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# The Asymmetries in Straight Jumps on the Trampoline Under Different Sensory Conditions

**Matjaž Pezdirc [1], Igor Pušnik [2], Maja Pajek [1], Ivan Čuk [1] and Karmen Šibanc [1,*]**

[1] Faculty of Sport, University of Ljubljana, 1000 Ljubljana, Slovenia; pezdirc.matjaz@gmail.com (M.P.); maja.pajek@fsp.uni-lj.si (M.P.)
[2] Faculty of Electrical Engineering, University of Ljubljana, 1000 Ljubljana, Slovenia
* Correspondence: karmen.sibanc@fsp.uni-lj.si

**Abstract:** The trampoline is a popular piece of sports equipment both for recreational use and for Olympic trampolining as a competitive sport. Maintaining body position during jumps is influenced by sensory inputs (visual, auditory, and somatosensory) and symmetrical muscle activity that help athletes to perform consecutive jumps as vertically as possible. To evaluate the effects of these inputs, 15 male and 15 female students (with an average age of 24.4 years, height of 174.3 cm, and average weight of 69.7 kg) performed 10 consecutive straight jumps under four sensory conditions: (1) looking at the edge of the trampoline, (2) without sight, (3) without hearing, and (4) without hearing or sight. Using insoles with integrated pressure sensors (Pedar®, novel GmbH, Munich, Germany), the contact forces on the trampoline during the jump were measured separately for the left and right feet. The results showed that the lack of visual input significantly shortened flight times and increased the asymmetry of ground reaction forces between the left and right legs. For example, in the second series without vision, the average normalized force difference between the legs increased by 0.33 G compared to the control condition. An ANOVA revealed significant differences in the ground reaction forces between sensory conditions, with vision playing a key role in maintaining body control. These results provide practical insights for coaches looking to improve jumping performance and address asymmetries during training by focusing on sensory feedback strategies.

**Keywords:** trampoline gymnastics; asymmetry; straight jumps; sensory models; forces on the trampoline; body control

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**Citation:** Pezdirc, M.; Pušnik, I.; Pajek, M.; Čuk, I.; Šibanc, K. The Asymmetries in Straight Jumps on the Trampoline Under Different Sensory Conditions. *Symmetry* **2024**, *16*, 1472. https://doi.org/10.3390/sym16111472

Academic Editors: John H. Graham and Ji-Huan He

Received: 28 August 2024
Revised: 25 October 2024
Accepted: 29 October 2024
Published: 5 November 2024

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## 1. Introduction

Jumps on the trampoline are compound movements consisting of two main phases: the flight phase and the contact phase with the trampoline. The contact phase can be further divided into the downward and upward phases. In the downward phase, gymnasts exert force with their legs, depressing the trampoline bed and storing energy, which is released in the upward phase to propel the gymnast into the air [1]. The downward phase is shorter, faster, and more powerful than the upward phase and is therefore crucial for building height and maintaining performance [2].

Asymmetrical movements can impair performance in trampoline gymnastics. If a gymnast generates a force at an angle outside the center of gravity, resulting from an (a)symmetrical movement or position on contact with the trampoline, this gives him or her the opportunity to rotate around the front axis (do a somersault). If this force is too strong, the gymnast will generate more spin and less height, resulting in a shorter flight time, which is one of the factors to be evaluated. Therefore, it is desirable that the jumps are performed high in the air and the rotation is slow, as this also results in the longest flight time. For this reason, it is very important for gymnasts to control their posture well [3]. Studies have shown that asymmetries in leg movements, such as differences in speed and angle on landing, can negatively affect balance and performance [4,5]. In addition, studies

on bilateral asymmetries in various sports, including gymnastics, confirm that even small asymmetries can lead to decreased performance and an increased risk of injury, especially in high performance athletes [6–8].

Gymnasts rely on various sensory inputs to maintain balance during jumps, including vision, proprioception, and the vestibular system [9–11]. Static balance refers to the maintenance of posture without movement, while dynamic balance involves the control of posture during movement [9]. In addition to the body's own mechanoreceptors, the body's sensory receptors also include receptors from the internal environment, which give us a feeling for the position of the body or individual body parts and positions, a feeling for active and inactive body movements (kinaesthesia), and a feeling for stress and problems. The correct coordination of these sensations enables the gymnast to maintain their center of gravity to ensure precise movements and stable landings [10]. Each of the three perceptual influences affects the reception of information from the external and internal environment. The somatosensory/proprioceptive unit receives information from the supporting surface and functions best when this surface is firm, unchanging, and stable; its function is impaired when the supporting surface is unstable or changing. The visual unit relies on information from the environment and the objects in it and works best when the visible environment is constant, which is even more important when the support surface is unstable. Difficult functioning of the visual unit is caused by a changing environment and/or darkness (poor lighting in the room). The vestibular system for maintaining balance recognizes information related to gravity and inertia. It is most important when we have an unstable surface, a changing environment, and poor vision, and it is least effective during unusual movements [11]. All three systems are interlinked. In particular, vision plays an important role, as it provides visual feedback for adjusting body position during flight [12].

Studies on asymmetry in gymnastics emphasize the importance of symmetry for performance and injury prevention. Bilateral asymmetries in leg strength and coordination have been observed in various sports, including gymnastics [8]. For example, a study comparing the morphological characteristics of elite male gymnasts between 2000 and 2015 found significant changes in symmetry and strength, highlighting the importance of symmetry for both performance optimization and injury prevention [13]. Symmetry is not only crucial for maintaining balance during jumps but also for reducing the risk of overuse injuries caused by repetitive asymmetric movements [14]. While previous studies have investigated the effects of sensory input on balance and coordination in various sports, there is a limited understanding of how sensory deprivation affects the control of body symmetry during repetitive trampoline jumps. Research has shown that sensory systems such as vision, proprioception, and vestibular inputs are crucial for maintaining balance during complex movements in gymnastics [9,12]. Specifically in trampoline gymnastics, recent studies have focused on jump mechanics and postural control, emphasizing the role of sensory feedback in optimizing jump height and minimizing asymmetries [1,15]. However, these studies often emphasize individual sensory systems without a comprehensive comparison of how their absence affects the asymmetry of bilateral leg movements during jumping.

