Comparison of Impact Forces in High and Low Impact Aerobic Dance Movements

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This study compared impact forces and loading rates in a high and low impact aerobic dance movement. Five subjects each performed five trials of the low impact front knee lift (LFKL) and five trials of the high impact front knee lift (HFKL). The data were recorded using an AMTI force plate at 1,000 Hz. A repeated-measures ANOVA was used to test for differences in selected variables for the LFKL and HFKL. Peak impact force was significantly lower in the LFKL than the HFKL, mean 0.98 BW and 1.98 BW, respectively. Mean loading rate was significantly lower in the LFKL (14.38 BW/s) than the HFKL (42.55 BW/s). Mean impact impulse during the first 50 ms of impact was significantly lower in the LFKL (0.0131 BW*s) than the HFKL (0.0295 BW*s). Based upon these differences in external ground reaction forces, it appears that low impact front knee lifts impose a significantly lower load than high impact front knee lifts.

Aerobic dance has become a very popular form of exercise in the last decade. The number of reported injuries attributed to participation in aerobic dance have also increased. Rothenberger, Chang, and Cable (1988) surveyed 726 aerobic dancers and found that 49% of them reported at least one injury related to aerobic dance. Among those dancers injured, 43% indicated that their injury was severe enough to cause them to discontinue participation temporarily. Rothenberger et al. also reported that 60% of the injuries occurred to the lower extremity. Several other surveys have found that the lower extremity is the most frequent site of injury in aerobic dance (Francis, Francis, & Welschons-Smith, 1985; Garrick, 1985; Garrick, Gillen, & Whiteside, 1986; MacIntyre, Clement, Taunton, McKenzie, & Filsinger, 1984; Richie, Kelso, & Bellucci, 1985). This relatively high incidence of injury has led some aerobic dance participants to change from high impact to low impact aerobics. Low impact routines consist of movements with one foot on the floor at all times. In contrast, high impact aerobics typically consist of a variety of flight phases involving hop-

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ping, skipping, and jumping movements. However, there is a lack of information on the magnitude of the peak impact forces and loading rates associated with either high or low impact aerobic dance.

Depending upon the loading rate and magnitude of impact forces, the muscles are able to serve as shock absorbing mechanisms and absorb a considerable amount of the energy associated with impact. The reaction time of the neuromuscular system to a stimulus has been reported to range from 50 to 75 ms (Jones & Watt, 1971; Nigg, 1985). Since the neuromuscular system takes approximately 50 ms to respond to a stimulus, it must depend upon preactivation of the muscles to absorb shock during the first 50 ms of a landing. Nigg (1985) used the terms passive and active to differentiate between forces that cause injury and forces that cause a positive training effect.

Passive forces are those that reach a peak in less than 50 ms. Since these forces are applied at a rate that is faster than the reaction time of the neuromuscular system, the muscles are unable to absorb the shock via flexion of the ankle, knee, and hip joints. Nigg, Denoth, and Neukomm (1981) indicated that active forces, those forces that reach peak value in more than 50 ms, can have a positive training effect upon the body such as increasing muscle strength and strengthening bone tissue.

Passive forces have been associated with injuries to both soft tissue and bone. Due to the inability of the musculoskeletal system to attenuate passive impact forces, the load is transmitted to bone and soft tissue. Light, McTillican, and Kleinerman (1980) studied the transient forces exerted upon selected bones at heel strike when walking at a pace of 1.47 m/s. Light et al. found that passive impact forces in walking resulted in peak tibial accelerations of 5 g and peak skull accelerations of 0.5 g. Hawes, Light, and Repond (1979) indicated that passive forces can cause shear and stretching of soft tissue which may lead to injury to nerve roots or nerve endings.

Radin et al. (1973) demonstrated that impulsive loading of 1 BW applied at a rate of 60 times per minute, for one hour, resulted in joint degeneration of rabbits, as judged histochemically. The authors indicated that fatigue failure of bone under impact loading is a function of both the degree and nature of the loading. Francis, Leigh, and Berzins (1988) measured passive forces of a single subject performing a hopping type aerobic dance movement. They found that passive impact forces in a typical aerobic dance movement resulted in peak tibial accelerations of approximately 3 g in less than 60 ms.

