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Influence of foot position and vision on dynamic postural strategies during the "grand plié" ballet movement (squatting) in young and adult ballet dancers.

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Introduction

Ballet dancers maintain postural stability during challenging tasks more easily than non-dancers [1,2]. However, their postural capacity is affected by external factors such as sloped floors [3], lighting [4], footwear and costumes [5] and internal factors such as degree of expertise [6], errors during training [7], fatigue [6,8] and injury [9]. These factors can reduce stability, particularly in technical dance movements, increasing the risk of injury. The annual incidence of injuries in professional dancers is between 67% and 95% [10]. It is thus essential to develop specific exercises to improve postural control and prevent injuries [7].

The postural control system continuously manages the body's state of equilibrium through the interaction of sensory-motor processes [11]. Balance is constantly perturbed by body and limb motion and the relevant sensory information is selected and integrated by the postural control system to maintain stability [12]. The regulation of body position requires vestibular, visual, and somatosensory information, including proprioceptive [13]. Some people are dominant in one modality [14], however all three systems are essential for the organisation of balance, especially during complex movements [13].

Dance training improves balance and movement capacity by developing specific dynamic postural strategies relevant for dancing requirements [15]. Trepman et al. [16], showed that dance include three types of muscle activity: characteristic activity required for the execution of specific dance movements; varied activity, which is characteristic of different dance idioms and varied activity, which may depend on factors such as balance, personal habits, and individual training background. Young dancers (YD), for example, lack stability because they are still in the process of developing specific dance abilities [6]. Moreover, dynamic strategies seem to be influenced by accelerations in growth, which could disturb proprioceptive references and internal body representations [4].

It is important to understand the characteristics and needs of YD to prevent injuries from the very beginning of the training. However, few studies have compared YD and adult dancers (AD). In static balance, the postural control of YD is less efficient than that of AD and YD are more visually dominant [17]. In dynamic balance, this visual dominance has been shown to be related to age [4] and moreover, appears to be reinforced when the training involves visual feedback from mirrors [18]. Interestingly, it has been shown that practicing specific dance exercises with the eyes closed (EC) improves balance after only 4 weeks [7]. Few studies have investigated the effect of vision on balance training, despite the fact that visual conditions vary greatly between dance studios and theatre productions [7] and that postural control depends on the availability of visual information [2]. Unnatural lighting in the theatre reduces the effectiveness of the dancer's visual system, reducing postural control and increasing the risk of injury. It is therefore essential to evaluate visual dependence in ballet dancers to increase understanding of their strategies and develop appropriate balance exercises to improve performance.

The *"grand plié"* is a basic dance movement, learned at the by the youngest of dancers *(figure 1)*. The movement is composed of three phases: lowering, complete squatting and rising [19]. Despite the importance of the *"grand plié"* in dance training, the effect of age and availability of visual information on postural strategies have never been investigated. Most studies have evaluated standard static balance tasks [2,4,17] that are not specific to ballet and thus do not highlight specific dance-related characteristics and requirements [16]. The "grand plié" movement has been shown to differentiate dancers with and without a history of ankle sprain [19] as well as contemporary and classical ballet dancers [16]. Thus, this movement seems to be a relevant marker to highlight specific dance abilities.

Six foot positions are trained in ballet. In the *"first position",* both lower limbs are in external rotation and in *"sixth position"* the feet are parallel [20,21]. Foot position influences postural strategies in bipedal stance [20] and during turns [22]. Parallel and tandem foot positions are more stable than open foot positions in both ballet dancers and control subjects [20], although between-group differences are only significant for the dance-specific "first position". In dynamic conditions, ground reaction force (GRF) parameters and joint moments during technical pirouettes are altered by the initial position of the feet [22]. We thus postulated that foot position would also affect postural control during the "grand plié". We chose this movement because it is dance-specific and is a basic dance-exercise that all ballet dancers are very familiar with. Moreover, it is sufficiently simple to be carried out by YD and with EC.

