KINETIC AND KINEMATIC CHARACTERISTICS OF IMPACTS FROM VARIOUS HEIGHTS EXPERIENCED BY CHILDREN

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In 1977, the United States Consumer Product Safety Commission reported treatment of 93,000 children in emergency rooms for injuries sustained on playgrounds. By 1986, the number had risen to over 200,000 and 70 percent of these cases were falls from equipment onto various play surfaces (U.S. Consumer Product Safety Commission, 1986). In addition to free play activities, today's youth are also experiencing acute injuries from single impact trauma during organized sports (Micheli, 1986).

A second type of injury now occurring in children, specific to organized sports, are injuries caused by overuse. Repetitive training to improve sport skills may increase the risk of injury (Micheli, 1983). Because the young child is at an important phase of growth and development, he/she might actually have greater susceptibility to injuries caused by overuse than the adult (Micheli, 1983 & 1984). Repetitive training in activities such as running, jumping, and landing may cause microtrauma to the tissues of the upper and lower extremities. Mubarek (1983) clinically demonstrated the susceptibility of the growth plate to injury from single impact trauma and indicated that injury may occur at the epiphysis of the hip or knee from repetitive microtrauma.

The impact landing from a jump has received less attention than its counterpart, the takeoff. However, the landing is more likely to result in injury as a result of inappropriate impact absorption. Because of the limited available research on landing impacts of children, this study was designed to determine the styles of landings utilized by children, peak forces encountered, temporal factors affecting impacts, and center of pressure pattern differences between styles.

Methodology

Subjects

The subjects of this investigation were 30 children (age = 103.3 $\pm$ 16.3 months; ht $\pm$ 130.66 + 9.78 cm; wt $\pm$ 28.4 + 6.4 kg) from several different elementary schools in Denton, Texas during the spring of 1987. Twenty-four females and 6 males volunteered as subjects. Several subjects, 15 females and 3 males, were youth athletes involved in gymnastics, basketball, baseball, and/or soccer. Parents were informed of all procedures and signed forms of consent.

Procedures

The apparatus used in this investigation consisted of a gymnastic parallel bar suspended between two volleyball standards equipped with adjustable T-bars. The apparatus was positioned directly above a forceplate. Each subject was assisted up to hold onto the bar. Subjects were given the command to drop down onto the forceplate just prior to data collection. No verbal instructions on how to land were given to any subject. Each subject performed two landing trials from four heights (15, 20, 25, and 30 cm). The order of heights was randomized for each subject. The first trial was considered a practice trial. However, forceplate data were collected on both trials at each height to determine if learning occurred between trials. During the second trial, both forceplate and film data were collected. To eliminate affects that might result from the variability of footwear worn by the subjects, all were tested without shoes. Segmental markers were attached over the fifth metatarsal, lateral malleolus, femoral condyle, and greater trochanter of the right lower extremity.

Film records were obtained with a 16 mm Locam high-speed motion picture camera operating at a nominal speed of 100 frames per second (fps). The Locam camera was equipped with a 50-120 mm Angineaux lens and internal LED timing light. The camera was positioned 9 m from and perpendicular to the center of the forceplate. The camera filmed the sagittal view of each subject's body from initial resting in the hanging position to final stable position after landing.

The film records were projected onto a horizontal surface with a Lafayette motion picture analyzer. Six segmental endpoints were digitized with a Numonics model 1224 digitizer interfaced to an Apple

IIe microcomputer and were analyzed with software written by Richards and Wilkerson (1984). The raw data were smoothed with a second-order low-pass digital filter set at 6 hz (Winter, 1982).

Force data were obtained from a Kistler Model 9261A forceplate. The three dimensional force signals were channeled through an amplifier interfaced to an Apple IIe microcomputer via an analog to digital converter. The sample rate was 600 Hz per channel. Graph paper was affixed to the forceplate and subject's feet were traced after landing. This was used to determine foot placement for center of pressure patterns. Force data were analyzed with software written by Richards and Wilkerson (1984).

