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Effects of eliminating visual cues on kinetic and kinematic parameters in back tuck somersault: A comparison between artistic gymnasts and parkour athletes

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Purpose: The aim of this study was to compare the effect of vision (i.e., open and closed eyes) on the kinetic and kinematic parameters of the standing back tuck somersault (SBTS) in artistic gymnasts and parkour athletes. *Methods*: Eleven male parkour athletes (age 22.53 ± 2.36 years; height 1.72 ± 0.08 m; weight 69.58 ± 3.72 kg) and seven male artistic gymnasts (age 21.96 ± 2.64 years; height 1.62 ± 0.02 m; weight 63.54 ± 1.35 kg) participated in this study. Each subject was asked to perform the SBTS in the same condition (i.e., first open-eyes then closed-eyes). 2D kinetic and kinematic analysis was conducted. *Results*: The results showed significant interaction (i.e., vision and sport) obtained at the take-off angle ($p < 0.05$ and $d = 1.992$), horizontal displacement ($p < 0.05$ and $d = 1.906$) and technical execution ($p < 0.05$ and $d = 1.972$). This interaction indicates that when vision is permitted, artistic gymnasts and parkour athletes were similar in all kinetic and kinematic parameters, and technical execution ($p > 0.05$). However, the elimination of vision during SBTS only affected parkour athletes (i.e., landing angle, ground reaction force, vertical velocity and technical execution, $p < 0.05$ and $d > 1.20$) while artistic gymnasts remain unchanged. *Conclusion*: We conclude that the specificity of the practice in each of the two sports disciplines influences the kinetic and kinematic control of the SBTS and suggests that with closed-eyes, the integration of afferent information relating to the vestibular and proprioceptive systems is different and specific to each discipline's goal. Artistic gymnasts seem to be better skilled in the mechanical and technical control of the SBTS than parkour athletes.

Key words: *motion analysis, standing back tuck somersault, open/closed eyes, artistic gymnasts, parkour athletes*

1. Introduction

It is generally accepted that recent models of movement control have recognized that the execution of voluntary movements involves cooperation between central planning processes responsible for movement initiation and feedback (and feedforward) mechanisms for online corrections of the ongoing movement [7], [34], [41], [44]. Although, vision is widely recognized as the main source of afferent information when a high level of spatial accuracy is needed [45], complex skills, like in gymnastics, requires the simultaneous contribution and integration of all available afferent information [5], [19]. This afferent information is principally issued from three sensory systems, which are the visual system, the vestibular system, and the tactilo-proprioceptive system [6], [19].

The otolithic organs located at the base of the vestibular system allow the sensation of gravity and the detection of linear acceleration of the head and of gravity [32]. The semicircular canals of the vestibular system are the main tools for detecting movements and angular acceleration of the head [9]. The proprioceptive system, also called intrafusal muscle fibers (located parallel to the standard or extrafusal muscle fibers), is

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composed of specialized sensors that detect the magnitude and rate of muscle stretch. Specifically, nuclear bag fibers detect the rate of muscle stretch and nuclear chain fibers sense the magnitude (amplitude) of stretch. The Golgi tendon organ is stimulated by muscle tension. When muscle tension increases at a level that would harm the tissues, the Golgi tendon organ sends a signal to the spinal cord facilitating the alpha motor neurons of the antagonist muscle and inhibiting those of the agonist, a kind of protective mechanism [24].

In artistic gymnastics, regardless of the gymnastic apparatus (e.g., floor, balance beam, high bar, etc.), most gymnastic exercises are performed in space, like all kind of back somersaults which involve a high degree of body control. This last skill is considered as one of the most frequently used skills in artistic gymnastics. This acrobatic movement, performed on the floor, trampoline or on other gymnastic apparatus, with a straight body or tucked legs, alone or combined with one or a series of movements requires a high degree of proprioceptive control, as the body must perform a series of coordinated movements in a specific sequence [27].

