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Characterization of Axial Forces to the Head During Kipping Handstand Push-ups

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Abstract

Background: Kipping handstand push-ups (kHSPUs) are performed by thousands of athletes. The safety of kHSPUs has been questioned because of vertical impacts upon the head, but there has been no previous study of the ground reaction forces sustained during these exercises.
Aims: This exploratory and observational cross-sectional study quantified the forces placed upon the head and borne by the neck during kHSPU, allowing comparison to the force ranges known to be damaging to the cervical spinal support elements. We also sought to determine the frequency of symptoms following these exercises.
Methods: Sixteen volunteers performed 3 sets of up to 7 kHSPUs with their head and one hand contacting force platforms. Force and video recordings were made while performing the exercises. Volunteers were asked if they had neck pain or headaches related to the exercises.
Result: Force profiles showed distinct landing and kipping peaks. Landing forces were higher than during a headstand, but less than body weight. Forces were greatest during the "kip," and usually exceeded body weight. Participants who reported pain following kHSPUs extended their neck during the exercises. Forces to the head during kHSPUs were below forces proposed for damage to the young male cervical spine, but overlapped those proposed for damage to female cervical spines.
Conclusion: While kipping handstand push-ups may be safe for young and previously uninjured male athletes, they may be unsafe for females and for those with previous injury or other compromising factors. Detailed inquiry about symptoms and neck injuries secondary to these exercises is warranted. Based on the initial observations here reported, until these exercises are shown to be safe, athletes should be informed about these possible risks prior to performing the exercises.

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INTRODUCTION

Millions of athletes worldwide are exposed to kipping handstand push-ups (kHSPUs) as part of their routine exercise programming. Handstand pushups require substantial strength in primarily the deltoids but also of the supporting muscles of the shoulder girdle and torso (Johnson et al., 2019). In this exercise, the participant first performs a handstand, on the floor, on bars, or against a wall. They then lower themselves to the floor or between their supporting hands, and then push themselves back up to a full handstand position, while keeping their body straight. In CrossFit, this is called a "strict" handstand pushup. During kHSPUs, the athlete uses the momentum of their lower body to allow faster and a greater number of repetitions. After first performing a handstand with the back against a wall, the athlete then lowers their body until their head contacts the floor. The legs are then flexed into an upside-down squat position, and then forcibly pushed upwards to gather vertical momentum. This movement is coordinated with pressing or pushing the body vertically back into the handstand position. In CrossFit, this movement is called a "kip," and the process is called "kipping." These exercises require high levels of both strength and coordination. Videos of kHSPUs are readily available on the internet by searching "kipping handstand push-up." Examples are here:

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Strict handstand pushup: https://www.youtube.com/watch?v=hvoQiF0kBI8
Kipping handstand pushup: https://www.youtube.com/watch?v=InRvHNUOlSs

Much controversy about the safety of kHSPUs appears in online discussions, typically from clinically trained coaches. Arguments include the possibility of neck injury and concussion, usually mentioning the impact from the descent as the probable mechanism of injury. However, there has been no study of the forces involved in kHSPUs, or the symptoms, if any, secondary to performing them. Because the exercises involve the head relatively slowly impacting the floor or a pad on each repetition, the chief concern is neck injury. Moreover, most athletes perform these exercises as fast as they can, taking less than 2 seconds per repetition (see data below), often at the risk of maintaining optimal technique.

The incidence of neck injuries in the training that includes these exercises is reported to be 3-10% of all injuries (Feito et al., 2018; Mehrab et al., 2017; Montalvo et al., 2017; Szeles et al., 2020), but there are no published details regarding the type or severity of the neck injuries that occur secondary to such training, and none mentioning kHSPUs. Forces on the head during yoga (Sirsasana pose) were reported to be 40-48% of body weight when stable (Hector & Jensen, 2015), but otherwise there are no published characterizations of short-term loading to the head during headstands. In this paper we provide the first quantification and analysis of the ground reaction forces during kHSPUs, using an exploratory, observational cross-sectional design.