The aim of this study is to determine whether there are significant differences in ground reaction forces between the left and right legs during trampoline jumps under different sensory conditions. By analyzing these differences, we hope to gain insight into how sensory inputs and asymmetries affect performance and how gymnasts can improve their techniques to minimize asymmetric forces and improve overall control during jumps. While some authors have highlighted the influence of visual feedback during the execution of complex aerial maneuvers on the trampoline [16,17], there is a gap in understanding the interplay between auditory and visual deprivation in the control of jump symmetry. The present study aims to address this gap by investigating how the absence of vision, hearing, or both affects the generation of ground reaction forces and the symmetry of these forces during trampoline jumps. Such insights are critical for refining training methods, particularly in environments where sensory input may be compromised, and for developing

strategies to minimize injury risks associated with asymmetric force production [7,18]. By directly comparing the effects of different sensory conditions on jumping performance, this study provides a new contribution to the field of sports biomechanics that is relevant to trampolining, as well as other sports involving dynamic air movement.

## 2. Materials and Methods

Conducting the pilot study prior to our investigation required a sample size of 19 ($F_L/F_g$, $F_R/F_g$, $F_T/F_g$) and 14 for $t_{sum}$ with a power of research of 0.80, with $\alpha < 0.05$ for four groups of tasks. As we wanted to improve the validity and significance of the study, we increased the sample size to N = 30. Therefore, 15 male and 15 female students from the University of Ljubljana (with an average age of 24.4 ± 1.76 years, an average height of 174.3 ± 9.37 cm, and an average weight of 69.7 ± 9.92 kg) participated in the study. All participants were familiar with the basic techniques of trampolining; studied kinesiology, sport training, or physical education programs; and had all attended gymnastics classes for one or two semesters during their studies. No professional gymnasts took part in the study. Participants were healthy and had not suffered any injuries in the six months prior to the study. Informed consent was obtained from each participant for voluntary participation in the study, including permission to use their data and photographs for publication. The study was conducted in accordance with the guidelines of the Declaration of Helsinki.

Insoles with integrated pressure sensors (Pedar®, novel GmbH, Munich, Germany) were used in the study (sampling frequency 200 Hz). The participants wore the insoles between two pairs of socks, one of which had a rubber bottom (Figure 1). The integrated pressure sensors were of different sizes and were used depending on the size of the participant. This is a good approximation of real trampoline conditions, as in many trampoline parks, special socks with rubber bottoms are a non-negotiable safety rule, but gymnasts are required to wear trampoline shoes and/or socks and/or foot protection during competitions [19]. As the participants only performed straight jumps on the trampoline as basic jumps, the insoles had no influence on the execution of the jumps in our study.




**Figure 1.** Pressure sensors used in a study (**left**) and socks with rubber bottoms (**right**).

The measurements were taken on the trampoline at the Faculty of Sport at the University of Ljubljana. The trampoline used in the study is an FIG competition trampoline certified by Eurotramp. All participants warmed up before the measurements in the same sports hall, started with 5 min of jogging, and performed 10 min of gymnastic stretching exercises for the upper and lower extremities. They then performed 10 straight jumps and 10 tuck jumps on gymnastics floor. The experiment consisted of performing 10 consecutive straight jumps on the trampoline under four different sensory conditions (see Figure 2): 1–looking at the edge of the trampoline (with full vision and hearing), 2–without vision (blindfolded), 3–looking at the edge of the trampoline without hearing (wearing ZEKLER 402 noise-attenuating earmuffs (ZEKLER, Ulricehamn, Sweden) while looking at the edge

of the trampoline), and 4–without hearing or vision (blindfolded and wearing ZEKLER 402 noise-muffling earmuffs). Each participant performed the four series of jumps in random order to minimize learning effects. During the jumps, the participants' arms remained slightly bent and their hands on their hips to minimize additional arm movements. A cross was marked in the center of the trampoline to indicate the starting position. A one-minute break was taken between each series of jumps to avoid fatigue. The information obtained from the measurements was exported from the loadsol® program and imported into Microsoft Excel for further processing.

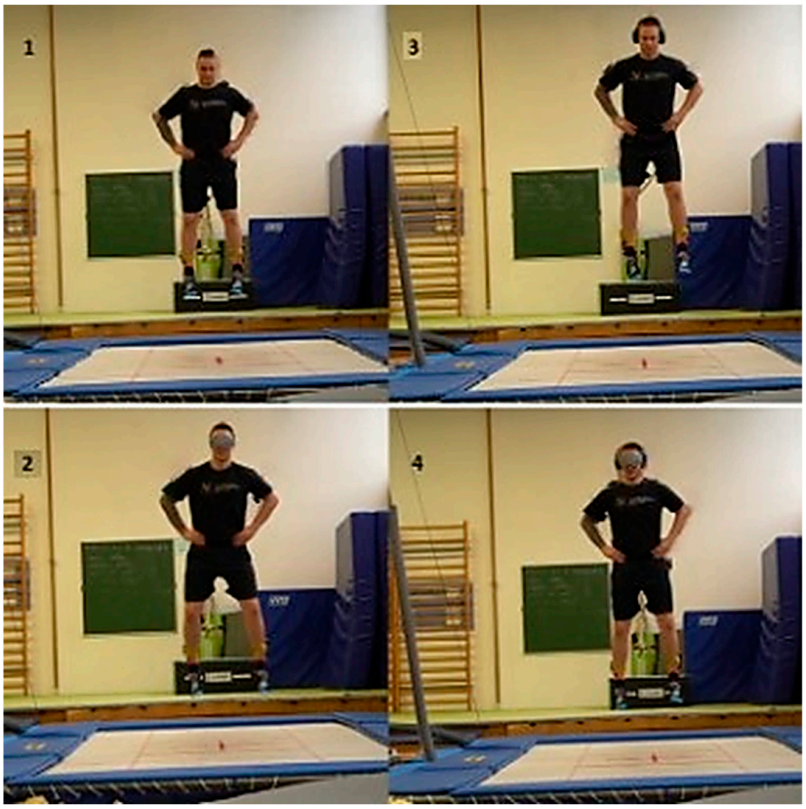



**Figure 2.** Straight jumps in the series. Note: 1–looking down at the edge of the trampoline, 2–without seeing, 3–looking at the edge of the trampoline without hearing, and 4–without hearing or seeing.

Ten consecutive jumps were chosen for the study, as this number is representative of a typical competition routine in trampoline gymnastics, in which gymnasts perform several jumps in succession with minimal interruptions [20]. This series allows for the measurement of consistent performance across multiple jumps and provides a more accurate picture of how gymnasts handle sensory input over time [2]. Performing multiple jumps also introduces a situation where fatigue could affect the ability to maintain symmetry, which is a critical aspect of performance in trampoline exercises [15].