For the interest of this study, we focused on the standing back tuck somersault (SBTS) on the floor. When performing this skill (i.e., SBTS), the gymnast's sight is directed forwards, then a little bit upwards when rotating backwards. In this case, the gymnast cannot see his own body as it has evolved, which highlights the importance of the vestibular system and proprioceptive afference for skills control. The question at hand is whether the gymnasts also rely on their visual system during the performance of the SBTS. In this regard, some researchers manipulated the presence or absence of vision to assess the subject's ability to use the visual cues available in the environment [13] or, more particularly, in the foveal or peripheral fields [12]. Bardy and Laurent [3], for their part, examined the visual basis of the regulation of the moment of inertia of the standing back tuck somersault in experts and novices in vision and non-vision conditions. In all cases, the findings support the importance of visual cues for orientation, regulation and control of the somersault when vision was allowed.

The kinetic and kinematic analysis of the different phases of the SBTS was widely investigated in several recent studies [22], [25]–[27], [29]. Indeed, Mkaouer et al. [28], for example, have attempted to compare the kinetic and kinematic parameters during the landing phase of standing back somersault following three different technical arm-swings performed during the preparatory phase in high-level male gymnasts. Results showed that despite the best vertical displacement being observed with the 270° arm angle technique, the 90° arm-swing angle seems to favor a better absorption of the ground reaction force upon landing by reducing the intensity of the impact with the ground and by affording a landing angle closer to the vertical. Morales et al. [29] on their part, aimed to study how hip extension in the take-off of the tucked back somersault influences the execution of the somersault. They demonstrated that the hip angle indirectly influenced the height and the angular velocity of the somersault.

Even if SBTS is frequently used by artistic gymnasts (AG), it is also well practiced by parkour athletes (PA). Athletes in this last sports discipline aim to move fluidly through their environment, using their bodies to overcome physical barriers in the most efficient way possible [31]. The focus is on developing skills like balance, agility and spatial awareness, as well as mental discipline and risk management. While there is some overlap between parkour and gymnastics in terms of the acrobatic movements they involve, their training methods and philosophies are quite different. Parkour is a non-Olympic discipline that emphasizes self-improvement and creative expression, while gymnastics is a highly structured sport with a focus on competition and achieving specific performance goals. However, it is worth noting that the majority, if not all, kinetic and kinematic studies of the back somersault concerned exclusively artistic gymnastics and a few other sport disciplines like diving but never, in our knowledge, the parkour sport.

Thus, the aim of this study was to compare the effect of vision (i.e., open and closed eyes) on the kinetic and kinematic parameters of the SBTS in artistic gymnasts and parkour athletes. We hypothesized that the artistic gymnasts could demonstrate better mechanical control of SBTS when vision is deprived than the parkour athletes.

2. Materials and methods

Participants

A priori power analysis with type I error of 0.05 and 80% statistical power was computed using G*Power software (Version 3.1, University of Dusseldorf, Germany [16]). The analysis indicated that a minimum of 16 participants is sufficient to observe a significant, large effect size (d = 1.20 and critical t = 2.114) for kinetic (i.e., vertical ground reaction force) and kinematic variables (i.e., joint angles and velocity) [27], [28].

In order to conduct this study, eleven parkours athletes (age 22.53 ± 2.36 years; height 1.72 ± 0.08 m; weight 69.58 ± 3.72 kg; training average 18 ± 2 h/week) and seven artistic gymnasts (age 21.96 ± 2.64 years; height 1.62 ± 0.02 m; weight 63.54 ± 1.35 kg; training average 20 ± 2 h/week) volunteered. The participants had no neurological, muscle nor tendon injuries and were in good condition. Of note, two participants were eliminated because they did not meet the required criteria and standards of the study. All participant agreed to participate in the study by signing a permission form after being fully told about the procedures, methods, various benefits, and potential risks of the study in advance. All gymnasts are familiar with the standing tuck back somersault. The trial was conducted in conformity with the Declaration of Helsinki for human experimentation [8] and was approved by the Ethical Committee of the National Observatory of Sport (ONS/UR/18JS01).

