reduce potential learning effects, each participant completed three practice trials for each test condition (i.e. arms vs. no-arms). For the free arm movement, participants were instructed to be able to move their arms without restrictions during the tasks. For the restricted arm position, compliance to the instructions was monitored visually by the investigators.

2.3 Kinematic Analyses

A twelve camera 3D motion analysis system (Vicon – Vantage 5, Oxford Metrics Group, Oxford, United Kingdom), synchronized with four 40x60cm force platforms (Kistler – 9281E, Switzerland), was used to collect movement data. Vicon Nexus 2.8 software controlled simultaneous collection of motion and force data at 200 Hz and 1000 Hz, respectively and the motion data were filtered using a fourth order Butterworth filter with a cut-off frequency of 10Hz. Anthropometric measurements were taken for the lower body PlugInGait model (Vicon, Oxford, United Kingdom) including the length of each leg (anterior superior iliac spine to medial malleolus), each knee width and each ankle width. Reflective markers were placed using the VICON PlugInGait lower-body marker set and then a static anatomical calibration trial was collected on each participant, and any subsequent movement away from this static anatomical position in dynamic trials was the relative amount of joint movement for the participant. Joint angles were calculated for the first 3 seconds following initial contact, defined as the instant the vertical ground reaction force exceeded 15 N. Joint angles were calculated using VICON PlugInGait where positive angles in the sagittal plane indicated that the pelvis was tilted forwards, hip was flexed, the knee was flexed, and the ankle was dorsiflexed. Positive angles in the frontal plane indicated that the pelvis had upward obliquity, hip was adducted, the knee was adducted (varus), and the ankle was inverted. Positive angles in the transverse plane indicated internal rotation of the pelvis, hip, knee and ankle. The mean average joint angle over the entire 3 seconds post landing were calculated for each joint movement, along with the standard deviation across the entire 3 seconds which was defined as the joint movement variability during landing. Minimum and maximum angles during the landing were also calculated for each joint movement. The range of motion (ROM) was calculated as the difference between the minimum and maximum joint angles for each joint movement.

2.4 Dynamic Postural Stability Index

Dynamic postural stability index (DPSI) was assessed using an anterior and lateral jump-landing task (in that order) on the dominant limb [15]. Foot dominance was defined as the foot used to kick a ball. DPSI is a unitless composite score of anteroposterior (y), mediolateral (x) and vertical (z) ground reaction forces (GRF) with a higher

DPSI indicating poorer postural control [15]. Participants were instructed to stand on two legs at distance of 40% of their body height from the centre of the force platform (AMTI, AccuGait, Watertown, MA). Each participant was instructed to jump forward (anterior jump) or to the right (lateral jump) over a 6-inch hurdle on to the force platform and land on their dominant limb, stabilise as quickly as possible and, balance for 10 s. Each participant completed a minimum of three practice attempts. Data were sampled at 1000 Hz (AMTI, Netforce, Watertown, MA) and data were passed through a 4th order low pass Butterworth filter with a 20 Hz cut-off frequency. DPSI was calculated using the first 3 seconds of the ground reaction forces following initial contact, defined as the instant the vertical ground reaction force exceeded 15 N (equation below). An average DPSI from the three trials in each condition was used for further analysis.

$$\boldsymbol{DPSI} = \left(\sqrt{\frac{\sum(\boldsymbol{GRFx})^2 + \sum(\boldsymbol{GRFy})^2 + \sum(\boldsymbol{body\ weight} - \boldsymbol{GRFz})^2}{\boldsymbol{number\ of\ data\ points}}}\right)$$

