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Postural Control During Cascade Ball Juggling: Effects of Expertise and Base of Support

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Abstract

Cascade ball juggling is a complex perceptual motor skill which requires efficient postural stabilization. The aim of this study was to investigate effects of experience (expert and intermediate groups) and foot distance (wide and narrow stances) on body sway of jugglers during three ball cascade juggling. A total of 10 expert jugglers

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and 11 intermediate jugglers participated in this study. Participants stood barefoot on the force plate (some participants wore a gaze tracking system), with feet maintained in wide and narrow conditions and performed three 40-seconds trials of the three-ball juggling task. Dependent variables were sway mean velocity, amplitude, mean frequency, number of ball cycles, fixation number, mean duration and its variability, and area of gaze displacement. Two-way analyses of variance with factors for group and condition were conducted. Experts' body sway was characterized by lower velocity and smaller amplitude as compared to intermediate group. Interestingly, the more challenging (narrow) basis of support caused significant attenuation in body sway only for the intermediate group. These data suggest that expertise in cascade juggling was associated with refined postural control.

Keywords
body sway, postural control, center of pressure displacement, cascade juggling

Introduction

Postural stabilization is critical to the task performance, as it facilitates the achievement of movement goals (Riccio & Stoffregen, 1988). It is not an end in itself and its success can be understood as accomplishment of the suprapostural task (defined as the behavioral goal that is superordinate to the control of posture; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). However, when there is competition between two motor tasks, individuals tend to prioritize postural stability over success on a more demanding secondary task (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997).

Posture provides support for nearly all ongoing activities and so must be considered as a core element within the coordination of most skills. The present study focuses on balance control during juggling as a representative way of understanding how people naturally engage in other activities while standing. Particularly, cascade ball juggling is a complex perceptual motor skill which involves the contribution of visual, proprioceptive, and haptic systems to keep the balls simultaneously moving in the air by tossing and catching them (Beek & Turvey, 1992; Garcia, Hayes, Williams, & Bennett, 2013). The juggler must throw each ball sufficiently high to provide time to deal with the other balls (Haibach, Daniels, & Newell, 2004). Previous studies have mostly analyzed learning and coordination dynamics of arm movements during cascade juggling (e.g., Huys, Daffertshofer, & Beek, 2003, 2004; Mapelli et al., 2012). Postural stabilization during juggling is important because it facilitates the juggling activity through balance adjustments made before, during, and after arm movements, which maintain reference values in the face of perturbations arising within the juggler (i.e., hand movements) or from external events (i.e., ball movements) (Leroy, Thouvarecq, & Gautier, 2008).

Expertise

Skill level affects juggling performance as well as the integration between posture and manual control. For instance, Leroy et al. (2008) investigated how posture is organized during cascade juggling; their results showed that, although arm patterns and sacrum lateral oscillations were spatially similar between groups, experts' latencies between the maximal flexion/extension of the elbow and the maximal lateral oscillations of the sacrum and their standard deviations were significantly lower as compared to the intermediate group, suggesting that experience modified the posture–juggling coupling. Expert jugglers are able to perform better anticipatory postural adjustments, allowing them to improve stability of arm and body movements aimed to correct ball trajectories (Hashizume & Matsuo, 2004; Huys et al., 2003; Leroy et al., 2008; Mapelli et al., 2012). Increased postural stability due to motor learning or development has been reported in other skills, such as rifle shooting (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996), gymnastics (Garcia, Barela, Viana, & Barela, 2011; Gautier, Thouvarecq, & Larue, 2008), manual rhythmic movements (Amado, Palmer, Hamill, & van Emmerik, 2016), and circus activities (Sahli et al., 2013). These evidences generally confirm postural improvement and greater adaptability as a result of practice and experience but differences between expert and intermediate jugglers were not yet determined in terms of center of pressure (CoP) displacements, a standard method in posturography (Duarte & Freitas, 2010).

Base of support

Reduction of the base of support has been used to perturb posture stabilization (Aguiar et al., 2015; Rodrigues et al., 2013, 2015). Body sway is affected by the distance between the feet (Mitra & Fraizer, 2004). Previous studies indicated that for static postural stability, a feet-together stance increases total sway path of the CoP compared to a larger feet distance (Day, Steiger, Thompson, & Marsden, 1993; Kim et al., 2014; Kirby, Price, & MacLeod, 1987). Kim et al. (2014) compared six different feet distances (0, 5, 10, 15, 20, 25 cm) and found that CoP mean distance decreased monotonically with feet distance. Interestingly, mean velocity of CoP showed a decrease followed by an increase, with the minimum at the feet distance of 15 cm or 20 cm, near to the measured natural feet distance of 16.5 cm ($SD = 3.8$); authors interpreted this finding as the effort minimization of postural control around the natural, preferred feet distance. However, the distance between the feet has not been systematically manipulated in dynamical contexts such as ball juggling.