Experimental design

This study was planned over two sessions, to see the immediate effect of eliminating vision on self-organization and mechanical control (i.e., kinetics and kinematics parameters) of standing back tuck somersault (SBTS) in comparison between artistic gymnasts and parkour athletes.

Technically, the SBTS is composed of four phases: counter movement, take-off, flight (airborn) and landing [22]. The aim of the counter movement is to create optimal conditions for the implementation of the take-off phase. This last phase aims to provide the projec tion velocity needed to lift the body and the angular momentum required to perform a rotary motion. The flight phase is composed by the grouping and the ungrouping of the body. The aim here is to conserve the angular momentum created initially [14]. Finally, the landing phase aims to break the angular momentum of the body and to restore a standing position without any damage to joints (Fig. 1).

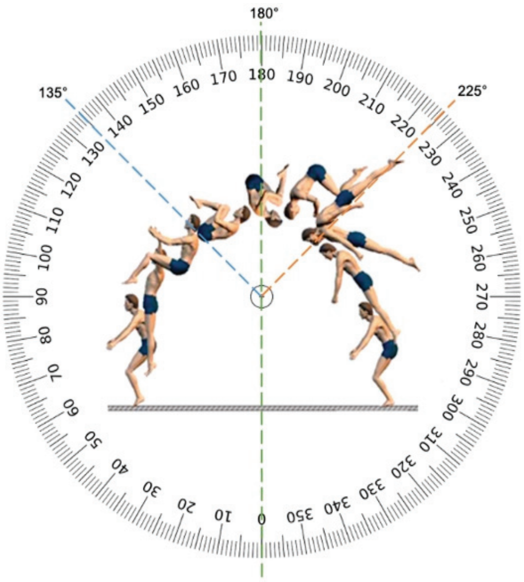

Fig. 1. Standing back tuck somersault with the different angles of study

During the first session, four international judges evaluated the technical execution (i.e., two attempts) of each gymnast/parkour athlete when performing a SBTS in normal condition (i.e., with open eyes) prescribed by the international gymnastics federation (FIG) code of point [17] in order to design a scoring scale (Table 1). This is a double method called "kinetic and kinematic", and it is done across two days from 14:00 to 16:00. Through the time code "TC-Link", video acquisition (i.e., 2D video analysis using PNJ cam S60 Full HD, 1080p, 120 Hz, AEE Technology, Saint Quentin Fallavier, France) is synced with the force-plate (i.e., Kistler Quattro Jump, type: 9290AD, ref. 2822A11, sampling frequency 500 Hz, Kistler Group, Winterthur, Switzerland) [1]. Kinovea 8.15 freeware (www.kinovea.org/en/downloads/) [38] was used for video data analysis [30]. The two trials were used for the absolute and relative reliability analysis.

During the second session (e.g., spaced by 24 hours and in the same hour of the day), the sample (i.e., AG

Table 1. Standing Back Tuck Somersault Scoring System

Scores	Take-off		Grouping		Ungrouping		Landing	
	take-off angle [°]	trunk/leg angle [°]	trunk/legs angle [°]	thigh/leg angle [°]	vertical displacement [m]	trunk/legs angle [°]	distance [m]	stability [m]
Very good (2 pt)	0–10	185–190	30–35	30–45	more than 0.50	165–175	on the spot	0 Step
Good (1.5 pt)	11–20	191–195	36–40	46–60	0.41–0.50	145–164	0.10–0.2	1 Small step
Average (1 pt)	21–30	196–200	41–45	61–75	0.31–0.40	125–144	0.21–0.30	1 Big step
Weak (0.5 pt)	more than 30	201–205	46–50	76–90	0.20–0.30	100–124 or less	more than 0.30	many steps

and PA) was asked to perform the SBTS with open-eyes, then with closed-eyes (i.e., blindfolded) to compare the two conditions (i.e., open and closed eyes) and emphasize the important points to better manage/self-organize the SBTS in absence of vision.