2.5 Statistical Analyses

Separate two-way analysis of variance (ANOVA) with repeated measures on both factors (e.g. *jump direction*; anterior vs. lateral × *arm condition*; free vs. restricted) were conducted to determine differences in dynamic balance and joint kinematics between free arm and restricted arm movements. The standing and counter leg outcomes were analysed separately. For all analyses, normality (Shapiro–Wilk Test) and homogeneity of variance/sphericity (Mauchly Test) were confided prior to undertaking parametric analyses. Post-hoc analyses with the Bonferroni-adjusted α for multiple comparisons were conducted to follow up significant effects. Data were also analysed for practical meaningfulness using magnitude-based inferences. For ANOVA's, effect sizes are reported as partial eta-squared value (η^2) where appropriate. Cohen's *d* effect sizes are reported for pairwise comparisons and were interpreted using thresholds of $\leq$0.2 (trivial), 0.2 (small), 0.6 (moderate), 1.2 (large), and 2.0 (very large). All values are expressed as mean ±SD. Data were analysed using SPSS version 25.0 (IBM Inc., Chicago, IL). The alpha value was a priori set at $p \leq 0.05$. Cohen's *d* effect sizes (ES) were calculated from similar studies from mean changes in postural sway [6] and Y balance reach distance [9]. Sample size was estimated using an *a priori* power analysis (G* Power software [Version 3.1.9.4] [16]) for Y balance reach distance (i.e. the variable with the smallest effect size) using the following parameters (power=0.80, alpha=0.05, effect size=0.83). The analysis revealed a sample size of 17.

3. RESULTS

3.1 Dynamic postural stability

A 2 (jump direction) × 2 (arm condition) way repeated measures ANOVA revealed no significant interactive ($F_{(1,17)}$=1.285, *p*=.273, η_p^2=0.70) or main effect of arm condition ($F_{(1,17)}$=0.096, *p*=.760, η_p^2=0.006) on the DPSI. However, the analysis did reveal a main effect of direction ($F_{(1,17)}$=50.915, *p*<.001, η_p^2=.750) (Figure 1). Follow-up *post-hoc* analyses revealed a significant and large magnitude difference between anterior and lateral DPSI when the arms were restricted (*p*<.001, ES=1.20) or used freely (*p*<.001, ES=1.00). For both arm conditions, the DPSI was greater for the anterior compared to the lateral direction.

***** FIGURE 1 ABOUT HERE ******

3.2 Joint kinematics

3.2.1 Average position

Significant arm condition × jump direction interactions were observed for counter knee joint flexion ($F_{(1,17)}$=9.184, *p*=.011, η_p^2=.325) and standing hip joint adduction ($F_{(1,17)}$=8.389, *p*=.040, η_p^2=.330) (Table 1). For the lateral jump, follow up *post hoc* analysis of the counter knee joint revealed that it was more flexed during the free versus restricted arm condition (*p*=.028, ES= –0.47). For the anterior jump, *post hoc* analysis of the standing hip joint revealed that it was less abducted during the free versus restricted arm condition (*p*=.004, ES=0.37).

***** TABLE 1 ABOUT HERE ******

3.2.2 Joint movement variability

Statistically significant arm condition × jump direction interactions were observed for counter ($F_{(1,17)}$=5.328, *p*=.034, η_p^2=.239) and standing ($F_{(1,17)}$=6.263, *p*=.023, η_p^2=.269) pelvis tilt and counter ($F_{(1,17)}$=5.749, *p*=.028, η_p^2=.253) and standing ($F_{(1,17)}$=7.285, *p*=.015, η_p^2=.300) pelvis obliquity (Table 2). For the lateral jump, *post hoc* analysis of the counter (*p*=.045, ES= –1.33) and standing (*p*=.044, ES= –0.75) pelvis obliquity revealed greater joint movement variability during the free versus restricted arm movement condition. For the anterior jump, *post hoc* analysis of the counter (*p*=.036, ES=0.36) and standing (*p*=.047, ES=0.33) pelvis tilt revealed greater joint movement variability during restricted versus free arm conditions (Figure 2).

***** TABLE 2 ABOUT HERE ******

3.2.3 Range of motion

Statistically significant arm condition × jump direction interactions were observed for counter ($F_{(1,17)}$=5.087, p=.038, η_p^2=.230) and standing ($F_{(1,17)}$=5.677, p=.029, η_p^2=.250) pelvis tilt and counter ($F_{(1,17)}$=9.049, p=.008, η_p^2=.347) and standing ($F_{(1,17)}$=10.839, p=0.004, η_p^2=.389) pelvis obliquity (Table 3). For the lateral jump, *post hoc* analysis of the counter (p=.021, ES= –0.77) and standing (p=.021, ES= –0.80) pelvis obliquity revealed greater ROM during the free versus restricted arm movement condition. For the anterior jump, *post hoc* analysis of the counter (p=.048, ES=0.33) and standing (p=.042, ES=0.30) pelvis tilt revealed greater ROM during restricted versus free arm conditions (Figure 2).