Gaze

Acquisition of visual information through eye movements may be related to how jugglers of distinct skill levels control posture and face balance perturbations.

Dessing, Rey, and Beek (2012) found that novices look at balls around their vertical peak position while experts present a more stable, “gaze-through” strategy, fixating at the scene’s central location. This experts’ parsimonious oculomotor/attention pattern possibly results in improved neural coding of ball motion and arm movement plans (Dessing, Daffertshofer, Peper, & Beek, 2007; Dessing et al., 2012). Additionally, experts present weaker frequency locking between point-of-gaze and ball movements as compared to intermediates, suggesting that experts become increasingly less dependent on visually tracking the ball motion (Huys & Beek, 2002; Huys, Daffertshofer, & Beek, 2004). It is well known that saccadic and smooth pursuit eye movements affect posture during quiet stance (Aguiar et al., 2015; Rodrigues et al., 2013, 2015). Nevertheless, previous studies have not analyzed the linkage between visual search patterns and body sway during the juggling task, as explored in the present study.

Although the debate about motor control during juggling has produced a considerable body of literature, further studies are necessary to clarify posture-related issues, such as the roles of expertise, reduced feet distance, and eye movements. The present study applies combined effects of expertise level and base of support on body sway and gaze behavior, which characterizes specific addition to the literature. The aim of this study, therefore, was to investigate the effects of skill level (expert and intermediate) and base of support (wide and narrow) on body sway of jugglers during three-ball cascade juggling.

Hypothesis 1. Expert jugglers’ CoP would oscillate less than that of intermediate jugglers.

Hypothesis 2. Experts’ body sway would be less affected by the basis of support reduction than intermediate jugglers. The narrow basis of support was expected to decrease the body sway stabilization, especially in the medio-lateral axis.

Hypothesis 3. For exploratory purposes, some participants’ eye movements were recorded. It was expected that expert jugglers would exhibit a smaller gaze spatial distribution than intermediate jugglers.

Method

Participants

Ten expert jugglers (age = 25.5 ± 2.4 years; height: 1.74 ± 0.06 m, weight: 67.5 ± 9.9 kg, juggling experience: 61.2 ± 28.0 months, juggling practice: 4.4 ± 2.2 hours/week) and 11 intermediate jugglers (age: 25.0 ± 4.5 years, height: 1.73 ± 0.60 m, weight: 72.9 ± 9.6 kg, juggling experience: 40.5 ± 20.1 months, juggling practice: 1.6 ± 2.4 hours/week) participated in this study. Expert jugglers were defined as those who could juggle (cascade juggling) five or more balls for more than 1 minute and intermediate jugglers were defined as those who could comfortably maintain three-ball cascade juggling for more than 1 minute but not able to juggle four or more balls (Leroy et al., 2008).

The mean number of trials in which participants were unable to perform was 0.40 ($SD = 0.70$) for experts and 11.82 ($SD = 9.09$) for intermediates. All participants were self-identified right-handers (we asked participants which hand they used for manipulating objects such as scissors and toothbrush) and had no visual impairments that prevented performing the required tasks. After written informed consent was provided, participants were invited to participate in the study. This study was approved by the research ethics committee of the São Paulo State University at Bauru, SP, Brazil.

Procedure

Each participant stood barefoot on the force plate (AccuGait, AMTI, 100 Hz, 50 × 50 cm), with feet maintained parallel to each other but aligned with the shoulder (wide condition) or together (narrow condition), performing three 40-second trials of the three-ball cascade juggling task. Participants were instructed to self-select cascade juggling speed, throwing the balls at the height of their eyes and keeping the hands horizontally aligned to the shoulders. Each trial was videotaped using a 60-Hz video camera (Sony DCR DVD 205), which was placed approximately 2 m from participants to monitor the performance. From these video data, the number of complete ball cycles was obtained through a frame-by-frame analysis and compared in order to identify possible spatiotemporal differences of the balls' motion. Cascade juggling trials were performed with three rubber balls with which the jugglers were familiar (diameter: 62 mm; mass: 121 g). The order of the trials was randomized. Trials that the participant was unable to perform the task for 40 seconds, i.e., dropping the ball or changing the foot position, were repeated.