It is clear from the literature that forces which are applied at a rate that exceeds the minimum time necessary for the muscles to change their level of activation (passive forces) can lead to injury of bone and soft tissue. Due to the paucity of data pertaining to load in aerobic dance, this study was designed to quantify the magnitude and rate of passive impact forces in aerobic dance exercises and to see if there were any differences between high and low impact aero-

**Methods**

Five subjects, four females and one male, gave informed consent for participation in this study. They were skilled in both high and low impact aerobic dance.
The subjects had participated in aerobic dance a minimum of three times per week for a mean of 4.4±1.67 years. The mean values for height and mass of the group was 167±4.54 cm and 60.0±4.83 kg, respectively.

Selection of Dance Step

The aerobic dance step selected for analysis is shown in Figure 1. The International Dance-Exercise Association (IDEA) defined this step as the Front Knee Lift (FKL). Each subject performed both high impact (HFKL) and low impact (LFKL) front knee lifts. As shown in Figure 1, the only difference between the two movements is that the HFKL consists of an airborne phase.

Data Collection

The data were collected with an AMTI force platform that was mounted flush with the floor surface. The subjects were given as many practice trials as needed to land consistently in the region of the force platform with the right foot and to achieve constant movement pace. Movement pace was monitored by visual inspection and verbal count. Each subject performed five high impact FKL trials and five low impact FKL trials. The order of trials was randomized; for example Subject 1 began with LFKLs and Subject 2 began with HFKLs. An individual trial consisted of a total of five FKL sequences in which the subject contacted

(A) HFKL

(B) LFKL

Figure 1. — Front knee lift aerobic dance exercise: movements are performed in order from 1-5. (a) High impact front knee lift (HFKL) consists of airborne phase, Sequence 3. (b) Low impact front knee lift (LFKL).
the force plate with the right foot. The force data for each trial were recorded during the third right foot contact of each of the five FKL sequences. All subjects wore the shoes they customarily used for aerobic dance. No attempt was made to control for shoe type.

Data Processing

Force data from five high impact FKL trials and five low impact FKL trials were recorded using a Zenith 248 microcomputer interfaced to the AMTI amplifier by a Data Translation DT-2801A, 12-bit analog-to-digital converter. For each trial, the data were sampled at a rate of 1,000 Hz for a total of 3.5 s. The force data were normalized by dividing by the subject's body weight in newtons. A typical vertical force curve for the high impact FKL is shown in Figure 2. As shown in Figure 2, the vertical ground reaction force consisted of three phases: propulsion, flight, and landing. The impact phase of landing can be subdivided into passive and active impact periods. Since the purpose of this study was to quantify the magnitude and rate of the impact forces, only the data pertaining to impact were retained for further analysis. The vertical force curves were analyzed from the beginning of the impact phase to the first local minimum following impact peak (see Figure 2). The same procedure was followed for the low impact FKL curve.

The vertical force curves were smoothed using a quintic spline routine. All derivatives and integrals were calculated from the analytical function generated by the quintic spline. Integration was performed using Simpson's rule. From each

Figure 2 — Typical high impact front knee lift (HiFKL) vertical force curve. The vertical force curve was analyzed from the beginning of the impact phase to the first local minimum following impact peak.
impact force curve, for both the high and low impact FKLs, the following de- pendent variables were calculated: peak impact force, time to peak impact force, passive impact impulse, peak impact impulse, peak loading rate, and time to peak loading rate. The passive impulse was defined as the area under the vertical force curve (Fz) during the first 50 ms of the impact phase. The peak impact impulse was defined as the area under the Fz curve from the beginning of impact to peak impact force.

All 25 trials for each impact condition were averaged to generate an average high and low impact FKL force curve. In order to avoid attenuation of impact peaks, the curves were aligned by impact peak and subsequently averaged for ward and backward. A quintic spline routine was used for time compression or dilation to generate average impact time. These average impact curves were used to depict variability in the magnitude of impact peaks within the two dance movements. Peak values, which were used in statistical analysis, were obtained from individual force curves rather than average curves.

An ANOVA for repeated measures was used to identify differences between high and low impact FKLs for each dependent variable. The alpha level was set at 0.05 for all comparisons.