***** TABLE 3 ABOUT HERE ******

***** FIGURE 2 ABOUT HERE ******

4. DISCUSSION

This study investigated the effects of arm movements on lower body joint kinematics and dynamic postural stability during anterior and lateral dynamic movements in children. Three unique findings emerged. Firstly, during the lateral jump, there was a reduced range of motion and joint movement variability in the pelvis when the arms were restricted, which was accompanied by greater counter knee extension. Second, during the anterior jump there was a greater range of motion and joint movement variability in the pelvis when the arms were restricted. Third, restricted arm movements had no effect on the DPSI during anterior or lateral jumps. Our findings are consistent with our previous work reporting that restricted arm movements did not alter the DPSI during an anterior jump in children [9]. We previously assumed that lower body neuromuscular strategies were able to effectively respond to the directionality of this task (i.e. sagittal plane movement involving little movement in the mediolateral direction [17]) and that the potential destabilising effects of restricting arm movements may only be evident under task constraints which challenge postural control in the frontal plane (i.e. lateral jumps) [9]. The present study extends the existing literature in two important ways. Firstly, an additional lateral direction jump was included to obtain a clear and more integrated insight into the nature of the directional impact of restricted arm movements on dynamic movement control in children. Second, lower body joint kinematics were investigated to advance our understanding of the potential postural compensatory mechanisms that may explain the null effects of arm restriction on anterior dynamic movement control.

4.1 Mediolateral dynamic postural stability

Previous studies on the impact of restricting arm movements observed significant reductions in stability mostly in the mediolateral direction [6-9]. The results of the present study in relation to joint kinematics showed there was a reduced range of motion and joint movement variability in pelvis obliquity when the arms were restricted during landing in the lateral jumps. This may represent a potential compensatory 'stiffening strategy' in an effort to provide more joint stability and maintain a tighter control of the centre of mass within the boundaries of the base of support [18]. It is also likely that the additional task constraint of restricting arm movements naturally decreased the degrees of freedom available in the motor control system [8] and caused a reduction in the number of available solutions to achieve the task goal [19], consequently permitting less ROM movement and joint movement variability. Therefore, these novel findings highlight that it is important for children to be introduced to different dynamic task constraints so that they can learn to control and organise the motor system degrees of freedom appropriately.

It is interesting to note that there was a greater tendency for extension of the counter knee during the lateral jump when the arms were restricted. It is possible that a greater knee extension of the counter leg (i.e. the only freely moving limb) during restricted arm conditions may have helped lower the centre of mass to its more natural position. This may reflect a better landing dynamic stability as the body's COM is controlled in a lower position [20], which can lead to improved postural stability. It is also plausible a more extended counter knee joint is another example of task constraints shaping the (re)organization of the motor system degrees of freedom [19]. In other words, the children are exploring the use of their lower-limbs to maintain balance under the constraint of lateral jumping with restricted arm movement.

4.2 Anteroposterior dynamic postural stability

Our results indicated a greater ROM and joint movement variability of pelvis tilt during the anterior jump when the arms were restricted. The first possible explanation may lie in the nature of the task performed. During an anterior jump landing, the postural control system must decelerate the COM as it travels in a downward and anterior direction [18]. It is likely that the arms serve as a counterweight to shift the body COM away from the direction of instability [3] or generate restoring torque to reduce angular momentum of the body [5]. Accordingly, the greater range of motion may potentially represent an elongated response of the pelvis when the arms were restricted in order to slow the anterior velocity of the upper body, absorb the vertical ground reaction force at impact and decelerate the vertical displacement velocity of the COM from landing to stabilization. Additionally, postural control mechanisms controlling anteroposterior dynamic balance reach maturity before the mechanisms involved in controlling mediolateral stability [14]. Motor development is largely affected by experience and the vast majority of activities of daily living are executed along the sagittal plane (i.e. running, reaching for an object) [14]. Thus, the anterior jump direction may utilise more practiced motor patterns and is consequently less challenging than the lateral jump direction which may have increased the ability of children to explore all degrees of freedom when the arms were restricted [21]. Contrary to our initial hypothesis, the restriction of arm movements did not affect the DPSI during either dynamic jumps.