The imported data represent the ground reaction force as a function of time (sampling frequency 200 Hz). Depending on the magnitude of the force, a search was performed after the start of the first jump and then after all ten jumps. Within the time interval, 10 local maximum values were then searched for, representing the maximum push-off force for the left ($F_{Lmax}$) and right leg ($F_{Rmax}$) for all 10 jumps in a single series. In addition to the force, the timing of the local maximum values of the left ($F_L$) and right leg ($F_R$) were also determined. This was done for all subjects and for all series of jumps that the subjects had to perform. Table 1 shows the variables that we defined to simplify the statistical analysis of the data.

**Table 1.** Abbreviations, variables, and units used in the article.

| Abbreviation | Variable | Unit |
|---|---|---|
| $t_T$ | Take-off contact time | second (s) |
| $t_L$ | Landing contact time | second (s) |
| $t_f$ | Flight time | second (s) |
| $F_L$ | Ground reaction force—left leg | force (N) |
| $F_L/F_g$ | Normalized sum of ground reaction force—left leg | G |
| $F_R$ | Ground reaction force—right leg | force (N) |
| $F_R/F_g$ | Normalized sum of ground reaction force—right leg | G |
| $F_T/F_g$ | Normalized total ground reaction force | G |
| $F_D$ | The difference in ground reaction forces between the right and left leg | force (N) |
| $t_R$ | Right leg contact time | second (s) |
| $t_L$ | Left leg contact time | second (s) |
| $t_D$ | Difference in contact time between left and right foot | second (s) |
| $F_{Dsum}$ | The sum of the ground reaction force difference between the right and left leg | force (N) |
| $F_{Dsum}/F_g$ | The normalized sum of the ground reaction force difference between the right and left leg | G |
| $t_{sum}$ | Total flight time | second (s) |
| $t_{Dsum}$ | The sum of the difference in contact time between the right and left foot | second (s) |

The take-off contact time ($t_T$) and the landing contact time ($t_L$) were used to calculate the flight time ($t_t = t_L - t_T$). The sum of all flight times within a series of 10 jumps gives the total flight time ($t_{sum} = t_{t1} + t_{t2} + \ldots + t_{t10}$). The same was done with the ground force for left and right separately and in total, whereby the values were finally averaged and normalized by the individual gravity ($F_g = m * g$) as follows:

$$F_L/F_g = (F_{L1} + F_{L2} + \ldots + F_{L10})/10/F_g \quad (1)$$

$$F_R/F_g = (F_{R1} + F_{R2} + \ldots + F_{R10})/10/F_g \quad (2)$$

$$F_T/F_g = (F_1 + F_2 + \ldots + F_{10})/10/F_g \quad (3)$$

For each jump, the difference in force between the left and right legs was calculated ($F_D = F_L - F_R$), and their absolute values were added to obtain the sum of the difference in ground reaction force between the right and left legs as $F_{sum} = F_{D1} + F_{D2} + \ldots + F_{D10}$. The values were finally averaged and normalized by a person's gravity as follows:

$$F_{D1} = \mathrm{ABS}(F_{L1} - F_{R1}) \quad (4)$$

$$F_{Dsum}/F_g = (F_{D1} + F_{D2} + \ldots + F_{D10})/10/F_g \quad (5)$$

The difference between the jump times for the left and right legs was calculated, and their absolute value of 10 jumps in the series was added to obtain the sum of the difference in jump times between left and right:

$$t_{D1} = \mathrm{ABS}(t_{L1} - t_{R1}) \quad (6)$$

$$t_{Dsum}/F_g = t_{D1} + t_{D2} + \ldots + t_{D10} \quad (7)$$

Microsoft Excel and the statistical data processing program SPSS 28.0 were used for data processing. Descriptive statistics, paired *t*-tests, and Spearman correlations between the jumps under different conditions were calculated. ANOVA for repeated measures was performed.

## 3. Results

Figure 3 shows the variables during one take-off in a straight jump. The green line shows ground reaction force for the left leg, where the blue line represents the ground reaction force for the right leg, and the orange line represents the ground reaction force for the total ground reaction force (the sum of the ground reaction force for left and right). During the landing, the force increased from the first contact with the trampoline (at 4.15 s) to the maximum extension of the trampoline at which the highest ground reaction force was measured (at 4.40 s), whereby the gymnast's speed was zero. After this maximum value, the gymnast began to move upwards, gaining speed, while the trampoline returned to its original state, and the force decreased. At the last contact (4.75 s), the gymnast reached the maximum take-off speed, after which the ground force dropped to zero, indicating the start of the flight.

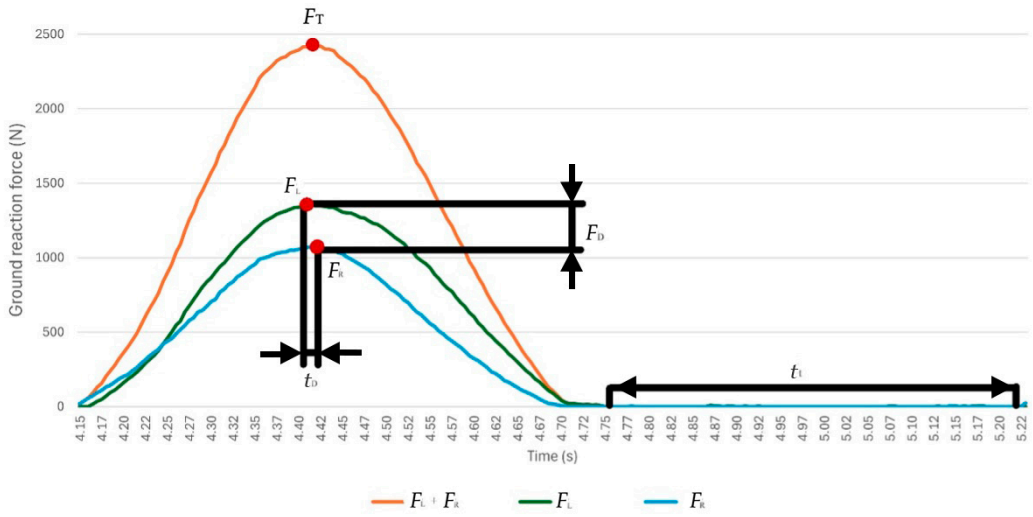



**Figure 3.** Variables during one take-off in a straight jump. Note: $F_T$ = total ground reaction force; $F_L$ = ground reaction force for the left leg; $F_R$ = ground reaction force for the right leg; $F_D$ = difference in ground reaction forces between left and right; $t_D$ = time difference in maximum ground reaction force for left and right leg; $t_f$ = time of flight.