The aim of this study was to assess the effect of age, foot position and visual condition on dynamic postural strategies during the "grand plié" in pre-professional and professional ballet dancers. We hypothesized that:

1) instability would be greater in YD, particularly in the open foot position and with the EC;
2) dynamic postural strategies would be modified by foot position and that the parallel position would be less stable than the turned out position because it is less frequently used in the ballet classroom;
3) instability would be further increased by a lack of visual feedback, especially for YD who use the mirror to a greater extent during exercises.

Material and methods

Participants

Forty high-level ballet dancers from the National Dance School of Marseille (France) were included in this study. They were allocated to one of two groups: YD (8–16 years) and AD (17–30 years). These age groups were chosen to reflect the fact that during puberty, dancing skills tend to regress temporarily as a result of the growth spurt, and also that female dancers have often a delayed menarche [23]. Before inclusion, a physiotherapist carried out a clinical examination to exclude any pathology that could affect balance (e.g. ankle sprain, scoliosis, tendinitis, lower limb pain, patello-femoral syndrome, cavity or flatness foot,...). If the dancers were visually impaired, we included them only when wearing glasses or corrective lenses. The YD (12.6±1.95 years) and AD groups (22.4±5.06 years) were both composed of 6 boys and 14 girls (this proportion represented a typical ballet class population). Participants trained for between 10 and 35 hours per week (YD: 14.4h±8.49, vs. AD: 23.8h±10.61, $p < 0.03$). All the dancers practiced classical dance as a sport specialization (i.e. year-round intensive training in a single sport at the exclusion of other sports) and had 4h of complementary practices per week (pilates or yoga). The number of years of dance training was a minimum of 4 years. All participants signed written informed consent after having received information about the study.

Procedure

Evaluation of the “grand plié” was carried out with the subjects standing on a force plate. An oral signal was given for the dancer to initiate lowering, complete squatting and rising ***(Fig1)*** [19]. The open configuration, corresponding to “first position”, was with heels together and external hip rotation to produce an angle of at least 140° between the feet [20]. The knees were abducted, in line with the toes.

Insert Fig1.

The parallel foot configuration, corresponding to the “sixth position”, was with the feet in parallel and no space between the heels. The knees were together, in line with the toes. Eyes-open (EO) and EC conditions were tested in both foot positions. The tests order was randomized for each participant. Three trials were carried out for each condition. Between each trial, the dancer left the force plate and walked a few steps.

Force-plate

The dynamic analysis was based on signals from the force-plate (AMTI®BP6001200, Biometrics™) recorded at a frequency of 500 Hz [24]. Anteroposterior, medio-lateral, and vertical GRF, and center of pressure (CoP) were calculated. CoP was defined as the resultant position of the force vector for all vertical GRF. Excursion of the CoP was measured in the anteroposterior and mediolateral directions. These parameters provide the best representation of static postural control strategies [25].

Data processing

The GRF and CoP signals were exported to GNU GPL Octave® (V.4.2.1, 2017), which was used for data processing. CoP surface (total area covered by the CoP trajectory computed as the 95% confidence ellipse – mm^2), CoP displacement length (the total length of the CoP trajectory computed as the sum of the distances between two consecutive points - mm), and maximal speed (mm/s) in the mediolateral (MaxVy) and anteropostérior directions (MaxVx) were calculated. The GRF was normalized by the mass of each subject, then the Impulse (force multiplied by time), Delta (maximal value – minimal value), minimum (Min) and maximum (Max) values, and standard deviations (SD) of each GRF component were calculated.

Statistics

Analyses compared: 1) YD and AD, 2) parallel and open foot conditions, and 3) EO and EC conditions. The statistical analysis included descriptive statistics. For each subject, the mean of the three trials was calculated for each condition. Means and standard deviations are reported for all variables. Prior to analysis Levene's test and Shapiro-Wilk test were performed to examine equality of variance and normality of distribution, respectively. An unpaired Student's t-test was used to compare YD and AD. One-way repeated analysis of variance (ANOVA) was performed to compare the 4 conditions for each group (open foot position, parallel foot position, EO, EC). Where Mauchly's test indicated a violation of sphericity, *p-value* were corrected using the Greenhouse-Geiser correction factor. In case of a significant interaction, a Bonferroni adjustment post-hoc test was used for the comparison two by two. A threshold value of $p<0.05$ was adopted to rule out the non-significant (NS) difference. All statistical analyses were performed using SPSS© (IBM analytics, V.25, 2017).