Results

Peak Impact Force

As shown in Table 1, the mean peak impact force for the low impact FKL was 0.98 BW and the mean peak impact force for the high impact FKL was 1.98 BW. This difference was statistically significant, F(1,4)= 12.56, p=0.002.

Since the magnitude of the high impact front knee lift was affected by the height of each jump, jumping height for the HFKL was obtained using the flight time of each jump. The subjects raised their center of gravity 5.60 ± 1.84 cm in the high impact front knee lift. This method of calculation assumes that the body position of the subjects was the same at takeoff and landing.

The time to peak impact force was significantly longer in the low impact

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<tr>
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<th>Low Impact FKL</th>
<th>High impact FKL</th>
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<tbody>
<tr>
<td>Peak impact force (BW)</td>
<td>0.98 ± 0.35*</td>
<td>1.98 ± 0.55</td>
</tr>
<tr>
<td>Peak impact force time (ms)</td>
<td>160.72 ± 46.88</td>
<td>103.66 ± 13.67</td>
</tr>
<tr>
<td>Passive impact impulse (BW·s)</td>
<td>0.0131 ± 0.008</td>
<td>0.0296 ± 0.006</td>
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<tr>
<td>Peak impact impulse (BW·s)</td>
<td>0.0916 ± 0.032</td>
<td>0.1077 ± 0.026</td>
</tr>
<tr>
<td>Peak loading rate (BW/s)</td>
<td>14.38 ± 14.61</td>
<td>42.55 ± 18.32</td>
</tr>
<tr>
<td>Peak loading rate time (ms)</td>
<td>98.72 ± 56.56</td>
<td>58.80 ± 32.18</td>
</tr>
</tbody>
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*Mean and standard deviation.
FKL than in the high impact FKL, \( F(1,4) = 12.43, p = 0.024. \) Specifically, time to peak impact force for the low impact FKL was 57.04 ms longer than time to peak impact force for the high impact FKL.

**Impact Impulse**

The passive impact impulse was significantly lower in the LPKL than in the HPKL, \( F(1,4) = 53.28, p = 0.002. \) As shown in Table 1, the mean for the HPKL was 0.0295 BW*s, which was more than twice the value for the mean for the low impact front knee lift.

Peak impact impulses were similar for both the HPKL and the LPKL, mean values of 0.1977 BW*s and 0.0916 BW*s, respectively. These differences were not significant, \( F(1,4) = 0.63, p = 0.471. \)

**Peak Loading Rate**

The peak loading rate for the HPKL was approximately three times greater than the peak loading rate for the LPKL, mean values of 42.55 BW/s and 14.38 BW/s, respectively. Peak loading rate for the LPKL was significantly different from the HPKL, \( F(1,4) = 16.21, p = 0.016. \)

The time to peak loading rate was significantly longer in the low impact FKL than in the high impact FKL, \( F(1,4) = 25.66, p = 0.007. \) Time to peak loading rate for the low impact FKL was 39.92 ms longer than the time to peak loading rate for the high impact FKL. In both the high and low impact FKLs a relatively large amount of variability was found in the time of occurrence of peak loading rate, \( SD \) of 32.18 ms and 56.56 ms, respectively.

**Typical Impact and Loading Rate Curves**

A typical impact portion of the LPKL curve is shown in Figure 3a. Impact force reaches a peak of 0.73 BW at 149 ms. The loading rate curve for Figure 3a is presented in Figure 3b. As shown in Figure 3b, the loading rate attains a maximum value of 7.4 BW/s at 53 ms. The impact phase of the HPKL is depicted in Figure 4a. In contrast to the LPKL, Figure 3a, the magnitude of the peak impact force is greater in the HPKL, peak force of 1.38 BW at 120 ms. The corresponding loading rate for the HPKL is presented in Figure 4b. As shown in Figure 4b, the maximum loading rate of 25.1 BW/s occurs 21 ms after landing in the high impact front knee lift exercise.