METHOD

General Procedures and Recruiting

The protocol for this study was approved by the Bove Consulting Institutional Review Board, #2022-01. The research was performed in accordance with the principles set forth in the Helsinki Declaration. All participants gave informed consent to participate in this research, and signed approved consent forms. The primary outcome of this study was to characterize axial ground reaction forces sustained by the head during kHSPUs, using force platforms (described below). To assess factors that may contribute to neck injury, video recordings were made of the head during the exercises. We stopped recruitment when the data appeared representative of the population performing kHSPUs, meaning that the variety of movements seen by both men and women had been captured.

Participants

Our recruiting goal was to include enough participants to give a representative picture of the exercises as performed. The method of performing kHSPUs is readily available online, and athletes are usually supervised by similarly-credentialed coaches. Therefore, a sample from any well-established gym is likely to be representative of the population performing kHSPUs. We recruited 16 participants from a single gym by word of mouth and by notices placed in the gym. Inclusion criteria included the willingness to participate, being at least 18 years old, and having the ability to perform at least 2 kHSPUs. Exclusion criteria included the inability to perform the exercises. Participants included 6 female and 10 male adults, ranging from 23 to 66 years old (Table 1). The investigator explained the procedures to each participant, and gave each an approved consent form to read and sign prior to participation. Each participant was asked questions regarding their performance of kHSPUs and other similar exercises to qualitatively establish their relative strength and skill level (Table 1). Each participant was asked if they experienced neck pain or headaches that were associated with performing kHSPUs. Because this was a descriptive and exploratory study, there was no separation by sex, age, or other factor.

Equipment

Two force platforms (PASPORT, PASCO, USA) and one plywood platform were covered with 5 cm thick foam cushions and covered with heavy polyester fabric. The density of the foam and the covering were similar to the exercise mats used by most athletes when performing this exercise. The platforms were positioned to measure the forces experienced by the head and by the right hand. Platforms were placed level and in the same plane, slightly offset so that the head and hands would land close to their centers. The force platforms were connected to a bridge amplifier (SPARKlink® Air, PASCO, USA) connected to a computer running Capstone software (PASCO, USA). The accuracy and precision of the instruments were confirmed using manufacturer's instructions. Video recordings focused on the head of each participant were made using the camera of an iPhone 10 to track movement of the head during the kHSPUs. The device was placed on a tripod 20 cm from the floor and took 30 frames per second.

Protocol for Data Collection

Participants were asked to warm up as they felt was appropriate, before starting. When ready, the participant stood on the middle platform for at least 5 seconds to measure their weight. Then the participant went into a handstand for at least 5 seconds to obtain a stable force measurement. They then descended into a headstand for at least 5 seconds to obtain a stable force measurement. The subjects then returned to standing. When ready, the participants performed 3 sets of up to 7 kHSPUs (maximum 21 repetitions), with rests between sets as desired. They were specifically instructed to perform the exercises as they normally do, meaning that their repetition speed and all other parameters of the exercises were not dictated or controlled other than by the participant. Data were collected at 1kHz and saved for offline analysis.

Table 1. Participant demographics.

Participant	Age	Sex	Years kHSPU	#kHSPU	# Strict
1	23	F	4	20	12
2	24	M	7	20	8
3	50	M	5	10	0
4	39	M	2	15	8
5	38	M	8	7	5
6	29	F	2	7	2
7	40	M	10	20	10
8	40	F	5	12	0
9	44	M	9	30	15
10	29	M	2	30	15
11	36	F	2	20	2
12	49	F	6	10	0
13	26	M	3	38	20
14	31	M	1	10	1
15	66	M	4	20	0
16	33	F	5	8	15
		Mean	**4.7**	**17.3**	**7.1**

The participant numbers in this table are matched to those in the figures. #kHSPU = maximum reported set of kipping handstand push-ups, Strict = handstand pushup performed without kipping.