Results

Comparison between AD and YD groups

In the parallel position with EO, CoP surface was higher in the YD group (AD: 60.39±20.62mm^2 vs. YD: 79.47±21.43mm^2, p=0.016), while in YD in the open position with EC, CoP surface was smaller (AD: 84.32±81.3mm^2 vs. YD: 54.47±22.13mm^2, p=0.029, ***Fig2*****).** CoP displacement length (p<0.003) and speed parameters (MaxVx: p<0.001, MaxVy: p<0.003) were greater in the YD group in all conditions, except for CoP MaxVy with EC which did not change significantly ***(Fig3)*****.**

Insert Fig2 and Fig3.

There were NS differences between AD and YD for anteroposterior GRF. With EC, mediolateral and vertical GRF Impulse ($p<0.001$), Min ($p<0.048$), Max ($p<0.049$), Delta ($p<0.031$) and SD ($p<0.008$) were lower in the YD ***(tables 1 and 2)***.

Insert tables 1 and 2.

With EO, all mediolateral GRF parameters were lower in YD ($p<0.023$), except for Impulse in the open position (NS). The vertical GRF Impulses ($p<0.001$) and SD ($p<0.015$) were lower in the YD but there was NS difference for Max and Delta vertical GRF ***(tables 1 and 2)***. Min vertical GRF was smaller in YD only in the parallel position ($p=0.028$).

Intra-group interaction between 4 conditions (EO, EC, parallel and open foot position)

The repeated ANOVA indicated eyes and foot positions effects on stability during “grand plié”. There was significant interaction for all CoP parameters (AD: $p<0.023$, YD: $p<0.004$) and anteroposterior (AD: $p<0.001$, YD: $p<0.001$) and mediolateral (AD: $p<0.001$, YD: $p<0.001$) GRF parameters. The parameters associated with vertical GRF showed significant interaction for AD ($p<0.034$), while in YD the results were NS.

Comparison of open and parallel foot positions

In both groups, with EO, CoP surface and MaxVy speed were greater in the parallel foot position compared with the open position ($p<0.002$), and MaxVx speed was slower ($p<0.034$) ***(Fig2 and Fig3)***. There were NS differences in CoP displacement length between foot positions, either for AD (open position: 116.04±19.5mm vs. parallel position: 120.42±20.43mm, NS) or YD (open position: 161.37±29.83mm vs. parallel position: 165.46±29.38mm, NS).

In both groups, with EC, CoP surface and MaxVy speed were greater in the parallel position compared to the open position (CoP surface: $p<0.05$, MaxVy speed: $p<0.048$, ***Fig2 and Fig3***). MaxVx speed ***(Fig3)*** and CoP displacement length were NS in both the AD group (open position: 134.31±26.53mm vs. parallel position: 131.67±22.80mm, NS) and YD group (open position: 174.02±26.99mm vs. parallel position: 175.36±29.56mm, NS).

For anteroposterior GRF, in the YD group, there were NS differences between foot positions with EO and EC. In the AD group, anteroposterior GRF Impulse (p=0.049), Max (p=0.03), Delta (p=0.016) and SD (p=0.036), were higher in the open foot position with EO, and the Min was lower (p=0.047). For this anteroposterior GRF component, there were NS differences between foot positions with EC in AD.

The greatest differences between the foot positions were found for mediolateral GRF in both groups. Mediolateral GRF Impulse (p<0.001), Min (p<0.042), Max (p<0.049), Delta (p<0.002) and SD (p<0.001) were higher in the parallel position for both eye conditions ***(tables 1 and 2)***.

With EC and EO, only the Delta vertical GRF was greater in the parallel position in AD group (p<0.049). However, the other parameters associated with vertical GRF did not change significantly in both group.