Nine participants (four experts and five intermediate jugglers) performed the juggling task using a wireless mobile eye tracker (Mobile Eye-5 glasses, ASL, Bedford, MA, USA) to measure gaze behavior (30 Hz). The eye tracker system was calibrated using the nine-point calibration method. Participants fixated their gaze on nine points displayed in a 3 × 3 grid. Calibration was also checked periodically between trials.

Data analysis

The three force and moment components, acquired in the vertical, anterior-posterior (AP), and mediolateral (ML) directions by the force plate, were used to analyze postural control. The first 10 seconds of each recording was not used to allow the juggler to stabilize his posture after starting cascade juggling. The mean CoP signal was also removed for each analysis. The data were then filtered with a fourth order low-pass Butterworth filter with a cutoff frequency of 3 Hz. The following parameters were calculated: the mean velocity of sway (i.e., the displacement of the total sway of the CoP divided by the total duration of the trial) and the standard deviation of sway displacement (i.e., the CoP variability around the mean CoP trajectory). Both parameters were calculated separately in the AP and ML directions. Furthermore, a spectral analysis (fast Fourier transformation) of the COP signal, separately in each direction, followed by a mean power frequency analysis was completed to provide an estimate of the median frequency contained within the power spectrum (software MATLAB, Mathworks). We choose to use these parameters because they indicate a global analysis which numerically expresses the magnitude of sway patterns; each parameter provides a distinct piece of information on postural control (Baratto, Morasso, Re, & Spada, 2002).

For gaze behavior, we analyzed the number of fixations, mean fixation duration, variability of mean fixation duration, and area of gaze displacement. The fixation criteria was as follows: fixation onset occurred when two times point of gaze standard deviation (95% confidence interval) was less than one degree of visual angle (horizontal and vertical) over 100 ms (seven data samples); fixation offset occurred when three data samples deviated from initial fixation value by more than one degree of visual angle (horizontal and vertical). Area of gaze displacement was calculated as the area of an ellipse that contained 85% of the horizontal and vertical gaze position data (see Figure 2), as suggested by Duarte and Freitas (2010).

Shapiro-Wilk's and Levene's tests were employed to check the normality of the distribution of data and the homogeneity of variances, respectively. Normal distribution of data and homogeneity of variances were not violated. For each dependent variable, two-way analyses of variance with factors for group (expert and intermediate jugglers) and condition (wide and narrow basis of support) were conducted with the last factor treated as a repeated measure. Tukey post hoc tests were carried out to identify the significant differences when significant main effect was found. In addition, the effect size (partial eta-squared, η_p^2) was measured for each statistical analysis. All the analyses were performed using SPSS (version 15.0) and significance level was set at .05.

Results

The number of complete ball cycles was not significantly related to group, condition, or the interaction between group and condition ($p > .05$), indicating the participants had consistent cascade juggling perceptual motor patterns. The mean number of complete ball cycles during the experiment was 17.87 ($SD = 0.70$) and 18.15 ($SD = 0.67$) for experts and intermediate jugglers, respectively. To illustrate the CoP behavior of intermediate and expert jugglers, Figure 1 shows a typical example of the time series of displacement of sway during cascade juggling on wide and narrow bases of support for both groups.