Data Analysis

Data were imported data into Spike 2 (CED, UK) for waveform analysis. The peak forces exerted by the head on the force platforms and the event times were collected for individual kHSPUs using the cursors supplied with the program (Fig. 1A). Because the more detailed methods of data extraction used were largely developed while analyzing the data, they are considered results and are presented in that section. We imported video recordings into Kinovea 0.9.5 (Charmont, 2021) for movement analysis. During at least two repetitions, the path of the external acoustic meatus was tracked, paying particular attention to the path during the weight-bearing phase of the exercise.

Statistical analyses and graphing were performed using Prism 9.5. Forces and duration data are presented for each participant as means with ranges to depict individual variability. Non-parametric ANOVA were used to compare force variability between participants. Because this report does not include statistical comparison of groups of participants, post-hoc tests are not reported with the ANOVA analyses. Unpaired t-tests were used to compare the variability of kipping forces to landing forces for each participant. Spearman r was used to seek correlation between otherwise disparate measures, such as landing force and body weight. The Fisher's exact tests was used to determine if there was a relationship between reported pain symptoms and head movements during the loaded phase of the exercises. A Mann-Whitney U test was performed to compare the report of pain following the exercises to the time of the loaded phase of the exercises. For all comparisons, p ≤

0.05 was considered statistically significant. Data associated with this manuscript are available from the corresponding author on request.

RESULTS AND DISCUSSION

Results

Participant Demographics and Analysis Methods

Most participants were considered advanced in terms of how long they had been attending any gym, how long they had been able to perform kHSPUs, and how many they could perform (Table 1). Twelve participants completed 21 kHSPU repetitions, with the others completing 15, 17, 18, and 20 repetitions. We recorded the force profiles of 322 kHSPUs. Force profiles were surprisingly complex (Fig. 1). The first force peak occurred when the head contacted the pad (Fig. 1A, arrow "L"), which we called the "landing force." The last force peak was when the participant "kipped," the process by which the legs were actively drawn towards the chest (reducing the force on the head) and then forcibly pushed upwards for momentum (increasing the force on the head; Fig. 1A, arrow "K"). We called this peak the "kip force." In 60% of the recordings, other peaks could be seen that did not represent landing or kipping (Fig. 1B; between "L" and "K"). These peaks were more pronounced in participants who were more deliberately bringing their legs into kipping position to ready themselves for the kip (confirmed using other full body video recordings, after the primary data collection). When present, the highest peak was recorded as the landing force (Fig. 1B, arrow "L"). Peaks also occurred due to rebound of the entire body or more mobile parts of the body, and if later in the repetition, could occur because of unloading weight from the wall (while on the head, the posterior pelvis may rest against the wall) or because of impact of the heels on the wall before the unloading was complete. These forces were not reported. When only two clear peaks were discernable (30% of recordings), they were recorded as the landing and kip forces. When only one peak was discernable (10% of the recordings), as in Fig. 1C for 6 of 7 repetitions, it was recorded as the kip force. Repetition durations were calculated by combining the duration on the head and the adjacent duration off the head (see Fig. 1C). Most participants showed consistent total repetition durations and percent of that duration on the head (Fig. 1D-E), but there were significant differences between participants (total repetition durations $F_{(15, 69)} = 52.8$, $p < 0.001$; % repetition duration on head $F_{(15,100)} = 70.1$, $p < 0.001$). Because there were no differences in performance between sets for individual participants (see below) all repetitions (n = 15-21) were combined for all further analyses.