Comparison between EO and EC

With EC, CoP surface (p<0.042) and displacement length (p<0.019) increased in both groups in both positions ***(Fig2 and Fig3)***. There was NS difference in Max Vx and MaxVy between eye conditions, except for YD in which it was higher Max Vx with EC in either foot position (p=0.05).

In both groups and both positions, with EC, all anteroposterior and mediolateral GRF parameters increased (Impulses: p<0.037, Min: p<0.047, Max: p<0.049, Delta: p<0.044, and SD: p<0.047, ***tables 1 and 2***).

In both groups, there was NS difference in all vertical GRF parameters between eye conditions for parallel and open feet configurations.

Discussion

The results of this study showed that dynamic postural strategies during the “grand plié” movement are influenced by age, foot position and visual availability. CoP displacement length and CoP speed were higher in the YD than the AD, especially in parallel position. In the same foot position, CoP surface, CoP speed and GRF parameters, particularly the mediolateral GRF components, were greater than in the open position, indicating that the parallel position was less stable. In the EC condition, anteroposterior and mediolateral GRF parameters were particularly altered, indicating that the lack of vision increased instability in both foot positions.

The analysis of dynamic strategies during the “grand plié” is an essential step in understanding and preventing injury. The “grand plié” is not challenging for ballet dancers, however it is an essential basic ballet movement that is practiced daily from the very first lessons [21]. As a result of training, dancers develop specific motor strategies to achieve this movement, which are more effective than those of non-dancers [26]. The strategies developed depend on the type of dancing [16] and are not highlighted by non-dancing-specific balance tasks, such as the simple one leg stance [18]. The results of this study demonstrate that the “grand plié” can differentiate YD from AD and is affected by foot position and visual conditions. Analysis of the factors that cause instability in this movement seems to be essential for injury prevention. Previous studies highlighted that instability and poor knee–foot alignment increase constraints at the knee and hip [27]. An increase in constraints on lower limb joints during movement may be associated with hip impingement [28] and risk of ankle injury [19]. Thus, the development of appropriate dynamic postural strategies during the “grand plié” may limit the risk of injury.

The parallel foot position was less stable than the open position, confirming our hypothesis. Previous studies involving the “grand plié” only tested the open foot position [16,19]. Two studies showed that heel spacing in the open foot position influences leg muscle activation and external knee rotation [26,27]. One study that evaluated stability during static standing found no difference in the parallel and tandem positions between dancers and non-dancers, however the dancers were more stable in the open foot position [20]. The present study showed that postural control strategies during the “grand plié” were affected by foot position with different degrees of lower limb rotation, and a previous study showed that lower limb rotation affects turn initiation during pirouettes [22]. The parallel foot position induced a higher CoP surface and higher CoP speed, although the CoP length displacement was the same in both foot conditions. The parallel foot position mostly affected the mediolateral GRF, as was found in a previous study of single leg stance with posterior displacement of the swing leg [17].

Movement control is three-dimensional [29,30] and postural adjustments occur in the plane perpendicular to the movement direction [30]. A large proportion of dance movements are trained at the barre. While this is useful for training technical aspects of the movements, it does not train essential postural strategies, particularly in the frontal plane [31]. Therefore, without the barre, the “grand plié” with the feet in parallel is more difficult, as shown by the higher values of mediolateral GRF parameters. Studies of balance tasks with or without the barre showed that balance strategies used by dancers vary depending on whether the barre is present, in contrast, non-dancers use the same strategy in both conditions [31,32]. In the EC condition, foot position had a smaller effect on stability parameters, probably because training is usually carried out with EO and the instability with EC was too great for fine adjustments in control to be observed.