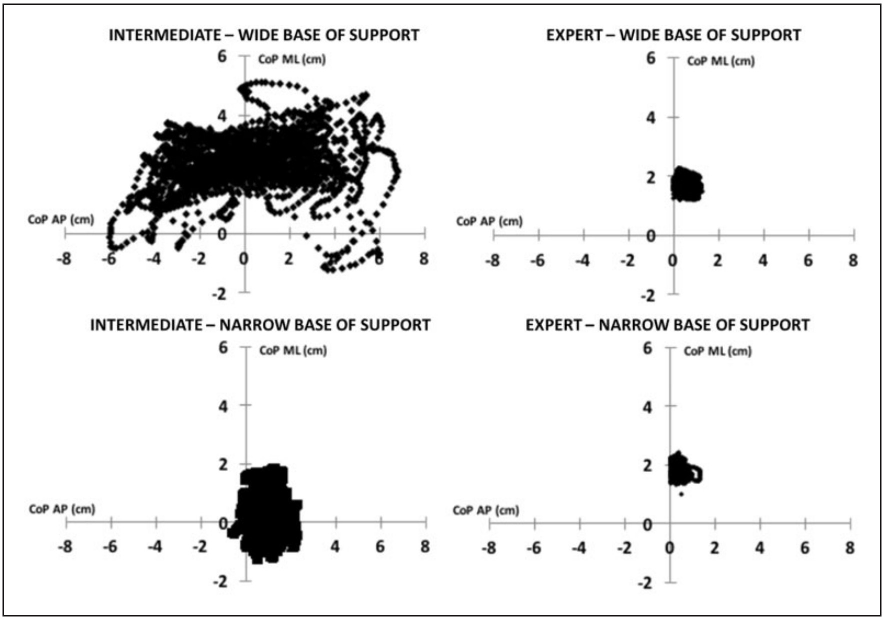

Figure 1. A typical example of the time series of displacement of sway during cascade juggling on wide and narrow bases of support in intermediate (left panels) and expert (right panels) jugglers.

Analysis of variance indicated significant main effects of group and condition on the dependent variables of postural control. Experts' body sway was characterized by lower velocity (AP) and smaller amplitude (AP and ML) as compared to the intermediate group (Table 1). Interestingly, the narrower basis of support caused significant attenuation in body sway for both groups, except for ML amplitude. However, the group by condition interaction indicated that this attenuation was significant only for intermediate jugglers as shown by the post hoc tests of mean velocity AP ($p < .001$) and AP sway amplitude ($p = .001$). Mean frequency of sway was significantly higher in the wide stance for both groups in AP.

To illustrate the gaze behavior of intermediate and expert jugglers, Figure 2 shows an example of the time series of displacement of line-of-gaze during cascade juggling on wide and narrow bases of support for both groups. Regarding gaze behavior parameters (Table 2), analysis of variance indicated a group by condition interaction, but no main effects of group or condition. Area of gaze displacement was significantly affected by the group by condition interaction; although post hoc comparisons between wide and narrow bases of support did not reach significance for experts ($p = .21$) and intermediates ($p = .08$), there were similarities between CoP (Figure 1) and gaze data

Table 1. Means and standard deviations of anterior-posterior (AP) and mediolateral (ML) mean velocity, sway amplitude, mean frequency, and number of ball cycles for the wide and narrow bases of support of experts and intermediate groups, with significance values for effects of group, condition, and group by condition interaction.

Dependent variable	Group	Condition	M	SD	Group effect (*p*)	Condition effect (*p*)	Group x condition interaction (*p*)
Mean velocity AP (cm/s)	Expert	Wide	4.33	2.56	.025 $F(1,19) = 5.91$ $\eta^2 = 0.23$	$< .001$ $F(1,19) = 24.74$ $\eta^2 = 0.56$	.047 $F(1,19) = 45.47$ $\eta^2 = 0.19$
		Narrow	1.54	1.54			
	Intermediate	Wide	9.55	6.69			
		Narrow	2.59	1.19			
Mean velocity ML (cm/s)	Expert	Wide	1.67	0.49	0.037 $F(1,19) = 5.02$ $\eta^2 = 0.21$	ns	ns
		Narrow	1.72	0.53			
	Intermediate	Wide	3.05	1.92			
		Narrow	2.75	1.46			
Sway amplitude AP (cm)	Expert	Wide	0.49	0.26	.023 $F(1,19) = 6.17$ $\eta^2 = 0.25$	.002 $F(1,19) = 12.14$ $\eta^2 = 0.39$	.037 $F(1,19) = 12.14$ $\eta^2 = 0.21$
		Narrow	0.34	0.06			
	Intermediate	Wide	1.09	0.76			
		Narrow	0.42	0.11			
Sway amplitude ML (cm)	Expert	Wide	0.33	0.08	.037 $F(1,19) = 5.03$ $\eta^2 = 0.21$	*ns*	*ns*
		Narrow	0.34	0.08			
	Intermediate	Wide	0.50	0.21			
		Narrow	0.45	0.19			
Mean frequency AP (Hz)	Expert	Wide	1.69	0.33	ns	$< .001$ $F(1,19) = 89.50$ $\eta^2 = 0.82$	ns
		Narrow	0.71	0.19			
	Intermediate	Wide	1.52	0.40			
		Narrow	0.90	0.32			
Mean frequency ML (Hz)	Expert	Wide	0.83	0.17	ns	ns	ns
		Narrow	0.80	0.13			
	Intermediate	Wide	1.00	0.33			
		Narrow	0.96	0.27			
No. ball cycles (units)	Expert	Wide	17.29	0.62	ns	ns	ns
		Narrow	18.13	0.78			
	Intermediate	Wide	16.62	0.78			
		Narrow	16.61	0.73			

Note. AP: anterior-posterior; ML: mediolateral; ns: nonsignificant ($p > .05$).