Ground Reaction Forces

Participants placed 69% (12.5 SD) of their body weight on their head during the headstand performed prior to the kHSPUs. Mean landing forces for each participant, with ranges to show the maximum and minimum forces, are shown in Fig. 2A. These are expressed as a percentage of body weight in Fig. 2B. Landing forces were more than the measured headstand force, but typically less than body weight. The mean peak landing force (n = 16, Fig 2A, top of range bars) was 896 N with a large range (SD = 232 N). There was a statistically significant difference in mean landing force between participants by ANOVA ($F_{(15, 137)} = 37.7$, $p < 0.001$). Mean landing forces were positively correlated to body weight (Spearman r = 0.67, $p < 0.05$).

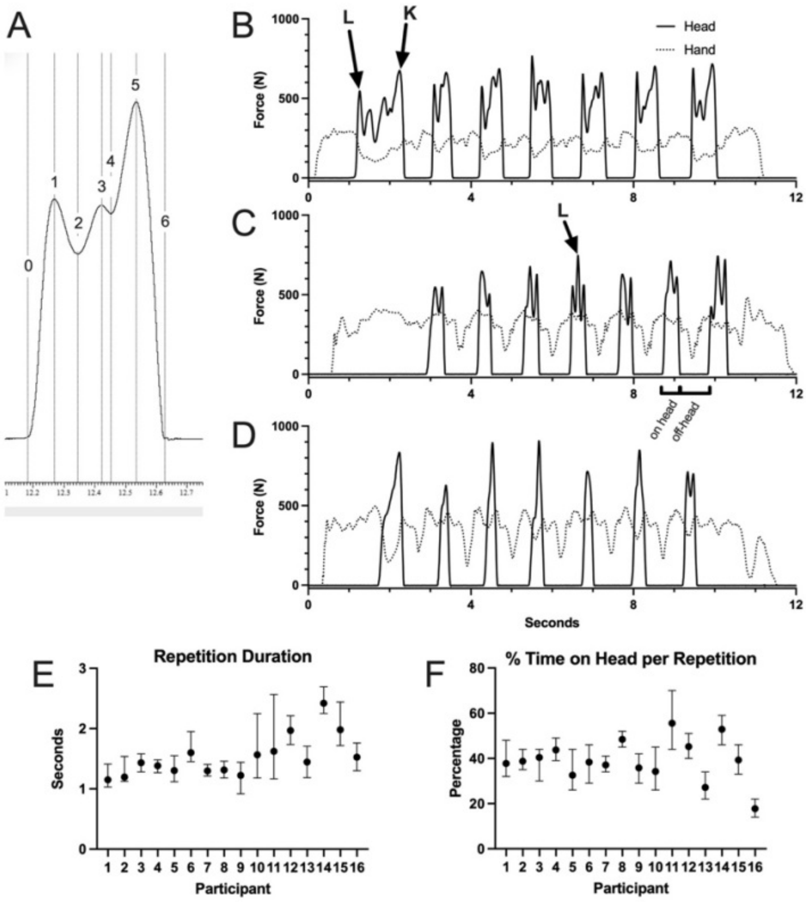

Figure 1. Representative recordings of forces on head during kipping handstand pushups (kHSPUs). A. Typical force waveform of a single repetition showing points measured. In this waveform, the peaks indicated by 1 and 5 were used for the landing and kipping forces, respectively. The time between 0 and 6 was recorded as the repetition duration. Peaks 2, 3, and 4 were used as required to calculate the landing or kipping force if necessary (such as in 1C, at "L"). Traces B, C, and D reflect the variety of kHSPU performance. All recordings are raw data of single sessions of repetitions. L = landing forces recorded, K = kipping force recorded. In C, the brackets show the time on head and time off-head, which combined were taken as the repetition duration. E. Repetition duration for each participant (means with ranges). F. Percentage of time on head for each repetition (means with ranges).