Procedures

Before data collection, each participant performed a ten-minute warm-up including jogging, stretching and jumping with stable landing exercises. The gymnast/parkour athletes started in a standing position on the force-plate with a camera placed in profile at 4 m. They were required to perform the SBTS with open-eyes, then with closed-eyes. Two attempts were allowed with 2 minutes of recovery between attempts and 6 minutes between each condition (i.e., open and closed eyes). The best trial is retained for analysis. Kinetic (i.e., ground reaction force and power), linear kinematics (i.e., vertical and horizontal velocity and displacement), and angular kinematic (i.e., take-off, grouping angle at 135° and 180°, ungrouping angle at 225° and landing angle) data and technical performance was collected and used for further analysis.

Statistical analysis

The data analysis was done using the SPSS 20 package (SPSS, Chicago, IL, USA) software. Data are reported as mean ± standard deviation (SD) and 95% confidence intervals (95% CI). Effect size (*d*) was calculated using GPOWER software [16]. The following scale was used for the interpretation of *d*: < 0.2, (trivial), 0.2–0.6, (small), 0.7–1.2, (moderate), 1.3–2.0, (large), and >2.0, (very large) [21], [39]. The normality of the distribution, estimated by the Shapiro–Wilk test, was acceptable for all variables. Therefore, mixed ANOVA was applied to compare the different SBTS conditions (i.e., open and closed eyes) and sports (i.e., AG and PA). Pairwise comparison was conducted using the *T*-test. Additionally, the relative and absolute reliability of SBTS in normal condition (i.e., open-eyes) were examined using the intraclass correlation coefficient (ICC) and the typical error of measurement (TEM) expressed as coefficient of variation (CV), respectively. The level of significance was set at $p < 0.05$.

3. Results

The absolute and relative reliability of SBTS measured for AG and PA was very high (Table 2). In addition, there is no significant difference ($p > 0.05$) between sports (i.e., AG and PA) in kinetics, linear and angular kinematics variables when performing SBTS in vision (i.e., open-eyes).

Results of mixed ANOVA showed a significant interaction vision*sports in the linear kinematics (i.e., horizontal displacement $\Delta_{\%} = -17.15\%$ vs. 21.52% respectively AG and PA with $p < 0.05$ and $d = 1.992$), angular kinematics (i.e., take-off angle $\Delta_{\%} = -10.75$ % vs. 19.89% respectively AG and PA with $p < 0.05$ and $d = 1.906$), and technical execution (i.e., $\Delta_{\%} = -5.21\%$

Table 2. Statistical analysis of the absolute and relative reliability of the standing back tuck somersault

R1 vs. R2		Mean ± SD	*T*-test (*p*)	TEM	$\text{TEM}_{(\%)}$	$\text{ICC}_{(95\%\ \text{CI})}$
Force [N/kg]	AG_{R1} AG_{R2}	28.90 ± 6.15 29.08 ± 6.31	0.239	0.01	0.04	0.999 (0.994–1.000)
	PA_{R1} PA_{R2}	24.52 ± 4.47 24.38 ± 4.69	0.469	0.60	0.28	0.910 (0.809–0.958)
Velocity [m/s]	AG_{R1} AG_{R2}	2.68 ± 0.20 2.69 ± 0.23	0.658	0.01	0.34	0.977 (0.868–0.996)
	PA_{R1} PA_{R2}	2.89 ± 0.29 2.86 ± 0.22	0.270	0.02	0.85	0.952 (0.898–0.977)
Power [W/kg]	AG_{R1} AG_{R2}	58.95 ± 8.17 59.02 ± 8.13	0.655	0.01	0.01	0.999 (0.994–1.000)
	PA_{R1} PA_{R2}	61.15 ± 10.59 61.08 ± 8.83	0.712	1.50	2.44	0.920 (0.831–0.963)
Vertical displacement [m]	AG_{R1} AG_{R2}	0.54 ± 0.05 0.55 ± 0.05	0.200	0.01	0.11	0.994 (0.968–0.999)
	PA_{R1} PA_{R2}	0.51 ± 0.12 0.50 ± 0.11	0.429	0.822	0.42	0.982 (0.962–0.992)

(AG) artistic gymnasts, (PA) parkour athletes, (R_1) first repetition, (R_2) second repetition, (TEM) typical error of measurement, (ICC) Intra-class correlation coefficient.