(Figure 2) in terms of experts' smaller displacements as compared with intermediates as well as the greater displacements under narrow base of support only for the intermediate group.

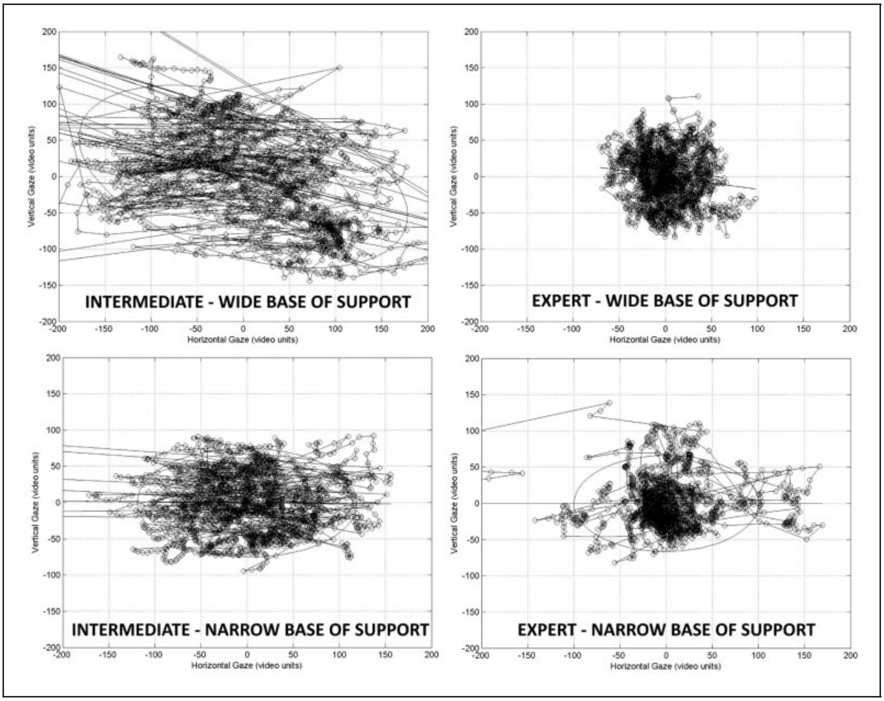

Figure 2. An example of the time series of displacement of line-of-gaze during cascade juggling on wide and narrow bases of support in intermediate (left panels) and expert (right panels) jugglers. Elipses represent area containing 85% of gaze data.

Discussion

The purpose of this study was to determine the effects of skill level and base of support on body sway of jugglers during three-ball cascade juggling. The main finding of this study was that only intermediate jugglers showed smaller oscillation in the narrow stance. In the following paragraphs, we will discuss hypotheses according to findings, offering interpretations of the effects of skill level, and base of support on body sway of jugglers during cascade ball juggling.

As expected, expert jugglers showed superior postural stabilization, corroborating the notion according to which juggling skill level is associated with decreased body sway (Hypothesis 1); it is the first time this has been demonstrated by CoP data. As mentioned above, expertise seems to similarly affect other motor skills, such as rifle shooting, manual rythmic movements, circus activities, and gymnastics. For instance, expertise in gymnastics was considered an intrinsic constraint of postural control because it affected the dynamical organization of posture in response to tracking a visual stimulus with the

Table 2. Means and standard deviations of number of fixations, mean fixation duration, variability of mean fixation duration, and area of gaze displacement for the wide and narrow bases of support of experts and intermediate groups, with significance values for effects of group, condition, and group by condition interaction.