Selection of Variables

Kinetic and kinematic variables were analyzed for each subject. Kinetic variables analyzed were (a) vertical peak forces, (b) impulse, and (c) center of pressure patterns. Temporal phases of the force curve were also analyzed. The two phases analyzed were the time from initial impact until peak force and from peak force until stability was regained by the subject. Kinematic variables analyzed were the absolute angles of the trunk, thigh, shank and foot measured relative to the right horizontal in a counterclockwise direction. In addition to this, segmental contributions to the movement were evaluated as previously defined by Hudson (1'982). Hudson's (1982) definition was extended to include the time period after peak accelerations were experienced. The time period from peak segmental angular acceleration until stability was re-established by the segment was also analyzed. Temporal percentages of adjacent segmental overlaps of contributions were also evaluated.

Evaluation of Data

Descriptive data were obtained from kinematic and kinetic data. Means and standard deviations were calculated for all variables at all trials and all heights. Two-way analysis of variance with repeated measures was used to determine if differences existed between the two trials at all four heights. When a significance was found, a Tukey post-hoc test was performed to determine which of the heights were significantly different from the others and if there was a significant difference between trials. Eleven variables were selected for analysis with a Pearson Product Moment Correlation with an alpha of .01. A two-way multivariate analysis of variance with repeated measures across heights and among heights was used to compare soft and hard landers. The alpha level was set at .05 and a Tukey post-hoc test was performed where significance was indicated.

Results and Discussion

Peak vertical forces were determined for each of the vertical heights. The mean peak vertical forces, standard deviations, and ranges for both trials across all heights can be seen in Table 1.

TABLE 1. Means, standard deviations, and ranges for peak impact forces

HEIGHT	MEAN	SD	RANGE
15 CM			
Trial 1	4.70	1.70	2.68 - 9.96
Trial 2	4.53	1.66	2.31 - 8.41
20 CM			
Trial 1	5.01	1.70	2.31 - 11.10
Trial 2	5.31	1.40	2.79 - 8.41
25 CM			
Trial 1	5.86	1.67	3.26 - 9.23
Trial 2	5.13	1.44	2.42 - 8.42
30 CM			
Trial 1	6.23	2.35	3.19 - 12.11
Trial 2	5.61	1.69	2.71 - 9.84

The two-way analysis of variance (ANOVA) of peak forces revealed a significant difference between trials across all heights ($\underline{F}$(1,28) = 16.99, P $\leq$.05). This indicated that subjects experience some learning from the first to the second trial. Subjects automatically decreased their peak vertical force from Trial 1 to Trial 2 without any instruction. The two-way ANOVA of peak forces also revealed a significant difference between heights ($\underline{F}$ (1,28) = 24.24, P $\leq$.05). The Tukey post-hoc evaluation indicated significant difference at a .05 level among all compared heights except between 20 and 25 cm on Trial 1. A significant difference between heights on the second trial was found only between the extremes of 15 cm and 30 cm. A significant difference between peak forces was expected due to the increasing heights from which subjects landed. Children appear to be experiencing considerably more impact force than adults as reported by Lees (1981), Mizrahi and Susak (1982), and Nigg, Denoth, & Neukomm (1981). These researchers have indicated that adult impacts ranged from 1.94 g to 4.69 g where landing from .5 m and 1 m, which is higher than the heights used in the current study for children.

Temporal Impact

The impact force was divided into two distinct time periods based on peak force. The first time period was from the moment of initial impact until the peak force was experienced by each subject. This time period is referred to an initial impact. The second time period occurred from peak impact to the point in time where stability is regained. This is referred to as the second force phase. Mean times for both phases and total landing time for all heights and trials can be seen in table 2.

TABLE 2. Means of temporal force curve variables*

	HEIGHT			
VARIABLE	**15 CM**	**20CM**	**25CM**	**30CM**
TOTAL LANDING TIME				
TRIAL 1	187	164	190	167
TRIAL 2	173	171	173	171
INITIAL IMPACT PHASE				
TRIAL 1	62	57	53	49
TRIAL 2	67	58	55	54
SECOND FORCE PHASE				
TRIAL 1	107	107	110	117
TRIAL 2	110	113	117	115