4.3 Limitations

It should be recognised that undertaking in depth kinematic and kinetic analysis in paediatric samples is more challenging than in adult samples and the value of the current study and future examinations lie in their unique significance in informing practices within children's motor development. The differences between arm conditions at the pelvis suggest that an underlying adaptive control strategy used to maintain postural stability involved upper body adjustments [8], which were not measured in the present study. Additional examination of whole-body movement patterns is needed to gain a clearer and more mechanistic insight into the nature of how the upper and lower body contribute to challenging postural control scenarios in children. Secondly, the participants in the current study were all boys and, as a consequence, the conclusions drawn here should not be inferred for girls. It would be of interest to examine the development of dynamic postural control strategies in groups of boys and girls of different ages. Finally, we utilised the DPSI as we aimed to examine the effect of arm constraints on the initial impact phase post-landing. The lack of observed difference in the DPSI between the free and restricted arm conditions may be because the measuring technique, based on the DPSI, may not be sensitive enough to detect reduced dynamic balance performance when the arms are restricted [22]. The calculation of the DPSI can be affected by the magnitude of the impact peak ground reaction force and places more emphasis on a participant's ability to absorb shock than maintain balance [23]. More traditional measures of postural stability, such as movements of the centre of pressure, could provide information on the postural control mechanisms during the stabilisation phase and quiet stance post-landing.

5. CONCLUSION

In conclusion, restricting arms movements in children leads to changes in the magnitude of joint position, joint movement variability and joint range of motion observed in anterior and lateral dynamic jumping tasks. Specifically, lateral jumping required the reduction of joint movement variability and joint ROM when the arms were restricted, suggesting a reduction in the number of available movement solutions to achieve the task goal. Conversely, anterior jumping required the increase of joint movement variability and joint ROM when the arms were restricted, suggesting an exploratory strategy because of previously developed experience.

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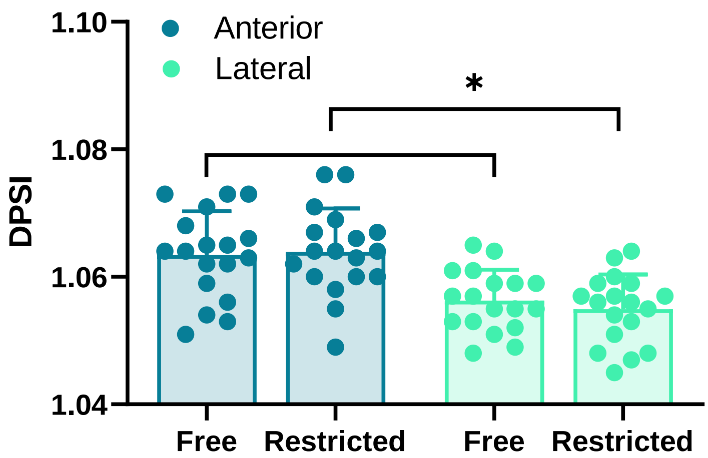

Figure 1. Mean ± SD and inter-individual DPSI during anterior and lateral direction jumps with free and restricted arm movements. *Significantly difference between jump directions (p<.001)