Kipping forces are similarly depicted (Fig. 2C-D). By participant, mean kipping forces were typically higher than their body weight. Mean kipping forces by participant were statistically significantly higher than the landing forces for 10, lower for 2, and not different for 4 participants (unpaired t-tests; Fig. 2E). Mean peak kipping force (n = 16, Fig. 2C, top of range bars) was 991 N (SD = 189 N). Kipping forces differed between participants ($F_{(15,189)} = 81.4$, $p < 0.001$), and were also positively correlated to body weight ($r = 0.57$, $p < 0.05$). Peak landing and kipping forces for each participant as compared to published failure forces of the cervical spine can be seen in Fig. 2F.

Head Movements and Post-Exercise Symptoms

Most participants (n = 10) had minimal to no head movement in the sagittal plane during the load-bearing part of the kHSPU, displaying an elliptical movement of the head (as indicated by the external acoustic meatus) during each repetition (Fig. 3A). Because this was most frequently observed pattern, was observed in the most advanced participants, and because none of these participants reported pain related to kHSPUs, it was considered "characteristic." However, the other 6 participants showed movement into extension during load-bearing (4 during the landing impact (Fig. 3B) and 2 during the kip (Fig. 3C)). None moved into flexion.

Five of the 16 participants (31%) reported having neck stiffness, pain, and/or headaches following kHSPUs. All 5 showed neck movement during the head load-bearing phase, moving into extension (Fig. 3 B-C). A Fisher's exact test showed a significant association between the report of pain and movement during the load-bearing phase (p = 0.001) with a positive predictive value of 0.83. There was no relationship between the presence or absence of reported pain and mean duration on the head (Mann-Whitney U test, p = 0.712). The participants were separated into groups by the presence (n=5) or absence (n=11) of symptoms after performing kHSPUs, and there were no statistically significant differences between these groups in landing or kip forces (raw or %-body weight), or duration on the head.