Differences between YD and AD were most apparent in the open foot position without vision. YD have less external hip rotation that AD in this position [33]. Equally, they have not yet developed the dance-specific motor strategies and external hip range of motion used by expert dancers [31]. The results of the present study confirmed that the YD were more dependent on the availability of visual information than AD [4,17]. The YD had longer CoP displacement lengths and higher CoP speed values than AD, confirming previous results in a single leg balancing task [4,17]. The CoP surface did not increase consistently in YD for all conditions. It appeared that the strategy used by the YD was to increase the number of CoP oscillations to maintain balance during movement, as found in a static single leg balancing task [17]. This difference between YD and AD can be attributed to changes in muscle activation strategies with greater expertise. One study showed that during a “demi-plié” movement (incomplete squatting), experienced dancers activated the biceps femoris muscle less at the end of the flexion phase than beginners [26]. Increased muscle activation and joint stiffness have been shown to be related to increased CoP displacement length and CoP frequency in standing [34]. The GRF analysis showed that all mediolateral and vertical GRF values were lower in YD than AD, confirming that they use stiffness strategies and corroborating results for the single leg stance [17]. Thus, training results in the development of postural control mechanisms specific to each movement, with lower levels of muscle activation, fewer joint constraints and less risk of injury. These results therefore suggest that training YD in different foot positions with EC would be pertinent to optimize balance strategies and reduce the risk of injury, as has been proposed for AD [7].

Regardless of foot position, lack of visual information reduced stability (especially for CoP parameters, anteroposterior and mediolateral GRF components) in both groups, as has been shown previously [4,17,21]. The ballet dancers showed greater dependence on visual information for postural control. Lighting during performances varies greatly, making it important to train balance and movement in different visual conditions. Notarnicola et al. has shown that the use of the mirror does not improve the acquisition of balance control [18], which confirms that the direct acquisition (and not mediated as reflex imagery) is important in the management of the space around the dancer and improve posture-dynamic strategies. In contrast, Hutt et al. [7] highlighted that exercises with EC increase the use of proprioceptive strategies for dynamic balance in dancers, improving balance performance. Since dance is often learned in front of the mirror, to limit the injuries related to instability, it is relevant to propose specific balance exercises with EC by associating with other factors of instability like the different foot position. In addition, dance teachers should favour training based more on somato-proprioceptive feedback by limiting the use of the mirror to a few corrections.

The main limitation of this study was the small number of subjects included. However, the recruitment of elite dancers was difficult because ballet schools typically favoured small classes to optimize training. The second limitation was the visual condition. To reproduce real theatrical conditions, it would have been better to test the dancers either in the dark or with dazzling lights. The method proposed here does not easily dissociate the effect of age and the number of years of training on the results. This would require a control group of non-dancers and longitudinal follow-up.

Analysis of differences in muscle activation between YD and AD would help to explain the increased CoP length and its implications for increased understanding of postural control strategies and fatigue. Barnes et al. [27] showed that the “grand plié” movement should not be carried out in 3rd and 4th positions (open foot positions with legs adducted and crossed), because of stresses placed on the knee joint. Thus, it would be interesting to analyse joint constraints in the parallel and open foot positions without crossed legs, to determine if these positions are useful for training postural strategies to prevent injury. Future studies should also test if there is a relationship between stability during the “grand plié” with feet parallel and performance in other technical complex movements. Moreover, it would be interesting to evaluate the effect of training the "grand plié" movement with and without the barre [32], and in different foot positions [26,27], on balance. Comparison of postural control strategies used by ballet and contemporary dancers should help to develop specific exercises relevant for specific dance-types, as proposed by Trepman et al. [16].

Conclusion

The results of this study demonstrate the utility of using a specific dance task to evaluate dynamic postural strategies in pre-professional and professional dancers. During the “grand plié”, the parallel foot position was more unstable, especially in frontal plane, than the open foot position. YD were less stable than AD and increased the frequency of oscillations to maintain equilibrium. Both groups were less stable with EC, whatever the foot position. Differences in foot position were greatest with EO and differences between YD and AD were greatest with EC. Foot positions and visual conditions are important factors to consider when training postural control during complex motor tasks. These conditions should be varied during training to improve balance control and reduce the risk of injury.

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Conflicts of interest:

The authors declare that they have no conflict of interests.

Table 1 : Open feet configuration (first position): for adult dancers (AD) and young dancers (YD) : all forces (anteroposterior – AP, mediolateral – ML and vertical – V) values for eyes open (EO) and eyes closed (EC) conditions.