Figure 4 shows the raw ground forces during the first series of jumps for the left leg (blue line), the right leg (orange line), and the combined force of both legs (green line). The jumps were performed one after the other, with the landings serving as a start for the next jump. The forces for each leg were between 1250 N and 1750 N, and the total force per jump was between 2500 N and 3250 N. No significant anomalies were observed during the first series in which the participants looked at the edge of the trampoline. All test subjects completed the measurements on the first attempt.

The ground reaction force determines the flight time and the height of the jump. The higher the ground reaction force, the longer the flight time and the higher the jumps. Figures 4 and 5 show the highest ground reaction forces for jumps 6 and 7, and the flight time was also longer after these jumps.

Figure 5 shows the raw ground reaction forces during the second series of 10 jumps (without vision) for the left leg (blue line), the right leg (orange line), and the combined force of both legs (green line). The ground forces for each leg were between 1000 N and 1750 N, while the total force per jump was between 2250 N and 3500 N. The differences between the forces of the left and right leg were much greater than in the first and third series (with vision), with differences of up to 500 N. During this series, three subjects lost control and were unable to complete ten consecutive jumps, so they had to repeat the series.

Figure 6 shows the raw ground forces during the third series of jumps (with mufflers, looking at the trampoline edge) for the left leg (blue line), the right leg (orange line), and the combined force of both legs (green line). The ground forces for each leg were between

1250 N and 2000 N, and the total force per jump was between 2250 N and 3500 N. No significant anomalies were observed in this series, and all measurements were successfully completed in the first trial.

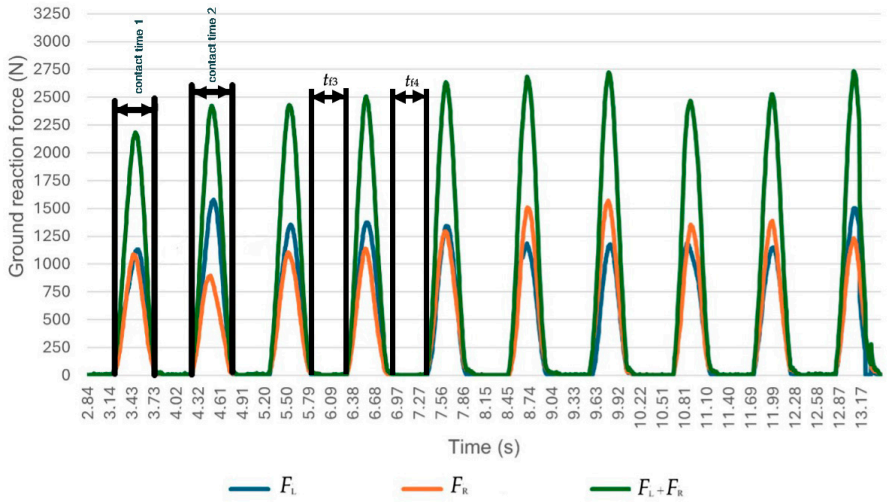



**Figure 4.** Raw ground reaction forces during the straight jump (1st series of jumps) for one person. Note: $F_L + F_R = F_T$ = total ground reaction force (green); $F_L$ = ground reaction force for the left leg (blue); $F_R$ = ground reaction force for the right leg (orange); $t_{f3}$ and $t_{f4}$ = flight time after 3rd and 4th jump in one series.

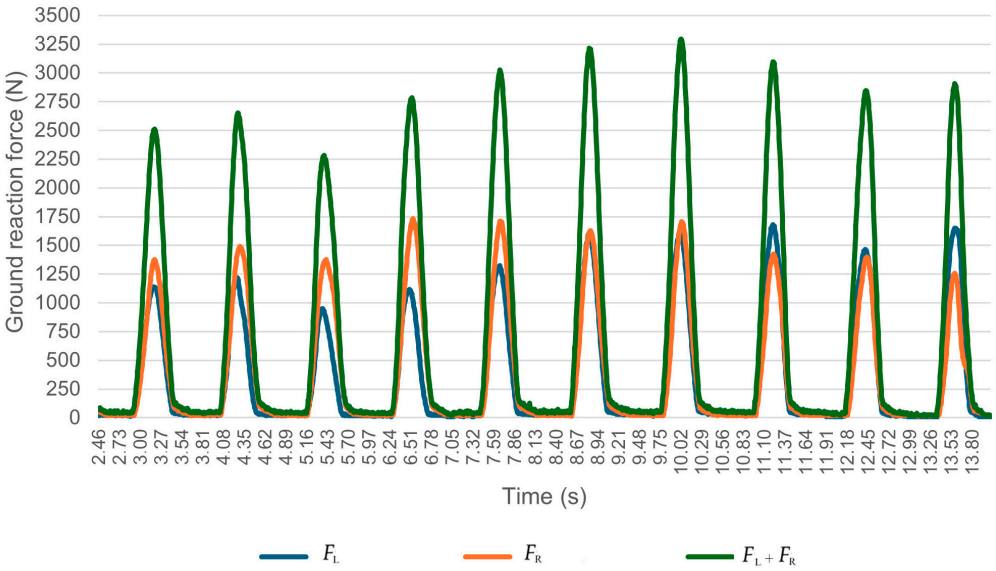



**Figure 5.** Raw ground reaction forces without seeing (2nd series of jumps) for one person. Note: $F_L + F_R = F_T$ = total ground reaction force (green); $F_L$ = ground reaction force for the left leg (blue); $F_R$ = ground reaction force for the right leg (orange).

Figure 7 shows the ground reaction forces during the fourth series of jumps (without seeing and hearing) for the left leg (blue line), the right leg (orange line), and the combined force of both legs (green line). The figure shows that the ground reaction forces of the right and left leg for each jump were between 750 N and 1750 N for each jump, and the total force of the single jump was between 2000 N and 2750 N. The differences between the ground reaction forces of the left and right leg were much greater than in the first and third series (with vision) and amounted to up to 700 N (take-off 2). In this series, two subjects lost control of their bodies during the execution and failed to perform ten consecutive jumps, so they had to repeat the series.