Table 3. Mixed ANOVA of the standing back tuck somersault in vision and blind vision conditions

Source		*df*	Mean square	*F*	Sig.	Effect size (*d*)	Power
Vision	Take-off angle	1	1.432	0.318	0.581	0.278	0.083
	Grp 135°	1	0.510	0.005	0.943	0.020	0.051
	Grp 180°	1	0.427	0.011	0.916	0.063	0.051
	Ung 225°	1	43.990	1.419	0.251	0.593	0.202
	Landing angle	1	7.131	0.142	0.712	0.190	0.065
	dx	1	14.000	0.102	0.753	0.155	0.060
	Fy	1	0.704	0.826	0.377	0.454	0.137
	Vy	1	0.010	0.239	0.632	0.246	0.075
	Py	1	0.222	0.006	0.940	0.020	0.051
	dy	1	8.578	0.144	0.709	0.190	0.065
	Perf	1	12.886	23.937	0.000**	2.444	0.996
Sports	Take-off angle	1	21.442	1.165	0.296	0.540	0.174
	Grp 135°	1	121.273	0.420	0.526	0.326	0.094
	Grp 180°	1	21.057	0.165	0.690	0.201	0.067
	Ung 225°	1	1.164	0.010	0.921	0.163	0.051
	Landing angle	1	2500.970	4.842	0.043*	1.493	0.543
	dx	1	140.018	0.381	0.546	0.306	0.089
	Fy	1	178.601	4.532	0.049*	1.350	0.516
	Vy	1	0.539	6.547	0.021*	1.278	0.671
	Py	1	91.800	0.890	0.359	0.473	0.144
	dy	1	87.112	0.657	0.430	0.402	0.119
	Perf	1	47.144	7.294	0.016*	1.530	0.718
Vision*sports	Take-off angle	1	19.484	4.327	0.050*	1.992	0.518
	Grp 135°	1	318.488	3.294	0.088	0.908	0.400
	Grp 180°	1	110.560	2.952	0.105	0.859	0.365
	Ung 225°	1	62.190	2.006	0.176	0.706	0.266
	Landing angle	1	0.029	0.001	0.981	0.020	0.050
	dx	1	546.667	3.989	0.050*	1.906	0.516
	Fy	1	1.013	1.188	0.292	0.544	0.176
	Vy	1	0.016	0.380	0.546	0.306	0.089
	Py	1	0.211	0.006	0.941	0.020	0.051
	dy	1	0.027	0.000	0.983	0.020	0.050
	TE	1	1.949	3.620	0.050*	1.972	0.503

(Grp 135°) grouping angle at 135°, (Grp 180°) grouping angle at 180°, (Ung 225°) ungrouping angle at 225°, (*dx*) horizontal displacement, (*dy*) vertical displacement, (*Fy*) vertical ground reaction force, (*Py*) vertical power, (*Vy*) vertical velocity, (TE) technical execution, (*) significant at $p < 0.05$, (**) significant at $p < 0.01$.

vs. –14.73% respectively AG and PA with $p < 0.05$ and $d = 1.972$). The kinetic variables did not show any interaction vision*sports (Table 3).

Within-group analysis showed a significant difference between SBTS conditions (i.e., open and closed eyes) only in PA, in the angular kinematic (i.e., take-off angle 8.23 ± 2.74° vs. 10.15 ± 4.13° respectively open and closed eyes with $p < 0.05$ and $d = 1.664$; Fig. 2a), the linear kinematics (i.e., horizontal displacement 0.33 ± 0.15 m vs. 0.43 ± 0.12 m, respectively open and closed eyes with $p < 0.05$ and $d = 1.760$; Fig. 2b), and the technical execution (13.27 ± 1.29 pt vs. 11.56 ± 1.97 pt, respectively open and closed eyes with $p < 0.01$ and $d = 2.914$; Fig. 2c) variables, AG remains quasi-stable (i.e., no significant difference) when performing SBTS with closed-eyes.