		Adult dancers			***Young dancers***			***AD vs. YD p values***	
Forces	***Variables***	***EO***	***EC***	***p value***	***EO***	***EC***	***p value***	***EO***	***EC***
AP	Impulses (N.ms)	9012 ± 3011	12012 ± 4098	***0.012***	8664 ± 1920	11293 ± 2244	***<0.001***	*NS*	*NS*
	Min (N)	-15.37 ± 4.68	-20.27 ± 8.90	***0.031***	-12.91 ± 4.52	-16.17 ± 4.80	***0.009***	*NS*	*NS*
	Max (N)	15.47 ± 5.60	18.38 ± 6.85	***0.049***	12.79 ± 3.66	15.62 ± 4.15	***0.014***	*NS*	*NS*
	Delta (N)	30.84 ± 9.61	38.65 ± 15.37	***0.044***	25.69 ± 7.20	31.79 ± 7.93	***0.001***	*NS*	*NS*
	SD (N)	4.95 ± 1.61	6.42 ± 2.25	***0.021***	4.49 ± 0.93	5.63 ± 1.13	***<0.001***	*NS*	*NS*
ML	Impulses (N.ms)	13536 ± 2709	19970 ± 4151	***<0.001***	12123 ± 2563	14713 ± 3056	***<0.001***	*NS*	***<0.001***
	Min (N)	-20.55 ± 5.16	-30.66 ± 9.38	***<0.001***	-16.96 ± 4.51	-19.68 ± 4.86	***0.009***	***0.023***	***<0.001***
	Max (N)	19.95 ± 4.43	28.35 ± 7.99	***<0.001***	14.82 ± 4.08	18.20 ± 5.20	***0.006***	***<0.001***	***<0.001***
	Delta (N)	40.50 ± 8.77	59.00 ± 16.23	***<0.001***	31.79 ± 8.21	37.87 ± 9.27	***0.009***	***0.002***	***<0.001***
	SD (N)	7.11 ± 1.32	10.35 ± 2.18	***<0.001***	6.06 ± 1.19	7.22 ± 1.47	***<0.001***	***0.010***	***<0.001***
V	Impulses (N.ms)	57352 ± 15398	63730 ± 18989	*NS*	48255 ± 13427	52121 ± 14351	*NS*	***<0.001***	***0.001***
	Min (N)	-84.52 ± 29.90	-109.06 ± 45.07	*NS*	-69.53 ± 32.62	-71.21 ± 30.49	*NS*	***NS***	***0.003***
	Max (N)	157.99 ± 96.92	184.92 ± 106.64	*NS*	116.46 ± 72.36	126.67 ± 84.73	*NS*	***NS***	***0.049***
	Delta (N)	242.51 ± 119.76	293.97 ± 143.03	*NS*	185.99 ± 90.58	197.88 ± 106.74	*NS*	***NS***	***0.019***
	SD (N)	38.02 ± 14.72	43.75 ± 17.88	*NS*	27.46 ± 11.83	28.35 ± 13.68	*NS*	***0.015***	***0.003***

Table 2 : Parallel feet configuration (first position): for adult dancers (AD) and young dancers (YD) : all forces (anteroposterior – AP, mediolateral – ML and vertical – V) values for eyes open (EO) and eyes closed (EC) conditions.