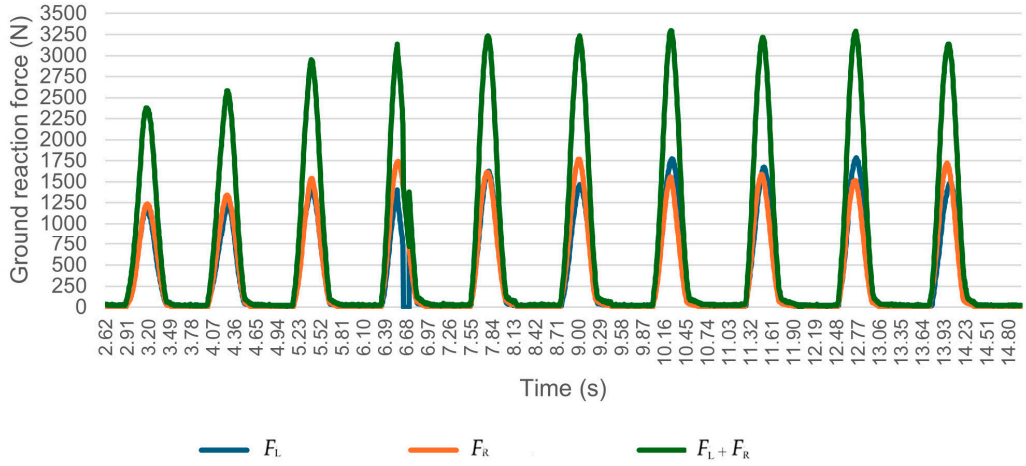



**Figure 6.** Raw ground reaction forces without hearing (3rd series of jumps) for one person. Note: $F_L + F_R = F_T$ = total ground reaction force (green); $F_L$ = ground reaction force for the left leg (blue); $F_R$ = ground reaction force for the right leg (orange).

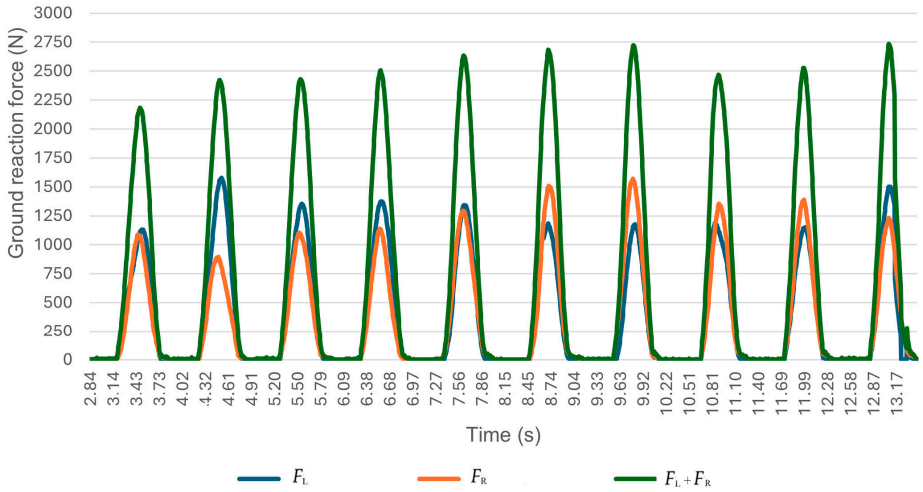



**Figure 7.** Raw ground reaction forces without seeing or hearing (4th series of jumps) for one person. Note: $F_L + F_R = F_T$ = total ground reaction force (green); $F_L$ = ground reaction force for the left leg (blue); $F_R$ = ground reaction force for the right leg (orange).

Table 2 shows the descriptive statistics of the ground reaction forces for $F_{NL}$, $F_{ND}$, $F_N$, $F_{Nsum}$, and $t_{sum}$ in all four jump series with indication of median, standard deviation, standard error, minimum and maximum value, Kolmogorov–Smirnov test, and normality distribution. The highest force values were determined in the first series and amounted to 3.08 G for the left leg and 2.80 G for the right leg, while the lowest forces were determined in the fourth series and amounted to 1.29 G for the left leg and 1.40 G for the right leg. The normality of the distribution of the variables was checked with the Kolmogorov–Smirnov calculation. The distribution was normal in most cases, but it was not normal in the second series for the $F_{NL}$ and $t_{sum}$, in the third series for the $F_{NR}$ and for $F_{Nsum}$, nor in the fourth series for the $F_{Nsum}$.

An ANOVA was performed (Table 3) and then a Bonferroni post hoc test (Table 4), as variance shows homogeneity. In both tables, each significance is marked in bold. $F_L/F_g$, $F_D/F_g$, $F_T/F_g$, and $t_{sum}$ showed significance in the ANOVA, and the effect size was large, between 14.9 and 23.1%, while $F_{Dsum}/F_g$ and $t_{Dsum}$ showed no significance and a small effect size (2–4%). The post hoc test showed that most differences existed when no vision was used. This is similar to what was mentioned before: there was a difference in forces and times, while the normalized sum of the ground reaction force and time difference between

the right and left leg showed no significant difference. Consequently, the differences between the left and right legs did not change within a series.

**Table 2.** Descriptive statistics of ground reaction forces and flight times.

| Variable | M | SD | SE | Min | Max | K-S |
|---|---|---|---|---|---|---|
| $F_{L1}/F_g$ | 2.14 | 0.36 | 0.07 | 1.52 | 3.08 | + |
| $F_{R1}/F_g$ | 2.13 | 0.31 | 0.06 | 1.51 | 2.80 | + |
| $F_{T1}/F_g$ | 4.27 | 0.63 | 0.12 | 3.27 | 5.88 | + |
| $F_{Tsum1}/F_g$ | 0.27 | 0.08 | 0.02 | 0.12 | 0.48 | + |
| $t_{sum1}$ | 6.32 | 0.99 | 0.18 | 4.33 | 8.82 | + |
| $F_{L2}/F_g$ | 1.87 | 0.34 | 0.06 | 1.42 | 2.90 | − |
| $F_2/F_g$ | 1.82 | 0.24 | 0.04 | 1.39 | 2.37 | + |
| $F_{T2}/F_g$ | 3.68 | 0.53 | 0.10 | 2.88 | 5.27 | + |
| $F_{Tsum2}/F_g$ | 0.33 | 0.11 | 0.02 | 0.16 | 0.56 | + |
| $t_{sum2}$ | 5.26 | 1.06 | 0.19 | 3.47 | 8.73 | − |
| $F_{L3}/F_g$ | 2.20 | 0.40 | 0.07 | 1.55 | 2.94 | + |
| $F_{R3}/F_g$ | 2.12 | 0.29 | 0.05 | 1.71 | 2.60 | − |
| $F_{T3}/F_g$ | 4.31 | 0.63 | 0.11 | 3.42 | 5.42 | + |
| $F_{Tsum3}/F_g$ | 0.30 | 0.17 | 0.03 | 0.12 | 0.82 | − |
| $t_{sum3}$ | 6.32 | 1.16 | 0.21 | 4.71 | 9.02 | + |
| $F_{L4}/F_g$ | 1.88 | 0.35 | 0.06 | 1.29 | 2.64 | + |
| $F_{R4}/F_g$ | 1.84 | 0.25 | 0.05 | 1.40 | 2.30 | + |
| $F_{T4}/F_g$ | 3.72 | 0.53 | 0.10 | 2.94 | 4.63 | + |
| $F_{Tsum4}/F_g$ | 0.32 | 0.11 | 0.02 | 0.14 | 0.66 | − |
| $t_{sum4}$ | 5.17 | 1.01 | 0.18 | 3.60 | 8.09 | + |