Between-groups analysis (i.e., AG vs. PA) showed a significant difference only in closed-eyes condition, in the kinetic (i.e., vertical force 29.31 ± 3.10 N/kg vs. 24.40 ± 2.64 N/kg, respectively AG and PA with $p < 0.05$ and $d = 1.705$), the linear kinematic (i.e., vertical velocity 2.79 ± 0.19 m/s vs. 3.01 ± 0.21 m/s, respectively AG and PA with $p < 0.05$ and $d = 1.278$), the angular kinematic (i.e., landing angle 77.57 ± 12.47° vs. 94.72 ± 15.66° respectively AG and PA with $p < 0.05$ and $d = 1.211$), and the technical execution (14.39 ± 2.40 pt vs. 11.56 ± 1.97 pt, respectively AG and PA with $p < 0.05$ and $d = 1.288$) variables, (Table 3). In open-eyes condition, there is no difference between AG and PA in SBTS in all variables studied.

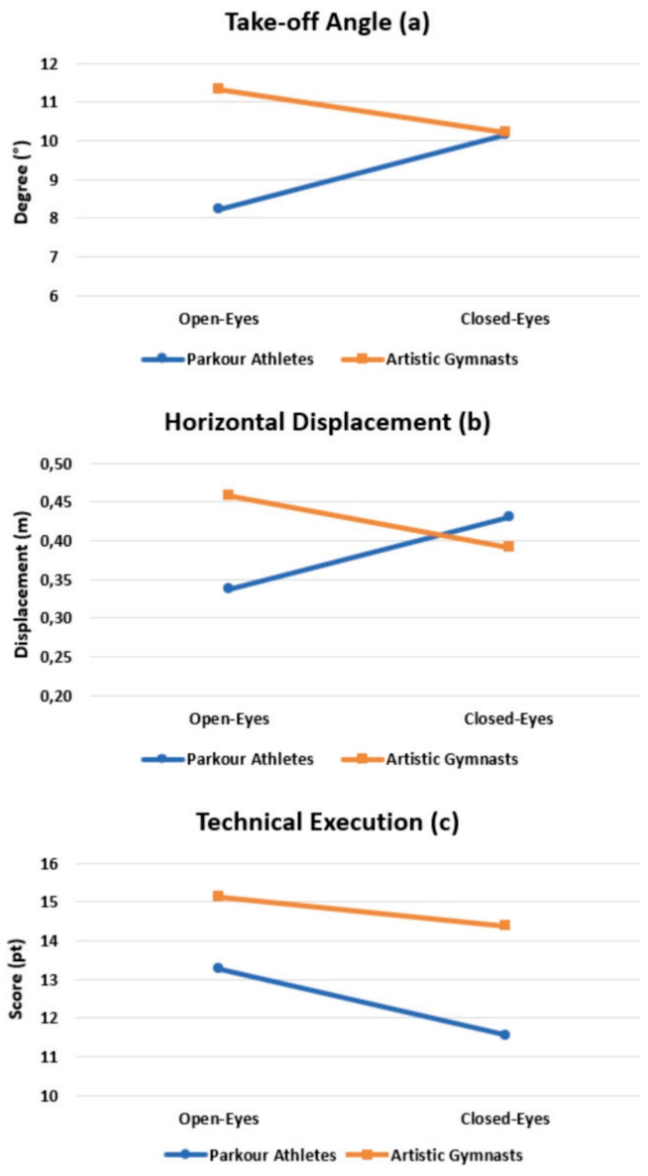

Fig. 2. Factors that vary between vision and blind vision

4. Discussion

This study aimed to compare the effect of vision (i.e., open and closed eyes) on the kinetic and kinematic parameters of the standing back tuck somersault in artistic gymnasts and parkour athletes.