		Adult dancers			*Young dancers*			*AD vs. YD p values*	
Forces	***Variables***	***EO***	***EC***	***p value***	***EO***	***EC***	***p value***	***EO***	***EC***
AP	Impulses (N.ms)	7659 ± 1953	10927 ± 3501	***<0.001***	8175 ± 2126	10432 ± 2845	***0.027***	*NS*	*NS*
	Min (N)	-13.45 ± 4.59	-17.47 ± 5.79	***0.001***	-12.24 ± 4.13	-15.25 ± 3.55	***0.016***	*NS*	*NS*
	Max (N)	12.39 ± 3.71	16.49 ± 5.62	***0.001***	11.70 ± 2.91	13.86 ± 3.68	***0.05***	*NS*	*NS*
	Delta (N)	25.84 ± 7.50	33.96 ± 10.86	***<0.001***	23.93 ± 6.18	29.10 ± 6.61	***0.014***	*NS*	*NS*
	SD (N)	4.21 ± 1.11	5.81 ± 1.86	***<0.001***	4.24 ± 1.01	5.41 ± 1.26	***0.008***	*NS*	*NS*
ML	Impulses (N.ms)	20461 ± 5737	23523 ± 6411	***0.024***	16490 ± 3657	17705 ± 3593	***0.037***	***<0.001***	***0.001***
	Min (N)	-30.12 ± 10.36	-36.96 ± 12.97	***0.047***	-24.64 ± 7.94	-27.57 ± 7.35	***0.035***	***0.006***	***0.048***
	Max (N)	29.91 ± 8.55	36.67 ± 12.65	***0.002***	22.51 ± 13.69	25.89 ± 9.38	***0.045***	***0.003***	***0.046***
	Delta (N)	60.03 ± 17.85	73.63 ± 22.65	***0.028***	47.14 ± 18.99	53.46 ± 15.81	***0.012***	***0.002***	***0.031***
	SD (N)	10.77 ± 2.88	12.62 ± 3.56	***0.044***	8.49 ± 2.29	9.12 ± 2.06	***0.047***	***<0.001***	***0.008***
V	Impulses (N.ms)	63668 ± 18225	70295 ± 19179	*NS*	43751 ± 12950	45349 ± 14757	*NS*	***<0.001***	***<0.001***
	Min (N)	-96.50 ± 40.19	-115.95 ± 44.66	*NS*	-74.80 ± 30.17	-79.39 ± 33.49	*NS*	***0.028***	***0.005***
	Max (N)	180.19 ± 104.35	214.54 ± 98.66	*NS*	133.41 ± 86.33	136.94 ± 113.58	*NS*	*NS*	***0.025***
	Delta (N)	276.69 ± 133.21	330.50 ± 135.15	*NS*	208.21 ± 105.43	216.33 ± 135.02	*NS*	*NS*	***0.010***
	SD (N)	42.75 ± 16.38	49.87 ± 17.77	*NS*	30.12 ± 13.04	30.84 ± 15.94	*NS*	***0.009***	***<0.001***

Figure legends :

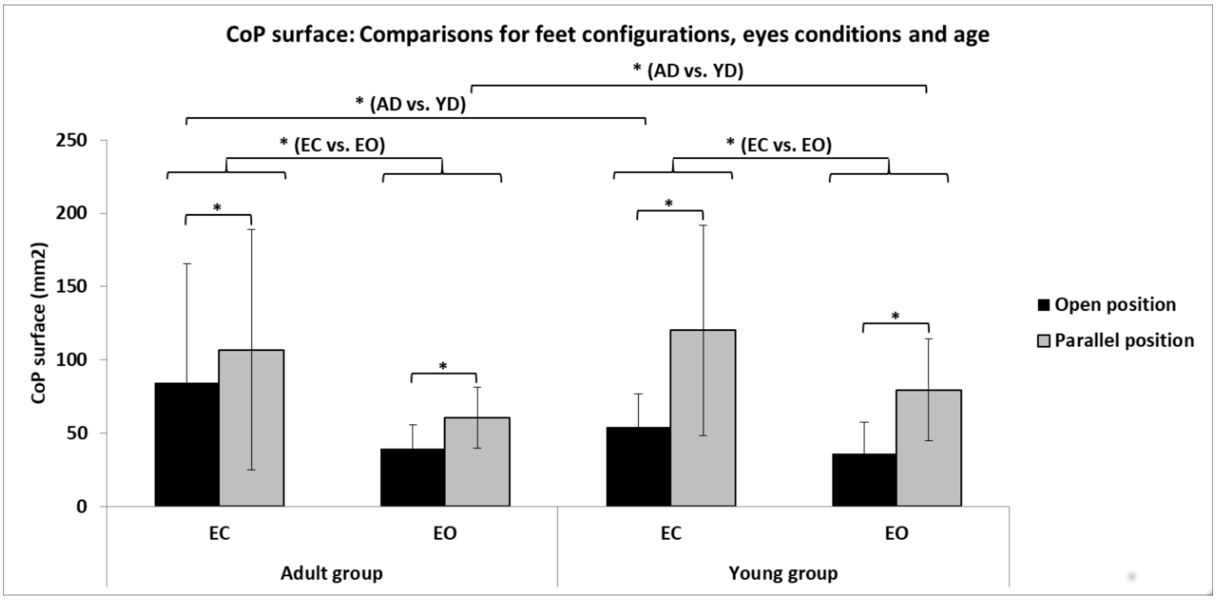
Figure 1 : Ballet « grand plié » movement in the end of squatting phase in open feet configuration.