Note: M = median; SD = standard deviation, SE = standard error; Min = minimum value; Max = maximum value; K-S = Kolmogorov–Smirnov test; "+" = normal distribution; "−" = non-normal distribution; $F_{L1–4}/F_g$ = normalized sum of ground reaction force—left leg for each series; $F_{R1–4}/F_g$ = normalized sum of ground reaction force—right leg for each series; $F_{T1–4}/F_g$ = normalized total ground reaction force; $F_{Tsum1–4}/F_g$ = sum of normalized total ground reaction force for each series; $t_{sum4}$ = total flight time.

**Table 3.** ANOVA results.

| Variable | | Sum of Squares | df | Mean Square | F | sig. | Eta-Squared |
|---|---|---|---|---|---|---|---|
| $F_L/F_g$ | Between Groups | 2.665 | 3 | 0.888 | 6783 | <0.001 | |
| | Within Groups | 15.192 | 116 | 0.131 | | | 0.149 |
| | Total | 17.857 | | | | | |
| $F_D/F_g$ | Between Groups | 2.613 | 3 | 0.871 | 11,592 | <0.001 | |
| | Within Groups | 8.717 | 116 | 0.075 | | | 0.231 |
| | Total | 11.330 | 119 | | | | |
| $F_T/F_g$ | Between Groups | 10.493 | 3 | 3.498 | 10,295 | <0.001 | |
| | Within Groups | 39.412 | 116 | 0.340 | | | 0.210 |
| | Total | 49.905 | 119 | | | | |
| $F_{Dsum}/F_g$ | Between Groups | 0.064 | 3 | 0.021 | 1461 | 0.229 | |
| | Within Groups | 1.699 | 116 | 0.015 | | | 0,036 |
| | Total | 1.763 | 119 | | | | |
| $t_{sum}$ | Between Groups | 36.318 | 3 | 12.106 | 10,899 | <0.001 | |
| | Within Groups | 128.841 | 116 | 1.111 | | | 0.220 |
| | Total | 165.158 | 119 | | | | |
| $t_{Dsum}$ | Between Groups | 0.093 | 3 | 0.031 | 0.901 | 0.443 | |
| | Within Groups | 4.005 | 116 | 0.035 | | | 0,023 |
| | Total | 4.099 | 119 | | | | |

Note: $F_L/F_g$ = normalized sum of ground reaction force—left leg; $F_R/F_g$ = normalized sum of ground reaction force—right leg; $F_T/F_g$ = normalized total ground force; $F_{Dsum}/F_g$ = the normalized sum of the ground reaction force difference between the right and left leg; $t_{sum}$ = total flight time for each series; $t_{Dsum}$ = the sum of the difference in contact time between the right and left foot.

Figure 8 shows the sum of the normalized differences of the ground reaction forces between the left and right leg for all four jump series and their differences.

**Table 4.** Bonferroni's post hoc test for multiple comparisons.

| Sensory Type | Sensory Type | Dependent Variable–sig. | | | | | |
|---|---|---|---|---|---|---|---|
| | | $F_L/F_g$ | $F_R/F_g$ | $F_T/F_g$ | $F_{Dsum}/F_g$ | $t_{sum}$ | $t_{Dsum}$ |
| 1 | 2 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| | 3 | 0.022 | <0.001 | <0.001 | 0.329 | 0.001 | 1.000 |
| | 4 | 0.036 | <0.001 | 0.002 | 0.638 | <0.001 | 0.790 |
| 2 | 1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| | 2 | 0.004 | <0.001 | <0.001 | 1.000 | 0.001 | 1.000 |
| | 4 | 0.006 | <0.001 | <0.001 | 1.000 | <0.001 | 1.000 |
| 3 | 1 | 0.022 | <0.001 | <0.001 | 0.329 | 0.001 | 1.000 |
| | 2 | 0.004 | <0.001 | <0.001 | 1.000 | 0.001 | 1.000 |
| | 4 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 4 | 1 | 0.036 | <0.001 | 0.002 | 0.638 | <0.001 | 0.790 |
| | 2 | 0.006 | <0.001 | <0.001 | 1.000 | <0.001 | 1.000 |
| | 3 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Note: $F_L/F_g$ = normalized sum of ground reaction force—left leg; $F_R/F_g$ = normalized sum of ground reaction force—right leg; $F_T/F_g$ = normalized total ground force; $F_{Dsum}/F_g$ = the normalized sum of the ground reaction force difference between the right and left leg; $t_{sum}$ = total flight time for each series; $t_{Dsum}$ = the sum of the difference in contact time between the right and left foot; 1 = 1st jump series; 2 = 2nd jump series without vision; 3 = 3rd jump series without hearing; 4 = 4th jumping series without vision or hearing.

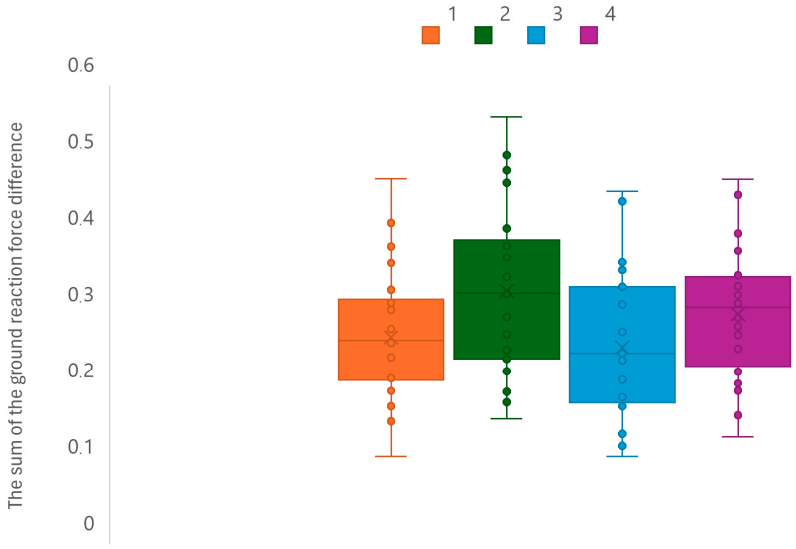



**Figure 8.** The sum of differences in ground reaction forces between the left and right leg for all four jump series. Note: $F_{Dsum}/F_g$ = the sum of the difference in ground reaction forces between the left and right leg; 1–4 = number of series; 1 = 1st series of jumps; 2 = 2nd series of jumps without vision; 3 = 3rd series of jumps without hearing; 4 = 4th series of jumps without vision or hearing.