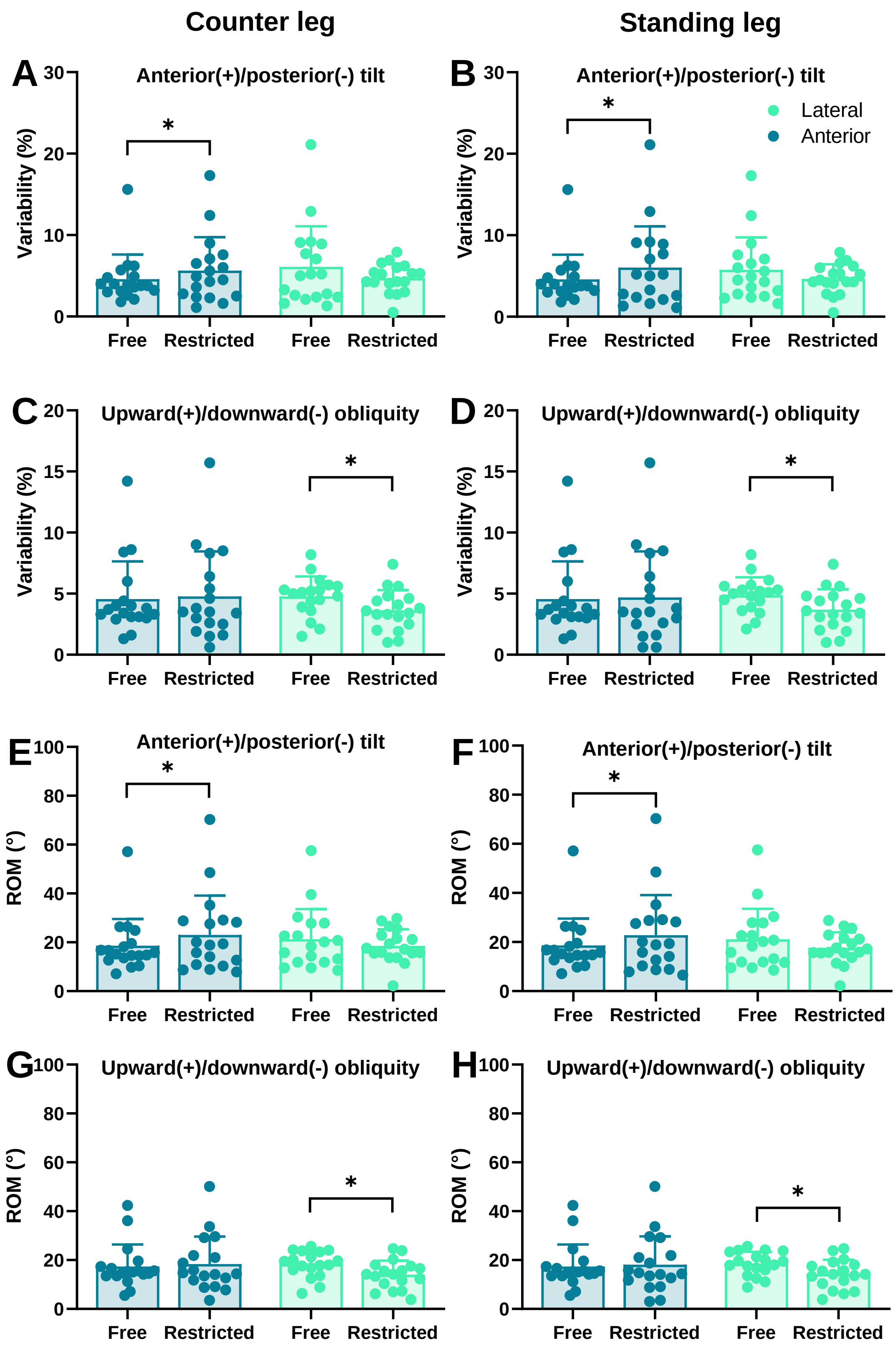

Figure 2. Mean ± SD and inter-individual pelvis variability (A-D) and ROM (E-H) during anterior and lateral direction jumps with free and restricted arm movements. *Significantly difference between ree and restricted arm conditions

Table 1: Mean ± SD average joint position of the counter and standing leg during the anterior and lateral jump