Figure 2 : CoP surface parameter (mm^2): Comparisons between feet configurations (open in black and parallel in gray) for both eyes conditions (eyes closed – EC and eyes opened - EO) for adult (AD) and young (YD) groups. A significant difference ($p<0.05$) is represented with "*" sign.

Figure 3 : CoP max Vx (anteroposterior direction) and max Vy (mediolateral direction) speed parameter (mm/s): Comparisons between feet configurations (open in black and parallel in gray) for both eyes conditions (eyes closed – EC and eyes opened - EO) for adult (AD) and young (YD) groups. A significant difference ($p<0.05$) is represented with "*" sign.

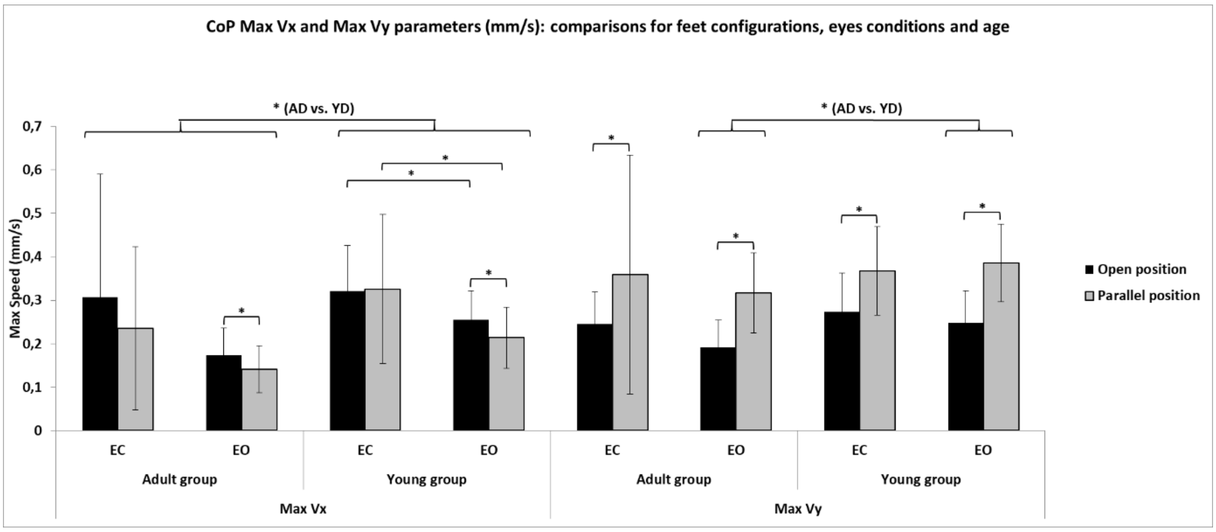
Figure 1

Figure 2



CoP surface: Comparisons for feet configurations, eyes conditions and age
* (AD vs. YD)
* (AD vs. YD)
* (EC vs. EO)
* (EC vs. EO)
*
*
*
*
250
200
150
100
50
0
CoP surface (mm2)
EC
EO
EC
EO
Adult group
Young group
Open position
Parallel position

Figure 3



CoP Max Vx and Max Vy parameters (mm/s): comparisons for feet configurations, eyes conditions and age
* (AD vs. YD)
* (AD vs. YD)
Max Speed (mm/s)
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
EC
EO
EC
EO
EC
EO
EC
EO
Adult group
Young group
Adult group
Young group
Max Vx
Max Vy
Open position
Parallel position