First, the result showed an interaction between vision modes (i.e., open and closed eyes) and sports discipline (i.e., AG or PA) at the level of the take-off angle, the horizontal displacement, and the technical execution parameters. Regarding the take-off, this interaction indicates that although the two groups behaved nearly the same at the take-off level in both open and closed eyes ($p > 0.05$), the elimination of vision caused a significant deterioration in the take-off angle among the PA (i.e., 8.23 ± 2.74° vs. 10.15 ± 4.13°, respectively open and closed eyes, $p < 0.05$), while the AG maintained their take-off position similar to that in vision (i.e., 11.33 ± 3.81° vs. 10.23 ± 2.35°, respectively open and closed eyes, $p > 0.05$). This result seems to suggest that when taking off in a visual condition, PA used certain visual cues that allowed them to control their take-off and to guide the orientation of their body and decide when to initiate rotation. In this regard, Berthoz and Pozzo [4] demonstrated that during the elevation phase the head is stabilized and the brain can use a combination of visual and vestibular cues to guide the movement, control the posture, and, more importantly, trigger the backward rotation with the appropriate orientation and acceleration. However, in a situation of closed-eyes, these visual cues are not available to use, which has affected the take-off angle of PA. These results support those obtained in several studies [3], [12], [13], [20], [23] which confirmed the use of visual cues during the back somersault.

Additionally, our findings show that the use of these visual cues is restricted to take-off. In fact, neither AG nor PA saw any significant effects from the loss of vision at the positions 135°, 180°, 225°, or the landing angle ($p > 0.05$). This lack of impact is most likely caused by the fact that the head's velocity when rotating backwards increases so much after take-off that the visual system is unable to process and integrate the information around it. The existence of a velocity barrier known as the "critical flicker fusion threshold" has also been demonstrated by Anand, et al. [2], beyond which the visual system is unable to retain a clear and continuous image of the world. Moreover, a gymnast's head peak angular velocity has been observed to reach 750°/s to 800°/s when executing the second phase (i.e., from 130° to 225°) of SBTS following take-off [3], [4]. This rate is widely superior to the average capacity of the visual system in humans (i.e., 200°/s), [4]. In this case, AG and PA rely on the vestibular and proprioceptive systems [46] integrating all the data from the system [10], [33] to control the SBTS.

Similar results were seen in horizontal displacement parameters. Indeed, when vision was permitted, the landing distance for the two groups was the same ($p > 0.05$). However, the privation of vision had affected the PA but not the AG as a consequence of the take-off angle achieved by each group in this same visual condition (i.e., eyes-closed). Thus, the horizontal displacement of the PA was larger eyes closed than eyes open (i.e., 0.338 ± 0.151 m vs. 0.430 ± 0.125 m, respectively open and closed eyes, $p < 0.05$), while no changes were noted in AG (0.458 ± 0.193 m vs. 0.391 ± 0.180 m, respectively open and closed eyes, $p > 0.05$).

Regarding technical execution, AG initially were equivalent to PA ($p < 0.05$), when vision was permitted and they maintained their level of performance when vision was eliminated (15.14 ± 1.88 pt vs. 14.4 ± 2.4 pt, respectively open and closed eyes, $p > 0.05$), while PA deteriorated as soon as they were deprived of vision (13.27 ± 1.3 pt vs. 14.4 ± 2.4 pt, respectively open and closed eyes, $p < 0.05$). This could be due to the fact that AG relies more on the repetition and automation of technical gestures in addition to the continual search for precision, perfection, virtuosity and stability [42]. This can not only reinforce the vestibular and proprioceptive sensations of the gymnast, but also enable him to be very little impacted when visual afferences are not available. On the other hand, PA relies more on variability, creativity and diversification of practice with a continual search for new figures and combinations, which, in turn, develop the vestibular and proprioceptive sensations, but not enough to enable the athletes to proceed without visual refferences. This explains why PA deteriorates as soon as the vision is withdrawn. In this case, PA athletes need to integrate visual afferences with the other sources of afferences to guarantee a high level of performance. In this regard, while some authors suggest that proprioception alone is sufficient for human gesture control [15], [18], [40], the combination of visual and proprioceptive afferents constitutes one of the essential parameters of sporting success [5], [19]. The proprioception is then calibrated by vision for optimal control of the motor gesture [19].