Joint	Variable	Anterior		Lateral		Arm × Direction ANOVA	η_p^2
		Free	Restricted	Free	Restricted		
Counter leg							
Ankle	Dorsi(+)/plantarflexion(-)	2.3 ± 13.4	3.6 ± 15.9	2.3 ± 11.3	5.8 ± 12.3	0.397	.043
	Inversion(+)/adduction(-)	-3.4 ± 15.7	-1.2 ± 11.1	-2.5 ± 10.8	-2.4 ± 10.2	0.339	.054
	Internal(+)/external(-)rotation	0.6 ± 30.3	-1.6 ± 29.9	1.7 ± 28.8	1.9 ± 28.8	0.525	.024
Knee	Flexion(+)/extension(-)	88.8 ± 22.4	92.4 ± 18.4	**90.1 ± 13.3***	**82.5 ± 18.8**	**0.011**	**.325**
	Adduction(+)/varus(-)	12.6 ± 27.6	13.6 ± 33.1	15.1 ± 26.9	13.3 ± 25.0	0.239	.081
	Internal(+)/external(-)rotation	1.4 ± 35.3	4.3 ± 29.7	3.7 ± 34.4	1.9 ± 33.1	0.098	.153
Hip	Flexion(+)/extension(-)	27.4 ± 10.1	30.2 ± 10.6	**34.7 ± 10.6†**	34.8 ± 16.8	0.320	.058
	Adduction(+)/abduction(-)	-4.5 ± 7.6	-7.3 ± 7.2	**-9.7 ± 6.0†**	-7.9 ± 9.2	0.121	.135
	Internal(+)/external(-)rotation	8.2 ± 31.0	7.1 ± 29.1	8.9 ± 27.1	7.7 ± 27.7	0.956	.000
Pelvis	Anterior(+)/posterior(-)tilt	21.9 ± 11.2	21.3 ± 13.9	**13.4 ± 7.1†**	10.1 ± 12.0†	0.410	.040
	Upward(+)/downward(-)obliquity	4.7 ± 5.0	5.9 ± 6.2	**-7.3 ± 11.2†**	-3.8 ± 9.6†	0.513	.026
	Internal(+)/exernal(-)rotation	-7.8 ± 13.6	-10.8 ± 15.8	**-55.0 ± 35.8†**	-53.3 ± 46.2†	0.718	.008
Standing leg							
Ankle	Dorsi(+)/plantarflexion(-)/	10.4 ± 7.9	10.5 ± 8.2	13.9 ± 10.5	15.5 ± 9.4†	0.377	.046
	Inversion(+)/adduction(-)	-3.6 ± 7.4	-4.0 ± 7.3	-5.5 ± 8.8	-4.5 ± 9.6	0.366	.054
	Internal(+)/external(-)rotation	11.7 ± 21.3	12.9 ± 22.0	14.1 ± 21.8	11.2 ± 22.6	0.191	.098
Knee	Flexion(+)/extension(-)	18.2 ± 8.3	19.9 ± 10.8	18.4 ± 8.6	20.1 ± 10.3	0.995	.000
	Adduction(+)/varus(-)	-3.1 ± 4.8	-4.0 ± 5.2	-4.4 ± 6.7	-3.4 ± 7.9	0.295	.064
	Internal(+)/external(-)rotation	-3.5 ± 16.7	-2.4 ± 17.9	-5.2 ± 17.6	-1.5 ± 21.2	0.569	.019
Hip	Flexion(+)/extension(-)	32.1 ± 20.0	32.9 ± 20.1	27.5 ± 8.5	26.5 ± 12.5	0.520	.025
	Adduction(+)/abduction(-)	**-2.6 ± 7.3***	**-5.4 ± 8.0**	-8.4 ± 9.3	-4.0 ± 5.9	**0.010**	**.330**
	Internal(+)/external(-)rotation	-11.0 ± 15.8	-10.9 ± 16.3	-15.9 ± 16.9	-14.3 ± 16.4	0.454	.033
Pelvis	Anterior(+)/posterior(-)tilt	21.9 ± 11.2	21.4 ± 13.7	**14.0 ± 7.0†**	**9.3 ± 11.5†**	0.144	.121
	Upward(+)/downward(-)obliquity	-4.7 ± 5.0	-5.5 ± 6.3	**7.3 ± 11.2†**	**4.5 ± 9.9†**	0.580	.018
	Internal(+)/external(-)rotation	7.8 ± 13.6	12.6 ± 13.8	**55.3 ± 35.7†**	**55.6 ± 46.9†**	0.193	.097

* Significant different to restricted arm condition p<.05. †Significantly different to anterior jump direction for same arm condition p<.05.

Table 2: Mean ± SD joint position variability of the counter and standing leg during the anterior and lateral jump