The Spearman coefficient was used to determine the correlation between the pairs of variables for each series of jumps separately: $F_L/F_g$, $F_R/F_g$, $F_T/F_g$, $F_{Tsum}/F_g$, $t_{sum}$, and $t_{Dsum}$. The correlations found were positive in all cases, as shown in Table 5.

In Table 6 we can see in the first, second, and third series, five variables are related. In the fourth row, there are four variables that are related. In the first series, the strongest correlation was between $F_R/F_g$ and $F_{TDsum}/F_g$ (r = 0.93), which means that one variable accounts for 87% of the variance and vice versa. The second strongest correlation was between $F_L/F_g$ and $F_{TDsum}/F_g$ (r = 0.91), from which we conclude that the two variables share 82% of the variance. There was also a strong correlation between $F_L/F_g$ and $F_R/F_g$ (r = 0.74). These two variables share 55% of the variance. There was a moderate correlation between $F_R/F_g$ and $t_{sum}$ (r = 0.43), which means that the two variables share 18% of the variance. There was a low correlation between $F_T/F_g$ and $F_{Tsum}/F_g$ (r = 0.36), which means that the two variables share 13% of the variance.

**Table 5.** Paired t-test between the normalized forces of the left and right leg in different jump series.

| Variable | M | SD | SE | Sig. *t*-test | M + 1.96 ∗ SE | M-1.96 ∗ SE |
|---|---|---|---|---|---|---|
| $F_{L1}/F_g$– $F_{R1}/F_g$ | 0.27 | 0.08 | 0.02 | 0.73 | 0.30 | 0.24 |
| $F_{L2}/F_g$– $F_{R2}/F_g$ | 0.33 | 0.11 | 0.02 | 0.32 | 0.37 | 0.29 |
| $F_{L3}/F_g$– $F_{R3}/F_g$ | 0.30 | 0.17 | 0.03 | 0.15 | 0.36 | 0.24 |
| $F_{L1}/F_g$– $F_{R1}/F_g$ | 0.32 | 0.11 | 0.02 | 0.40 | 0.36 | 0.28 |

Note: M = median; SD = standard deviation. SE = standard error; Sig. = significance; M + 1.96 ∗ SE = upper bound M; M–1.96 ∗ = SE lower bound M; $F_{R1–4}/F_g$–$F_{L1–4}/F_g$ = difference of normalized sum of ground reaction force between the left and right leg for each series.

**Table 6.** Series of jumps that significantly share variance.

| Variable | $F_R/F_g$ | $F_T/F_g$ | $F_{TDsum}/F_g$ | $t_{sum}$ |
|---|---|---|---|---|
| $F_L/F_g$ | 1,2,3,4 | 1,2,3,4 | 2,3 | |
| $F_R/F_g$ | | 1,2,3,4 | | 1,4 |
| $F_T/F_g$ | | | 1,2 | 3 |

Note: 1—first series; 2—second series; 3—third series; 4—fourth series; $F_L/F_g$ = normalized sum of ground reaction force—left leg; $F_R/F_g$ = normalized sum of ground reaction force—right leg; $F_T/F_g$ = normalized total ground force; $F_{TDsum}/F_g$ = sum of normalized total ground force differences; $t_{sum}$ = total flight time.

In the second series, $F_L/F_g$ and $F_T/F_g$ were very strongly correlated (r = 0.88). They share 77% of the variance and vice versa. In addition, $F_R/F_g$ and $F_T/F_g$ were also very strongly correlated (r = 0.85), i.e., they share 72% of the variance. There was a moderate correlation between $F_L/F_g$ and $F_R/F_g$ (r = 0.54), i.e., they share 29% of the variance. $F_L/F_g$ and $F_{TDsum}/F_g$ were also moderately correlated (r = 0.4) and share 16% of the variance. There was also a low correlation between $F_T/F_g$ and $F_{TDsum}/F_g$ (r = 0.38).

In the third series, there was a very strong correlation between $F_L/F_g$ and $F_{T/}/F_g$ (r = 0.94), which share 88% of the variance. There was also a very strong correlation between $F_R/F_g$ and $F_T/F_g$ (r = 0.87), which share 76% of the variance. There was a strong correlation between $F_L/F_g$ and $F_R/F_g$ (r = 0.70), which share 48% of the variance. There was a weak correlation between $F_L/F_g$ and $F_{TDsum}/F_g$ (r = 0.39) and between $F_{TDsum}/F_g$ and $t_{sum}$ (r = 0.37).

In the fourth series, there was a very strong correlation between $F_L/F_g$ and $F_T/F_g$ (r = 0.92), sharing 85% of the variance. In addition, $F_R/F_g$ and $F_T/F_g$ were also very strongly correlated (r = 0.82), i.e., they share 67% of the variance. There was a moderate correlation exists between $F_L/F_g$ and $F_R/F_g$ (r = 0.59). They share 34% of the variance. $F_R/F_g$ and $t_{sum}$ were also moderately correlated (r = 0.42) and share 17% of the variance.

When calculating the power of the study for $F_{Dsum}/F_g$ with the current data, it dropped to 0.37. To achieve the preliminary power, the sample size should be 77 and for $t_{Dsum}$ 124 (power dropped to 0.24). The ANOVA revealed that these two variables were not significant, as the sample was not large enough.

## 4. Discussion

This study emphasizes the importance of sensory inputs, especially visual and proprioceptive feedback, for maintaining symmetry and body control during trampoline jumps. The results suggest that vision plays a crucial role in reducing asymmetry between the legs, which is consistent with previous research emphasizing the importance of visual input for maintaining balance and movement control in gymnastics [12]. The practical application of these findings is of great importance for trampoline gymnasts and coaches seeking to improve performance consistency and minimize the risk of injury. A comparable study has not yet been conducted, which is why we have started one. We have seen from our own experience what people rely on and want to know why. Is it symmetries in force generation or just a control problem? The ANOVA showed no differences between the

left and right legs, which leads us to the conclusion that it is a control problem and not an execution problem.