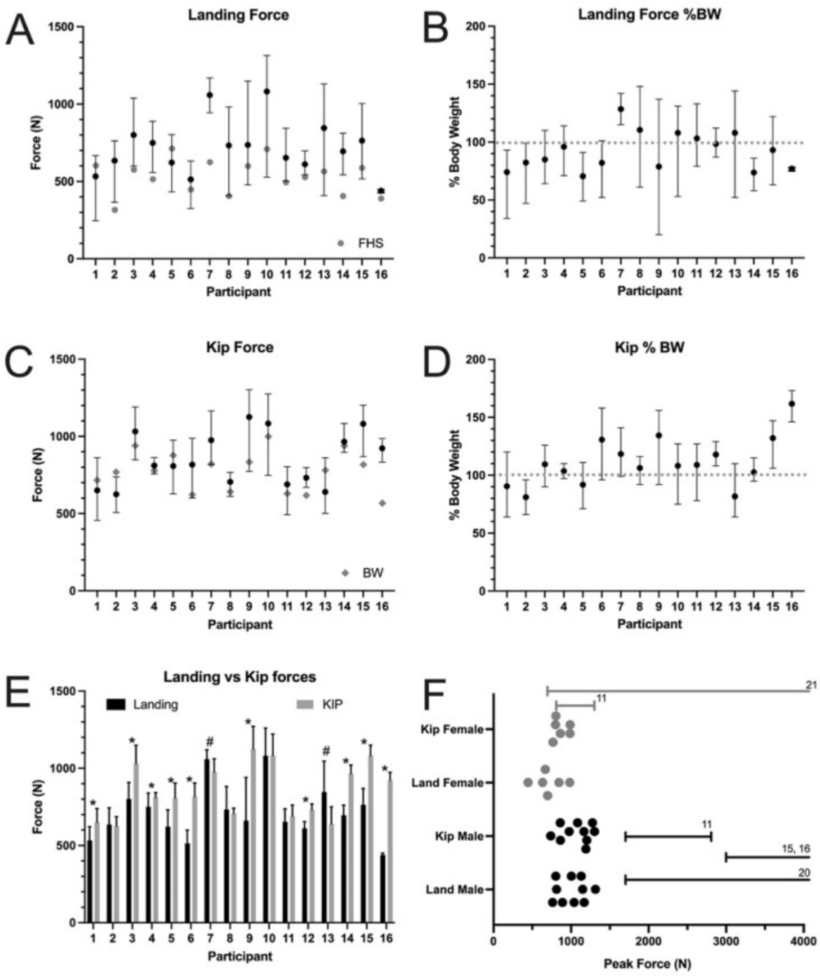

Figure 2. Forces on head during kHSPUs for each participant. A and C. Landing and kipping forces are depicted (means with ranges). In A, gray circles are the force measured during headstand (FHS). In C, gray diamonds are body weights (BW). B and D. Landing and kipping forces expressed as the percentage of BW. 100% BW shown with interrupted gray line. E. Comparison of landing and kipping forces (means with SDs). * = kipping higher than landing, # = landing higher than kipping (t-tests, p≤0.05). F. Maximum landing and kipping forces for each participant. Bars represent published ranges of forces shown to cause neck injury from axial loads to head (numbers correlate to source references).

Other Comparisons

Comparisons were made to quantify and qualify participant skill and fatigue, which may be related to safety. Mean duration on the head was strongly statistically correlated to the sum of the number of peaks per participant (from all repetitions; Spearman r = 0.78, p = 0.001), which seemed to be related to coordination of the movements. Traces were subjectively evaluated for smoothness (Fig. 4A-C), with the intent to judge relative coordination. As can be appreciated in Fig. 4A, the longer duration on the head also showed a higher variability of the forces on the head. This reflects the gradual lowering of the legs in preparation for the kip. A more coordinated movement is represented in Fig. 4B, where the trace is smooth and the force exerted by the hand increased with the head leaving the force platform. The seemingly most coordinated pattern is seen in Fig. 4C (participant 16), where there is almost constant force by the hand, a short time on the head, and one peak. For each participant, simple linear regression of the repetition speed, duration on and off the head, and landing and kip forces were performed. None of these changed with the number of repetitions (data not shown), which was interpreted as indicating that the participants did not fatigue enough during the sets to alter their movement patterns.

While this paper was being prepared, we had the opportunity to collect data from Participant 14 one year after their initial participation. They were new to these exercises when initially tested, and a sample force graph appears in Fig. 4A. While the later graph of the forces on the head appeared similar in overall shape, the mean repetition duration, landing forces, and kipping forces were statistically significantly reduced (duration: 1.28 ± 0.13s vs 0.86 ± 0.07s, $p < 0.0001$; peak landing: 695 ± 66 N vs 540 ± 57 N, $p<0.0001$; peak kip: 965 ± 56N vs 757 ± 43N, $p < 0.0001$). This participant used more shoulder strength and held their head in a more neutral posture throughout the second testing.