Joint	Variable	Anterior		Lateral		Arm × Direction ANOVA	η_p^2
		Free	Restricted	Free	Restricted		
Counter leg							
Ankle	Dorsi(+)/plantarflexion(-)/	7.5 ± 6.7	7.7 ± 4.8	6.0 ± 2.1	5.3 ± 3.3	0.532	.023
	Inversion(+)/adduction(-)	2.8 ± 3.2	2.4 ± 1.6	2.3 ± 1.5	2.6 ± 1.6	0.252	.076
	Internal(+)/external(-)rotation	6.5 ± 3.8	6.5 ± 3.1	6.3 ± 2.8	6.9 ± 4.4	0.668	.011
Knee	Flexion(+)/extension(-)	12.1 ± 6.8	13.9 ± 8.7	12.5 ± 3.5	14.2 ± 6.2	0.907	.001
	Adduction(+)/varus(-)	6.6 ± 3.8	5.6 ± 2.4	6.9 ± 2.1	6.6 ± 2.3	0.411	.040
	Internal(+)/external(-)rotation	6.1 ± 4.1	7.4 ± 7.9	6.8 ± 3.2	7.0 ± 4.5	0.287	.066
Hip	Flexion(+)/extension(-)	6.5 ± 2.0	7.7 ± 3.6	7.3 ± 2.9	7.6 ± 3.4	0.235	.082
	Adduction(+)/abduction(-)	5.0 ± 2.4	5.1 ± 2.4	8.6 ± 3.8	8.9 ± 4.4	0.882	.001
	Internal(+)/external(-)rotation	5.5 ± 3.2	5.6 ± 3.1	6.2 ± 2.2	5.6 ± 2.2	0.301	.063
Pelvis	Anterior(+)/posterior(-)tilt	**4.6 ± 3.0***	**6.1 ± 5.0**	5.6 ± 4.1	4.7 ± 1.8	**0.034**	**.239**
	Upward(+)/downward(-)obliquity	4.6 ± 3.1	4.8 ± 3.7	**4.8 ± 1.6***	**3.6 ± 1.7**	**0.028**	**.253**
	Internal(+)/external(-)rotation	5.5 ± 3.1	7.9 ± 12.0	9.7 ± 4.8	8.8 ± 5.2	0.150	.118
Standing leg							
Ankle	Dorsi(+)/plantarflexion(-)/	5.5 ± 3.0	6.2 ± 3.4	7.0 ± 4.0	6.7 ± 5.3	0.153	.116
	Inversion(+)/adduction(-)	2.6 ± 1.5	2.8 ± 1.6	5.5 ± 6.4	3.9 ± 3.8	0.155	.115
	Internal(+)/external(-)rotation	8.6 ± 2.9	8.5 ± 3.4	12.3 ± 7.0	9.9 ± 5.1	0.179	.104
Knee	Flexion(+)/extension(-)	7.7 ± 2.1	7.9 ± 1.9	8.0 ± 1.7	8.4 ± 2.0	0.749	.006
	Adduction(+)/varus(-)	3.4 ± 1.8	3.6 ± 3.0	4.7 ± 2.5	**5.4 ± 2.5†**	0.580	.018
	Internal(+)/external(-)rotation	4.7 ± 1.7	4.8 ± 1.8	5.8 ± 2.0	**6.0 ± 2.0†**	0.777	.005
Hip	Flexion(+)/extension(-)	7.6 ± 2.2	8.6 ± 3.1	8.4 ± 3.9	8.3 ± 2.4	0.267	.072
	Adduction(+)/abduction(-)	4.8 ± 2.4	5.4 ± 2.9	6.4 ± 3.3	6.1 ± 2.2	0.301	.063
	Internal(+)/external(-)rotation	5.2 ± 3.2	4.6 ± 2.2	8.2 ± 9.5	8.9 ± 7.2	0.471	.031
Pelvis	Anterior(+)/posterior(-)tilt	**4.6 ± 3.0***	**6.0 ± 5.1**	5.8 ± 4.0	4.6 ± 1.8	**0.023**	**.269**
	Upward(+)/downward(-)obliquity	4.6 ± 3.1	4.7 ± 3.8	**4.9 ± 1.5***	**3.7 ± 1.7**	**0.015**	**.300**
	Internal(+)/external(-)rotation	5.5 ± 3.1	7.7 ± 12.0	9.7 ± 4.8	8.5 ± 5.3	0.136	.126

* Significant different to restricted arm condition p<.05. †Significantly different to anterior jump direction for same arm condition p<.05.