Dependent variable	Group	Condition	*M*	*SD*	Group effect (*p*)	Condition effect (*p*)	Group × condition interaction (*p*)
No. fixations (units)	Expert	Wide	102.59	23.41	ns	ns	ns
		Narrow	113.08	16.19			
	Intermediate	Wide	116.60	23.68			
		Narrow	126.20	20.51			
Mean fixation duration (s)	Expert	Wide	0.26	0.13	ns	ns	ns
		Narrow	0.24	0.10			
	Intermediate	Wide	0.19	0.05			
		Narrow	0.22	0.07			
Variability of mean fixation duration (s)	Expert	Wide	0.26	0.15	ns	ns	ns
		Narrow	0.19	0.04			
	Intermediate	Wide	0.24	0.11			
		Narrow	0.22	0.07			
Area of gaze displacement (video units)	Expert	Wide	14,307.11	17,885.20	ns	ns	0.028 $F(1,7) = 7.60$ $\eta^2 = 0.52$
		Narrow	18,570.69	21,346.80			
	Intermediate	Wide	20,536.96	11,489.52			
		Narrow	15,922.72	6,818.89			

Note. ns: nonsignificant ($p > .05$).

head (Marin, Bardy, & Bootsma, 1999). Additionally, specific postural experience modified the ability to coordinate and regulate posture when gymnasts could react rapidly after destabilization to reduce CoP and angular lower limbs movements; to stabilize posture, gymnasts used their knees, whereas the nongymnasts used their hips (Gautier et al., 2008). In a study with jugglers, Leroy et al. (2008) found that, although experts and intermediate participants showed similar body sway amplitude (measured through sacrum lateral displacement), the skilled group was able to perform anticipatory postural adjustments differently from novice jugglers. Similarly, the findings of the present study clearly show that greater skill level in juggling is associated with more consistent patterns of CoP displacements, characterized by measures of mean velocity and amplitude in both AP and ML axes. In addition, intermediate participants had a much higher number of trials in which they were unable to complete the juggling trial as compared to experts, corroborating the effect of skill level on task performance.

The increased body sway of intermediate jugglers could be explained by the larger area of gaze displacement observed throughout each trial (our third hypothesis). A more stable, spatially reduced gaze pattern, named gaze-through strategy (Dessing et al., 2012), may improve movement planning via the attentional system (Shulman, Remington, & Mclean, 1979; Williams & Davids, 1998). During a gaze fixation, balls move in the retinal periphery, which most likely involves a stage operating in gaze-centered coordinates that is more accurate (Dessing, Crawford, & Medendorp, 2011; Dessing et al., 2012). With a more stable gaze, movement planning is improved because the entire visual background is stable with allocentric and gaze-centered representations aligned (Dessing et al., 2012; Huys & Beek, 2002). In the present study, although visual information acquisition through fixation patterns (number of fixations, mean duration of fixations and its variability) was not affected by group or condition, the significant base of support by group interaction found for the area of gaze displacement seems to corroborate the experts' gaze-through strategy, suggesting an attentional linkage between postural (CoP) and visual (gaze) stability. As expected, experts were less dependent on foveal vision (Huys & Beek, 2002), which is in line with the notion that experts are more capable of decoupling the control of posture and bimanual rhythmic arm movements (Amado et al., 2016); intermediates moved their gaze around a larger visual area, suggesting they were spatially searching for the balls, which seems associated with the destabilization of body sway.

In sum, intermediate jugglers performed under a higher attentional load (with the maximal number of balls of which they were capable—three, as compared with at least five balls for experts) and prioritized the manipulative task (once the juggling task was successfully maintained) as compared to postural control, increasing sway differently from experts who were able to deal better with both manipulative task and postural control (Yogev-Seligmann, Hausdorf, & Gilardi, 2012). It is worth of note that the present study used a small sample size for this exploratory gaze data, and it is well known the high inter-individual variability of this type of data (Williams, Davids, Burwitz, & Williams, 1993) requiring this interpretation be confirmed with larger sample size.

The narrow base of support was expected to increase body sway, especially in the ML axis (our second hypothesis). The significant effect of base of support was surprising in the sense that greater postural instability is expected during more challenging tasks, but the opposite was observed. Particularly, intermediate jugglers increased the sway laterally more than experts to facilitate their arm movement pattern, as shown by the significant main effect of group on the ML sway amplitude. Leroy et al. (2008) found similar trunk lateral displacements between groups, but their jugglers were in regular, wide stances; authors interpreted these movements as a minimization of the center of mass trajectory while juggling, supporting their hypothesis of facilitatory postural control. In line with this interpretation, Giese, Dijkstra, Schoner, and Gielen (1996) suggested that posture may relate to other movement tasks by stabilizing against the mechanical perturbations induced by such movements. When the participants of the present study had to place their feet together, the smaller base of support was not sufficient to allow the larger postural compensation for arm movements observed during the wide stance condition, with their body sway being mechanically constrained in order to accomplish the task requirements.