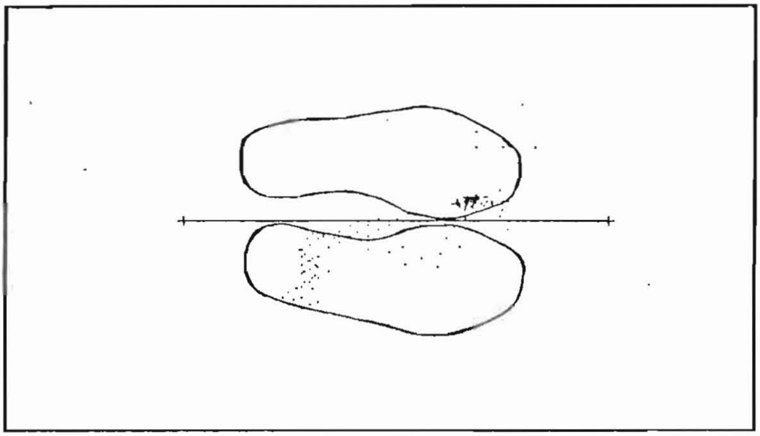
* Times in ms.

The one-way ANOVA across heights for initial impact time was F (1,29) = 13.87, $P \leq .05$ for Trial 1 and F (1,29) - 19.03 $P \leq .05$ for Trial 2. The Tukey post-hoc evaluation revealed significant differences existed between 15 cm and 30 cm in addition to 20 cm and 30 cm for Trial 1 and 15 cm and 25 cm as well as 15 cm and 30 cm for Trial 2. No significant differences were found across heights for the second force phase or total landing time. This indicated that as height of landing increased, the initial impact force time decreased. As reported by Lees (1981), the total time of force absorption only last for 150 to 200 ms even though the total time of landing lasts for one second. The subjects of this study adjusted the amount of initial impact time relative to the amount of impact force experienced.

Impulse and Center of Pressure

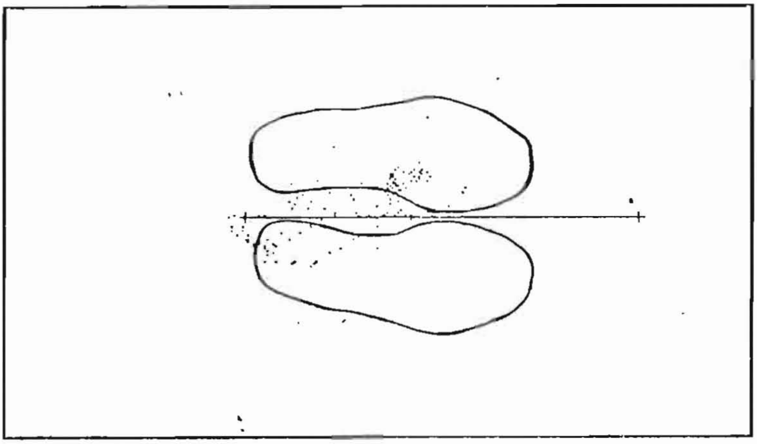
Impulse for the total impact was evaluated. Significance was found with a one-way ANOVA between heights F (1,29) = 40.31, $P \leq .05$ for Trial 1 and F (1,29) = 24.85, $P \leq .05$ for Trial 2. The Tukey post-hoc evaluation indicated significant difference between all possible comparisons of heights except 20 cm and 25 cm for both Trials 1 and 2. Impulse as a measure has been previously used to characterize and compare impacts under different conditions (Mizrahi & Susak, 1982). Center of pressure patterns were analyzed for each subject for each trial at each height. Valiant and Cavanagh (1983) distinguished flat foot landers from forefoot landers relative to vertical peak forces and the patterns of center of pressure. Large vertical peak forces were exhibited by flat foot landers in this study as well as in the study by Valiant and Cavanagh (1983). Flat footed landers in both studies landed with an initial contact toward the middle of the foot with peak force to the rear. The forefoot landers of both studies demonstrated initial impact with the ball of the foot upon landing with a rocking rearward onto the heel. Illustrations of the center of pressure patterns for both flat footed and forefooted landers can be seen in Figure 1. Because peak pressures occur at different times after initial contact, the rate of change of center of pressure is greater for the flat foot landers as compared to the forefoot landers.