Table 3: Mean ± SD joint range of motion of the counter and standing leg during the anterior and lateral jump

Joint	**Variable**	**Anterior**		**Lateral**		**Arm × Direction ANOVA**	**η_p^2**
		Free	**Restricted**	**Free**	**Restricted**		
Counter leg							
Ankle	Dorsi(+)/plantarflexion(-)/	31.1 ± 24.5	31.6 ± 17.7	26.0 ± 10.7	25.5 ± 15.9	0.873	.002
	Inversion(+)/adduction(-)	12.7 ± 11.9	12.0 ± 7.4	12.7 ± 9.3	13.9 ± 8.1	0.318	.059
	Internal(+)/external(-)rotation	31.4 ± 17.1	31.4 ± 12.7	33.0 ± 17.3	35.2 ± 17.2	0.527	.024
Knee	Flexion(+)/extension(-)	66.8 ± 26.5	67.7 ± 27.4	72.3 ± 19.9	72.6 ± 28.7	0.902	.001
	Adduction(+)/varus(-)	32.4 ± 15.4	29.4 ± 11.3	38.7 ± 12.1	**35.5 ± 11.1†**	0.965	.000
	Internal(+)/external(-)rotation	29.2 ± 18.5	33.8 ± 29.5	34.8 ± 22.0	33.8 ± 23.9	0.114	.121
Hip	Flexion(+)/extension(-)	37.6 ± 9.0	41.7 ± 11.0	32.3 ± 9.1†	**32.1 ± 10.4†**	0.243	.079
	Adduction(+)/abduction(-)	22.0 ± 7.8	22.5 ± 8.4	35.3 ± 9.9†	**36.5 ± 13.2†**	0.825	.003
	Internal(+)/external(-)rotation	29.3 ± 13.8	29.4 ± 12.4	32.2 ± 11.2	28.6 ± 9.0	0.201	.094
Pelvis	Anterior(+)/posterior(-)tilt	**18.6 ± 11.0***	**23.1 ± 16.0**	21.3 ± 12.3	18.6 ± 6.8	**0.038**	**.230**
	Upward(+)/downward(-)obliquity	17.4 ± 9.0	18.4 ± 11.3	**18.3 ± 5.4***	**14.0 ± 5.8**	**0.029**	**.250**
	Internal(+)/external(-)rotation	22.0 ± 9.5	28.4 ± 34.6	**36.4 ± 16.8†**	33.2 ± 18.6	0.203	.093
Standing leg							
Ankle	Dorsi(+)/plantarflexion(-)/	45.7 ± 24.1	51.0 ± 24.8	50.7 ± 25.3	47.6 ± 24.3	0.095	.156
	Inversion(+)/adduction(-)	12.7 ± 6.2	13.5 ± 7.4	22.7 ± 21.8	16.0 ± 11.2	0.058	.195
	Internal(+)/external(-)rotation	40.4 ± 10.6	41.5 ± 13.0	48.6 ± 22.2	41.7 ± 15.4	0.153	.116
Knee	Flexion(+)/extension(-)	37.7 ± 7.4	40.1 ± 6.1	36.8 ± 8.1	35.9 ± 8.4	0.231	.083
	Adduction(+)/varus(-)	18.9 ± 7.8	21.0 ± 10.6	23.4 ± 8.7	26.1 ± 10.4	0.801	.004
	Internal(+)/external(-)rotation	27.4 ± 8.8	28.4 ± 8.4	28.9 ± 10.9	31.6 ± 12.5	0.587	.018
Hip	Flexion(+)/extension(-)	31.0 ± 8,0	33.9 ± 10.1	31.5 ± 11.1	31.6 ± 8.7	0.365	.049
	Adduction(+)/abduction(-)	21.4 ± 6.9	22.4 ± 8.4	26.9 ± 9.7	26.5 ± 7.0	0.657	.012
	Internal(+)/external(-)rotation	28.2 ± 13.2	26.6 ± 11.5	35.5 ± 24.3	39.6 ± 24.5	0.229	.084
Pelvis	Anterior(+)/posterior(-)tilt	**18.6 ± 11.0***	**22.8 ± 16.3**	21.1 ± 12.4	17.6 ± 6.4	**0.004**	**.389**
	Upward(+)/downward(-)obliquity	17.4 ± 9.0	18.1 ± 11.6	**18.6 ± 4.8***	**14.3 ± 5.9**	**0.008**	**.347**
	Internal(+)/external(-)rotation	22.0 ± 9.5	27.8 ± 34.8	**36.4 ± 16.7†**	32.9 ± 18.8	0.193	.097

* Significant different to restricted arm condition p<.05. †Significantly different to anterior jump direction for same arm condition p<.05.