Intermediate jugglers showed significantly smaller oscillation in the narrow stance. It was hypothesized that experts would be less affected by the basis of support reduction than intermediate jugglers (Hypothesis 2), which was supported by the results. Expert jugglers showed differences in body oscillation between narrow and wide stances, which were not significant, while the intermediate group was clearly affected by the smaller basis of support and had to reduce more drastically their body sway to keep balance and the juggling task ongoing. Previous studies have shown effects of the experience and motor specialization on the improvement of postural control (Leroy et al., 2008; Marin et al., 1999; Perrin, Deviterne, Hugel, & Perrot, 2002; Yoshitomi et al., 2006). The present results seem to suggest a "posture first" strategy during the juggling task, according to which individuals prioritize posture (Shumway-Cook et al., 1997), reducing body sway in more difficult postural task (narrow bases of support), over success on a more demanding secondary task (cascade juggling).

The data could also be generally explained through the notion of facilitatory postural control (Stoffregen, Smart, Bardy, & Pagulayan, 1999), according to which posture facilitates the achievement of suprapostural tasks. However, Mitra (2004) proposed an adaptive resource-sharing view of postural–suprapostural multitasking, adding the possibility of a hybrid pattern between autonomous and facilitatory type of control. Mitra's hypothesis predicts facilitatory control when keeping balance is easy (wide basis of support, in the present study), the suprapostural task requires high precision (e.g., visual information pickup relative to balls and arms), and it can be helped by postural adjustments (e.g., ML body sway) allowing a facilitatory sway over an automatic response to visual information. According to this view, as the postural difficulty increases (e.g., in the present study this is the narrow base condition), information associated with more automatic postural responses to visual stimuli and do not compromise the suprapostural task. This characterizes a hybrid pattern of body sway (Mitra, 2004). Autonomous patterns are characteristic only when the postural task becomes extremely difficult and/or the risk of balance failure becomes imminent, situations in which facilitation is not possible.

The core notion of this model is that the control of postural and suprapostural elements share the same capacity-limited resources. Several aspects are responsible for the prioritization of these resources to each task component: precision involved, effectiveness of available information, difficulty of simultaneously acquiring this information, and the cognitive (attention and working memory-related) load (Mitra, 2004). Present data showed that posture was altered in an adaptive manner to aid juggling performance. The definition of expertise (ability to juggle five balls or more) favored the group's more complex sensory-motor skills and increased the relationship between the base of support and the arm motion. A relatively lower cognitive load for the experts, minimizing the competition for the same resources, might explain why they were less affected than intermediate jugglers when the base of support was reduced. On the other hand, a reduction in the amount of movement, such as smaller arm movements, could also explain the reduce body sway. Less movement causes a minimization of energy expenditure, which seems to improve postural control. The present results suggest that oscillating more in the wide basis of support was advantageous, allowing adjustment of posture to the arm movements of juggling; the narrower base of support may have constrained trunk movements, limiting the efficiency of adjustments to ball trajectory as mentioned above. In addition, a wide base is the natural (preferred) foot distance for the stance. This base of support requires less effort to maintain static postural control, which may reduce neuromuscular fatigue or may reserve neuromuscular control effort to cope with unexpected disturbances (Kim et al., 2014). Therefore, intermediate jugglers showed reduced body sway during juggling on the narrow base, which could represent a conservative strategy to avoid loss of balance. However, even so they were efficient in the manipulative task.

Limitations and conclusion

Several limitations of this study are evident. Despite the importance of the findings, we did not analyze hand movement and hand/ball relation. This information is important to show if hand movements influenced body sway and how this aspect is related to postural control. However, we tried to minimize this problem by standardizing the upper limb position. We suggest to consider hand movement and hand/ball relation in future studies. We analyzed the gaze behavior in half of the participants; as mentioned above, these results should be assessed with caution.

Expertise in cascade juggling seems to be associated with refined postural control. Overall, experts had a reduced sway as compared to intermediate jugglers. Additionally, experts' smaller attenuation of body sway due to increased stance difficulty was sufficient to control cascade juggling successfully. However, intermediate jugglers needed to reduce their body sway to keep balance and the cascade juggling task ongoing under the narrow stance.

Declaration of Conflicting Interests

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