FIGURE 1. Center of pressure of soft landers*



* Forefoot

FIGURE 1a. Center of pressure of hard landers*



* Flatfoot

Variable Relationships

Eleven variables were selected for correlational analysis. The variables selected were peak forces, temporal factors of the force curve, segmental contributions to movement based on accelerations, and temporal measures of overlap of adjacent segments in their contributions to movement. The level of significance was set at .01 which required a $r = .423$ for a significant relationship between variables to exist. Several trends and/or relationships were noted. Subjects generally reached peak force sooner at all heights when experiencing larger peak forces at impact. A very high positive correlation ($r > .80$) was found across all heights between total time of the force curve and the time from peak force until stability was re-established by the subject. The longer the time spent in impact, the more time was spent in re-establishing stability from the occurrence of the peak force. In connection with this trend, the foot appeared to contribute a great deal to the time spent from peak force until stability. The larger the total time of the force curve, the more extended the time from peak acceleration until stability was re-established in the foot.

Hard versus Soft Landers

In an attempt to distinguish between soft and hard landers the softest five landers were compared to the hardest five landers at each height. A two-way (group x trial) multivariate analysis of variance with repeated measures was performed on peak forces and temporal phases of overlap of segmental contributions to the movement. Temporal time patterns were divided into two phases for each of the lower extremity segments. The first phase was defined as the initiation of angular acceleration which produced downward movement of the body until the maximum angular acceleration was achieved. The second phase was defined as the time from maximum angular acceleration until stability of that segment was achieved. During this time period, the segment was still angularly accelerating, but in increasingly smaller amounts. This phase is identified as resistance to the downward vertical force. To control for the inflation of alpha with multiple tests (Cohen & Cohen, 1975), a Bonferroni adjusted alpha of .007 was applied to the data to check for significance. No differences were found between the soft and hard landers (F (3,27) = 6.98 $P > .05$) or the type of landing by height interaction (F (3,27) = 16.40, $P < .05$). To determine which variables were significantly different across heights, Tukey post-hoc tests were performed. All paired comparisons of peak force at the various heights except between 25 cm and 30 cm were significant. In all comparisons in the initial impact phase, the foot and shank segmental overlaps of contribution to the movement were significant except the 15 cm and 20 cm height comparison. All comparisons in the initial impact phase, the shank and thigh overlaps of contribution were significant. With the exception of 20 cm and 25 cm all comparisons of the thigh and trunk segmental overlaps during the initial impact were significant. During the second force phase, all comparisons between heights of the foot and shank segmental overlaps were significant with the exception of 15 cm and 20 cm. The shank and thigh segmental overlap during the second force phase were significant for all comparisons with the exception of 15 cm and 20 cm. In all comparisons in the second force phase, the segmental overlap between the thigh and the trunk were significant.

Conclusions

Children in this study experienced larger peak vertical forces when the landing was unfamiliar. Subjects automatically decreased this peak vertical force once experiencing the impact at the specific height. Regardless of the heights from which the children were landing, the peak vertical forces experienced were consistently larger than those reported for adults at considerably higher heights. Children may either be able to experience larger peak vertical forces, or the forces they encounter are not safe and account for the large number of traumas experienced by this group.

Significant differences in peak vertical forces were noted across heights. It was not surprising that increasing heights produced increasing vertical forces. The question then becomes how might the landing change kinetically or kinematically with increasing peak vertical forces. Temporal patterns of the vertical force curve did not change significantly with one exception. The time spent in initial impact appear to be related to the peak vertical force experienced by the performer. The more peak vertical force experienced by the lander the sooner that peak occurs in the total landing force pattern. Even though a significant difference did not occur in the second force phase or total landing time and the second force phase. It appears that the longer the time for the total landing, the more time is utilized in the second force phase. Review of temporal patterns of contribution of lower extremity segments revealed that the foot segment time pattern was positively related to the extended second force phase. This might suggest that the foot plays a positive role in the re-establishing of stability or balance.

The largest percentage of adjacent segmental overlaps were significantly different from each other at the different heights. Most of the percentages of overlap between adjacent segments were below 50 percent which suggests a sequential pattern of force absorption. These percentages were not definitive enough to suggest that landing is sequential. The children of this study may still be maturing in their development of the landing pattern.

Further study is suggested in determining the different kinetic and kinematic characteristics of mature versus immature patterns of landing. In addition to this, a study to examine the changes in technique within the individual lander is suggested to determine the different characteristics of hard versus soft landings.

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