Trampoline jumps, like many other gymnastic movements, are compound movements consisting of different flight and contact phases. Previous studies have shown that the downward phase of the contact cycle is shorter and more powerful than the upward phase [1]. Consequently, optimal symmetrical force generation in this phase is crucial for maintaining verticality and maximizing jump height. As has been observed in competition, athletes who are unable to generate symmetrical force or apply force obliquely run the risk of introducing unwanted rotational forces, leading to destabilization and a decrease in performance [3].

The asymmetry of movement has been studied intensively in connection with other gymnastics disciplines. One study [4] has shown that asymmetries in landing mechanics, particularly in relation to the speed and angles of the legs during somersault landings, can negatively affect balance and overall performance. Our results extend these observations to trampolining, where asymmetric force generation, particularly under sensory conditions, leads to shorter flight times and less control over body alignment. This is particularly important in competitions where precise movement control and the minimization of horizontal displacement are critical for success [19].

The practical application of these results is important for coaches and athletes. Training programs should emphasize sensory feedback, particularly visual and proprioceptive training, to improve spatial awareness and control during jumps. This can be achieved through exercises that simulate sensory deprivation or alter sensory input so that the athlete is forced to rely on other feedback systems to improve their adaptability and control. In sports such as diving or artistic gymnastics, similar training strategies could be used to optimize rotational control and landing symmetry, both of which are critical in complex aerial maneuvers [16]. Auditory information alone has been found to be sufficient to maintain synchrony in trampoline jumping [21]. The crucial role of auditory information in sports performance, especially in the processing of environmental sounds, is to improve timing, spatial awareness, and coordination. In many sports, including gymnastics and trampolining, athletes can assess the interaction between their body and the apparatus by hearing, for example, the tension of the springs or the sound of their feet hitting the ground. This input helps athletes adjust their movements in real time to optimize balance and posture [18]. Studies suggest that although auditory feedback is often considered secondary to visual information, its absence significantly alters the balance of sensory integration, so training must be adapted to ensure that athletes can maintain their performance under different sensory conditions [18,22–24]. This study highlights the importance of auditory information in sports such as gymnastics and trampolining, where auditory feedback enhances real-time adaptation of body control, balance, and spatial awareness, adding to findings on the role of sensory input in maintaining symmetry during jumps.

Moreover, the results of this study are not only relevant to gymnastics. In sports such as figure skating and diving, athletes face similar challenges in terms of balance and control in the air. Symmetrical force generation and body control are equally crucial in these sports for the execution of precise turns and landings [25,26]. Training programs in these sports could benefit from similar approaches by incorporating exercises that challenge proprioceptive and visual feedback to improve body control under different sensory conditions. This link emphasizes the broader applicability of trampoline track-based research to other sports that require aerial performance and balance.

In terms of injury prevention, this study emphasizes the importance of symmetry in preventing overuse injuries. Asymmetrical movements can lead to increased strain on one side of the body and contribute to the development of chronic conditions [14]. The findings of Kašček Bučinel et al. [27] particularly emphasize the role of body symmetry in maintaining balance after dynamic activities such as drop jumps. Their study highlighted that asymmetries in force distribution can impair stability, making athletes more susceptible to injury during repeated jumps. This finding is particularly important for gymnastics,

where maintaining a symmetrical distribution of force on landing is crucial to reduce stress on the joints. In addition to gymnastics, asymmetries in strength development have also been associated with an increased risk of injury in other sports such as running and basketball [6]. To minimize these risks, coaches and athletes should integrate symmetry-oriented exercises into their training program. Conditioning exercises that promote an even distribution of force during take-off and landing, for example, could be crucial for injury prevention in sports that require high jumping performance [27].

Our research confirms that different modes of perception have a significant influence on body control during straight jumps on a trampoline. It has been shown that vision is a key factor for successful control during jumps, while the exclusion of hearing does not have such a strong influence. Body control is simultaneous for the whole.

Body control occurs first as a whole, while a specific type of sensory control has no significant effect on the asymmetries of left and right ground reaction forces.

Future research could focus on the long-term effects of sensory training programs, particularly visual and proprioceptive training, to improve symmetry and performance in trampolining. Investigating whether prolonged training reduces injury risk and improves control under sensory deprived conditions would provide valuable insights for athlete development. While this study examined the role of sensory input, future research could investigate how fatigue affects symmetry in trampoline exercises. By increasing the number of consecutive jumps or simulating competition conditions, researchers can investigate the combined effects of sensory deprivation and physical fatigue on jumping performance and control. Future research should also consider the role of upper body movements, such as arm posture and shoulder control, on overall body stability and symmetry during jumps. Investigating how these factors influence balance and force distribution could lead to a more holistic understanding of jumping dynamics. More complex aerial movements such as somersaults and spins need to be explored to understand how asymmetry affects rotations and landing stability. Comparing straight jumps with more complex elements could reveal new strategies to improve performance consistency in different movements. Future research could also investigate the psychological aspects of sensory deprivation and explore how gymnasts cope with stress and concentration during sensory demanding exercises, as well as how mental strategies could improve performance under such conditions. By addressing these areas in future research, we can further refine training methods and reduce the risk of asymmetries and injuries in trampolining.

## 5. Conclusions

This study confirms the importance of sensory input, particularly vision, in maintaining body control and symmetry during trampoline jumps. Vision was found to be the most influential factor in controlling ground reaction forces and minimizing asymmetry between the legs. The absence of visual feedback resulted in significantly lower jumps, shorter flight times, and increased asymmetry in force production. These results suggest that coaches should prioritize sensory training, especially visual cues, to improve body control and reduce asymmetries in trampoline routines.

**Author Contributions:** Conceptualization. M.P. (Matjaž Pezdirc), I.Č., M.P., I.P. and K.Š.; Data curation. M.P. (Matjaž Pezdirc), I.Č. and K.Š.; Formal analysis. M.P. (Matjaž Pezdirc) and I.Č.; Investigation. M.P. (Matjaž Pezdirc), I.Č., I.P., M.P. (Maja Pajek) and K.Š.; Methodology. M.P. (Matjaž Pezdirc) and I.Č.; Software. M.P. (Matjaž Pezdirc), I.Č. and K.Š.; Supervision. I.P and M.P. (Maja Pajek); Visualization. K.Š., M.P. (Matjaž Pezdirc), I.Č., M.P. (Maja Pajek) and I.P.; Writing—original draft. M.P. (Matjaž Pezdirc), K.Š., I.Č., M.P. and I.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by the Slovenian Research Agency within the research program Kinesiology of monostructural, polystructural, and conventional sports—No. P5-0147.

**Data Availability Statement:** The data presented in this study are available upon request from the corresponding author.

**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, Analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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