**Mean Impact Force Curves**

The average impact force curve for all 25 trials of the LPKL is presented in Figure 5. The center line depicts the average impact force and the shaded region shows the range of vertical impact force. As shown in Figure 5, peak impact force ranged from 0.56 BW to 1.58 BW in the LPKL. The average impact force curve for all 25 HPKL trials is shown in Figure 6. In the high impact front knee lift the peak impact force ranges from 1.02 BW to 2.62 BW. The minimum impact force curve for the HPKL is similar to the average impact force curve for the LPKL, Figures 6 and 5, respectively.
Figure 3 — (a) A typical impact phase vertical force curve for the low impact front knee lift (LFKL). (*) Indicates peak impact force of 0.73 BW, at 149 ms. (b) Loading rate curve for the low impact front knee lift (LFKL). (o) Indicates peak loading rate of 7.40 BW/s at 53.00 ms.)
Figure 4 — (a) A typical impact phase vertical force curve for the high impact front knee lift (HFKL). (* indicates peak impact force of 1.38 BW at 150 ms.) (b) Loading rate curve for the high impact front knee lift (HFKL). (* indicates peak loading rate of 25.19 BW/s at 21.00 ms.)
Figure 5 — Average impact phase vertical force curve for low impact front knee lift (LFKL). The center line indicates average force curve and the shaded area represents the range of Fz. (* indicates peak impact force of 0.98 BW at 160 ms.)

Figure 6 — Average impact phase vertical force curve for high impact front knee lift (HFKL). The center line indicates average force curve and the shaded area represents the range of Fz. (* indicates peak impact force of 1.96 BW at 103 ms.)
Discussion

Nigg (1985) defined forces that reach a peak in less than 50 ms as passive forces. Since these forces are applied at a rate that is faster than the reaction time of the neuromuscular system (50–75 ms), the muscles are unable to absorb the shock via flexion of the ankle, knee, and hip joints. Nigg et al. (1981) indicated that ineffective attenuation of passive forces may result in microtrauma to soft tissue and bone. In the present study, the impulse of the first 50 ms of contact was defined as a passive impulse. Significant differences were found in the passive impulse between the HFKL and the LFKL. The passive impulse for the high impact front knee lift was 2.25 times greater than the passive impulse for the low impact front knee lift, 0.0295 BW·s and 0.0131 BW·s, respectively.

Significant differences were also found in loading rate, peak impact force, and time to peak impact force between high and low impact front knee lifts. When compared to the low impact front knee lift, the high impact front knee lift was found to have a 2.02 times greater peak impact force, a 57.04 ms shorter time to peak impact force, and a 2.95 times greater loading rate. Based upon the above differences in loading rates and peak impact forces, it appears that low impact front knee lifts impose a significantly lower stress upon the musculoskeletal system than do high impact front knee lifts. Aerobic dance participants who choose a low impact routine rather than a high impact routine may lower their susceptibility to overuse injury by reducing the load imposed on a given bout of exercise.

Peak impact force for the HFKL was found to be significantly different from peak impact force for the LFKL. However, when compared to walking and running, the magnitude and time of occurrence of the impact force peak does not appear excessive. In the present study, peak impact force was 1.98 BW and time to peak impact was 103.68 ms for the HFKL. Simon et al. (1981) demonstrated that peak impact forces in walking ranged from 0.5 to 1.25 times body weight. The frequency components of these impact forces varied from 10 to 75 Hz. The magnitude of peak impact force for the HFKL is greater than the peak impact force in walking, yet the time to peak impact force is shorter in walking than in the high impact front knee lift, indicating that the passive force component may be greater in walking.

When comparing the magnitude of impact force in high impact aerobic exercise to other exercise forms, it becomes clear that so-called high impact aerobics is a relatively low impact exercise. Valiant and Cavanagh (1985) studied landings from basketball rebounds. They found that vertical impact peaks ranged from 2.3 to 7.1 BW and time to impact peak ranged from 37 to 120 ms depending on landing style (forefoot or flatfoot), respectively. Orguven and Berme (1988) reported that peak impact forces in gymnastic landings ranged from 8.2 to 11.6 BW.

Conclusions

When comparing the high impact front knee lift to the low impact front knee lift, the former resulted in a significantly higher peak impact force, shorter time to peak impact force, higher passive impact impulse, higher peak loading rate, and shorter time to peak loading rate. Based upon these differences in external ground reaction forces, it appears that low impact front knee lifts impose a significantly lower load than high impact front knee lifts.