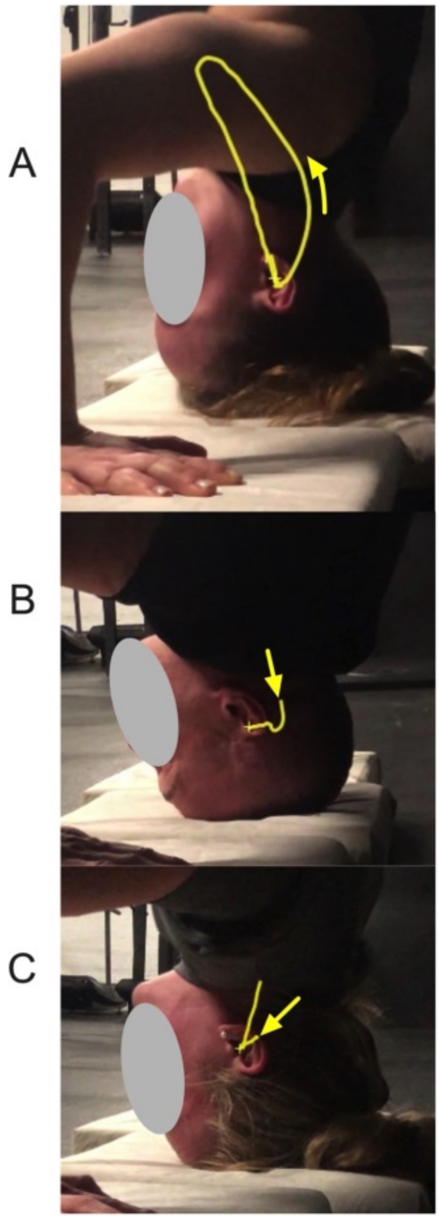

Figure 3. Head movements during kHSPUs. A. The head and neck remained stable during the weight-bearing phase (participant #1). The arrow indicates the direction of the path of the external acoustic meatus (EAM) during one full repetition. This overall pattern of movement was shared by the more experienced participants, and was accepted by this analysis as "good technique." B. The EAM moved forward during the landing. C. The EAM moved forward just prior to the kip. In both B and C, the arrow indicates the direction of the movement, which is reversed from A. These paths of the EAM indicate neck extension during the kip; both participants reported neck pain and headaches following kHSPUs.

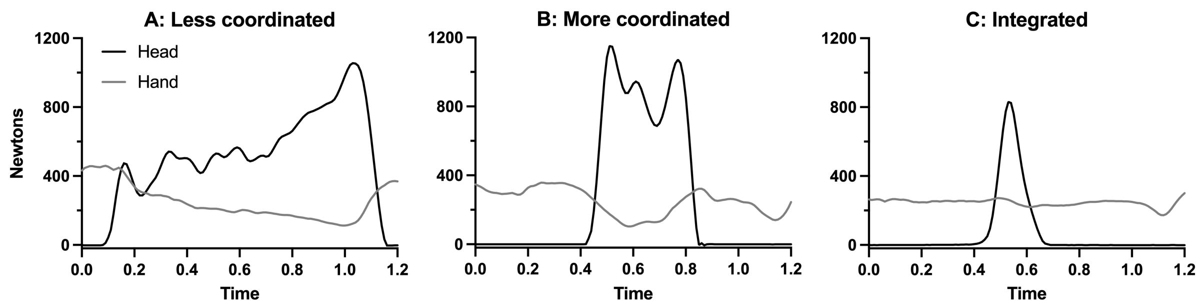

Figure 4. Sample force profiles suggesting coordination differences among participants. A. The relatively long duration and varying force on the head is consistent with the inexperience of this participant (<1 year). B. This was the most typical force profile, showing the initial landing force, a smaller force when the legs came into kipping position, and the kip force, with smooth transitions. C. This force profile was considered to reflect the most coordinated effort and most efficient exercise. Note that the force on the hand remained steady, indicating that the participant (#16) did not rest on their head during the exercises. Yet, this participant (#16) still placed >800N (~1.5X body weight) on their head during the kip (Fig. 2 C-D).

Discussion

In this report we describe the forces borne by the head during kHSPUs in 16 experienced volunteers. Forces ranged from 0.5 - 1.300 kN, below the reported threshold for catastrophic failure predicted for young males with healthy spines but overlapping with published failure levels for females (however, see discussion below). The forces were higher during the kip than during the landing. Head movement during the load-bearing phase of the exercise was strongly correlated with self-reports of post-exercise neck pain and/or headache.