Secondly, our results showed that when vision was not permitted, AG produces more ground reaction force during take-off than PA (29.3 ± 7.1 N/kg vs. 24.4 ± 2.6 N/kg, respectively AG and PA $p < 0.05$). On the other hand, in this same back somersault sequence, the PA was faster than the AG (3.0 ± 0.2 m/s vs. 2.79 ± 0.19 m/s, respectively PA and GA, $p < 0.05$). Taking the requirements of these two sports disciplines into account, this result seems very plausible. Indeed, in artistic gymnastics, the gymnast seeks amplitude and virtuosity in his execution of the gesture, which would allow for a certain ease in space and favor a better landing. This requires more vertical force but less execution speed. On the contrary, in the parkour sport, the athlete seeks a rather smooth and harmonious combination of a series of technical gestures requiring more speed but less amplitude and thus less force. Consequently, the landing angle was smaller in AG than PA ($p < 0.05$). This results from their high speed, so that they are forced to open their trunk-leg angle earlier and larger to coincide with landing at the right standing point on the floor and avoid overestimation [27].

Finally, taking into account that the AG and PA practice their sport on average between 18 and 20 hours per week with feedback, the findings in this study partially contradict the specificity of the practice hypothesis [35]–[37], [43]. This hypothesis suggests that learning is specific to the source of afferent information available during practice, which is more likely to ensure optimal accuracy. Thus, the more one practices with a given source of afference, the more one becomes reliant on it. This was not the case in this study. In fact, on one hand, the changes in performance seen in PA when vision was eliminated support the specificity of the practice hypothesis. On the other hand, the unchanged performance of AG when vision was eliminated doesn't seem to support it. This implies that this hypothesis is dependent on the sports discipline and can't be considered for all sports disciplines. Indeed, because the goals of the two sports disciplines are different, as previously mentioned, and determine the way one source of afference is used, our findings highlight rather the hypothesis of the specificity of the practice's goal. This hypothesis needs to be assessed later with a transfer test. One other reason can explain why AG's performance remained unchanged when visual afferences were eliminated. It could be that the tasks used to assess the specificity of a practice hypothesis were relatively simple, like aiming [35], walking [37], powerlifting [43] or tracking task [11]. Indeed, SBTS is a complex acrobatic skill where the velocity of the head during rotation is too high to permit using visual afferences easily [3], [4]. Thus, control of the skill is assured principally by the integration of vestibular and proprioceptive systems. This is why the hypothesis of the specificity of practice can't be supported here. To confirm this assumption, we need to manipulate those last sensory systems in a further study using, for example, a stable and unstable surface which would make the proprioceptive input unreliable, a way to eliminate the proprioceptive cues.

5. Conclusions

When all the findings of this study are considered, it is clear that controlling a skill like SBTS with eyes closed, requires a high level of integration of all available afferent information. When vision is eliminated, both groups (i.e., AG and PA) react similarly in some of the kinetic or kinematic parameters studied. However, on some other parameters (i.e., take-off angle, horizontal displacement, and technical execution), the elimination of vision only affected PA. The absence of kinetic/kinematic changes in AG seems due to the fact that vision is not the main player and that the proprioceptive and vestibular systems appear to play, a major role or that these last systems were able to account for the absence of vision in AG, which was not the case for PA.

Despite, the fact that the two sports activities sufficiently develop the sensory systems responsible for the movement guidance, orientation, and control of SBTS, the specificity of the practice in each of the two sports disciplines suggests that, in the absence of vision, the integration of afferent information relating to the vestibular and proprioceptive systems is different and is specific to each discipline's goal.

It was suggested then that results in this study partially support the specificity of the practice hypothesis and proposed a hypothesis of specificity of practice's goal. Moreover, the complexity of the SBTS can be the raison for not supporting the specificity of the practice hypothesis where tasks used were relatively simple. Further manipulations are needed to confirm those assumptions.

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