Research Contributions

The literature taken together support that 3.6 - 4kN is the tolerance of the healthy young male cervical spine to catastrophic injury (Nightingale et al., 1997; Nightingale et al., 1996), but forces in the range here reported are close to those shown to cause severe injury in some experiments (Alem et al., 1982; Alem et al., 1984; Nightingale et al., 1997; Nusholtz et al., 1981; Yoganandan et al., 2016; Yoganandan et al., 1986). The population performing this exercise includes males and females of all ages. While the difference in the forces for males shown in Fig. 2F in comparison to the published forces may seem acceptable for most healthy participants it must be stressed that the tolerance forces were proposed for young male cervical spines without degeneration, and are the limits at which *catastrophic* injuries occur. Older and female spines have a lower tolerance for injury (Pintar et al., 1998). Cervical spinal degeneration occurs secondary to injuries, occurs in most individuals as they age (Tao et al., 2021). and reduces the strength of spinal holding elements (Maiman et al., 1983), all of which render individuals more susceptible to compressive injuries (Yoganandan et al., 2018).

The observation that the kipping forces were higher than the landing forces is important. Participants should know that they will not avoid high forces to the head by attempts to land relatively gently. As examples, two of the participants, both <30 years old, stated that they had suffered multiple concussions during sports, and attempted to land relatively gently on their heads. One of them (participant 2) had among the lowest peak kip forces, but the other (participant 6) had a much higher peak kip force (0.98 kN) compared to their peak landing force (0.63 kN).

We observed a high rate of post-kHSPU symptoms (31%), and show that movement of the head during these exercises is a predictor for neck pain and/or headaches. While there is no way to strengthen the neck to withstand compression, it is possible to strengthen and train towards greater stability. Modeled as a column, the cervical spine is stiffest and thus more capable of withstanding axial loading when the force vector passes through the occipital condyles and the T1 vertebral body (Cusick & Yoganandan, 2002; Pintar et al., 1995). Any bending compromises the stiffness of the cervical spine, and renders it more susceptible to injury (Maiman et al., 1983). All who perform these exercises should be taught to keep their neck as stiff and stable as possible, and to position their head so that their vertex contacts the floor (or pad). The alternative is to not land on the head at all, and perform the "strict" handstand pushup, without kipping, where there is minimal to no force on the head. In one participant, we were able to demonstrate a positive effect of training, in terms of a reduction of landing and kipping forces on the head, as well as holding a head in a safer posture (as in Figure 3B). It is not known what training this participant had received to achieve this improvement.

Limitations

The primary limitation of this study is in terms of interpretation since there are no clear published data to allow a conclusion of safe versus unsafe. It is unethical to prospectively study forces that cause damage in living humans, reflected in the relative lack of literature for direct comparisons to the present results. We also chose volunteers, and did not select for sex, skill level, or other factors, because we wanted to capture the variability of the performance of this exercise.

Suggestions

There has been no report, including case studies, of injuries following kHSPUs. Some participants in our study had been performing kHSPUs regularly for up to 12 years with no reported negative effect. This apparent disparity presents difficulty making a blanket statement about safety. However, since a history of head and neck injury, degenerative changes, and age reduce neck load-bearing capability, such athletes should be dissuaded from performing kHSPUs. The motions of the head observed in this study were associated with post-kHSPU pain, were not readily appreciated, but were apparent using slow motion video. It is recommended that coaches perform this relatively easy analysis on athletes, especially those who suffer post-kHSPU symptoms. Athletes and coaches should also know that more padding will cause more force to be translated to the neck (Nightingale et al., 1997; Pintar et al., 1995).

CONCLUSION

Kipping HSPUs are unique, quirky, and fun, and require strength and coordination. However, we show that they appear unsafe at least for females to perform, since the forces overlap with those published as causing severe neck injury. Age and previous injury are critical to consider when deciding to participate in this exercise. As in American football, where concussions occur regularly, kHSPUs will likely remain an exercise performed by many thousands of people worldwide. These exercises are typically performed while a clock is running, and technique can become secondary to performing the maximum number of repetitions. It is hoped that further study into the incidence of post-kHSPU symptoms will be performed to allow better coaching towards kHSPU safety.

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AUTHOR CONTRIBUTION STATEMENT

GMB performed all aspects of this study.

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