PATELLOFEMORAL JOINT FORCES BETWEEN TWO NON-IMPACT CARDIO MACHINES

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**Introduction**

Anterior knee pain is the most common complaint amongst physically active children and adults seeking medical treatment in sports medicine clinics, accounting for 62% of all knee injuries, according to Scott and Winter (1990).

Strother & Samoil (1989) note that anterior knee pain, or patellofemoral pain syndrome (PFPS), accounts for 57% of all knee problems in runners. Davis and Powers (2010) have reported that approximately 2.5 million runners will be diagnosed with PFPS in a calendar year, leading to the appropriately labeled “runner's knee.”

Perhaps, for this reason, many health seekers have abandoned running for activities with less perceived knee stress, such as non-impact cardio trainers. Over the past ten years, for example, elliptical trainer use has increased dramatically and has become a popular exercise modality in both recreational fitness and rehabilitation. Although elliptical devices employ motions that replicate running and walking patterns, few descriptions of their joint loading exist in the literature.

One study, by Lu, Chien, and Chen (2007) did compare knee joint moments in an elliptical device to walking, and discovered significantly higher forces in the former activity, leading them to suggest that changes in the design of elliptical devices would “help to reduce harmful joint loadings.”

While some studies have examined the relative metabolic benefits of elliptical trainer use, few studies, if any, have investigated whether there are differences in patellofemoral joint loading with different types of non-impact cross trainers. It is possible that different machines may provide specific benefits, or detriments, in regards to patellofemoral joint stress.

The purpose of this investigation, therefore, was to examine the differences in patellofemoral joint stress variables on two different non-impact cross trainers at a standardized work load.

**Methods**

All subject recruitment, testing procedures, data acquisition, kinematic analysis, and kinetic data generation through inverse dynamics were performed independently by the Biomechanics Laboratory of the Physical Therapy Program, University of Wisconsin-La Crosse.

**Subjects**

Eight male (28 ± 9.4 yrs, 179.3 ± 4.4 cm, and 84.8 ± 12.9 Kg) and eight female (23.0 ± 1.3 yrs, 170.5 ± 5.0 cm, and 69.8 ± 5.1 Kg) college students volunteered as subjects for this study. Participants were made aware of any and all potential risks involved. All participants gave their written consent, approved by the university’s institutional review board.

**Testing Procedures**

Two non-impact cardio cross trainers were selected for this investigation; the Precor AMT 835 (Precor, Woodinville, WA) and the CYBEX 750 Arc Trainer (CYBEX International, Medway, MA). The AMT is an
adaptive motion trainer, meaning that users may define their own movement paths of the foot pedals. Each pedal has a fixed vertical displacement of 27.94 cm, but has a variable horizontal travel, in the anterior and posterior (AP) directions, with a maximum displacement of 50.80 cm. Users may create movement paths ranging from a run-like ellipse to a more vertical stair climbing action.

The Arc Trainer, in contrast, employs an invariable arcuate movement path with a 60.96 cm chord length. The foot plate moves forward along this pathway, then reverses direction and returns to the starting position along the same path.

Kinematic and kinetic data were captured while subjects exercised on the two non-impact devices at the same relative work intensity. Accordingly, work rates on each device were adjusted so that the subjects performed the test trials at 75% of their age-predicted maximum heart rates, using the formula; HR Max = $207 - (0.7 \times \text{age})$, as suggested by Gellish and colleagues (2007). Pace was held constant at 100 steps per minute on both devices.

Due to the variable nature of the motion pattern of the AMT, subjects were instructed to maintain an elliptical pattern, similar to a normal, running gait, throughout the data acquisition phase of the exercise. This pattern was enforced by the experimenters during the testing procedures.

Additionally, the AMT has no fixed incline adjustment against which to model the Arc Trainer’s incline. Consequently, the Arc Trainer was utilized at its default factory incline setting throughout the experiment. Arm motion was omitted from the procedures on both devices.

Subjects first familiarized themselves with one of the exercise devices, and after a standardized warm-up, began exercising at progressively increasing workloads. Heart rate was measured during the exercise bout with a Polar heart rate monitor (Polar Electro Oy, Kempele, Finland). Workload settings were recorded when subjects reached and maintained the 75% steady state heart rate target. A fixed rest period was then introduced in order to return the subjects to a normal, resting state.

A brief warm-up was given after the rest interval, and then the subjects began exercising at the prescribed workload. Once a steady state was reached, 10 complete cycles of the motion pattern were performed to enable data capture. Following this, the subjects were given an adequate rest period and the process was repeated on the alternate device. The sequence of testing on the devices was counterbalanced across all subjects, to avoid effects due to testing order.

**Instrumentation and Data Capture**

An eight camera motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) was used to capture kinematic data. Cameras were sampled at 120 Hz for motion capture. Twenty eight spherical, retroreflective markers were placed on the pelvis and lower extremities using a modified Helen Hayes approach (Kadaba, Ramakrishnan, & Wootten, 1990). Instead of wand markers, standard surface markers were used. Three markers placed on each segment created four rigid bodies associated with the pelvis and right limb in X, Y, Z space.

These data were synchronized with a portable force platform (Cybex, Medway, MA) instrumented with three vertical load cells in the base plate and one external horizontal load cell, each sampling at 720 Hz.
Sagittal plane kinematic data from the right leg and pelvis and kinetic data from the portable instrumented foot plate were measured over 10 cycles and synchronized to a common frequency of 120 Hz. Data were filtered with a low pass Butterworth recursive filter at 8 Hz based on the frequency content of the kinematic data. All data were normalized to 100 samples per gait cycle, based on the vertical excursion of the pedal on the machine. The low point in the movement was used to identify the start and end of a cycle.

**Data Analysis**
The filtered sagittal plane two-dimensional kinematic and kinetic data were used to calculate joint angles, pedal reaction forces, hip and knee moments, total hip and knee work, and patellofemoral joint reaction force, using an inverse dynamics approach (Eng & Winter, 1995). Custom programs in Matlab (Mathworks, Boston, MA) were used to perform all calculations.

Kinematic variables were expressed as angles, and later converted to radians in order to compute total work. Force data were calculated as percent body weight per Newton, and further converted into joint moments as Newton-meters per kilogram.

**Patellofemoral Joint Force**
Calculations of patellofemoral joint force were based on the previous investigation by Brechter and Powers (2002a), and are outlined in equations 1 – 4. The first step was to calculate the quadriceps force from the knee joint angle, knee moment and the effective lever arm of the quadriceps muscle, using the following formula:

\[
QLA = \text{Quadriceps Lever Arm (meters)} = 8.0 \times 10^{-8} \times \theta^3 - 1.29 \times 10^{-5} \times \theta^2 + 2.8 \times 10^{-4} \times \theta + 0.046
\]  

(1)

Where \( \theta \) = knee angle

\[
QF = \frac{\text{Quadriceps Force (Newtons / kg)} }{\text{Knee moment (Newtons/Kg) / QLA}}
\]  

(2)

Next, the ratio between patellofemoral joint reaction force and quadriceps force was approximated to give a constant, \( k \):

\[
k = ( -3.84 \times 10^{-5} \times \theta^2 + 0.47 \times 10^{-3} \times \theta + 0.462 ) / ( -6.98 \times 10^{-7} \times \theta^3 + 1.55 \times 10^{-4} \times \theta^2 - 0.0162 \times \theta + 1 )
\]  

(3)

Finally:

\[
PFJF = \frac{\text{Patellofemoral Joint Force (Newtons/Kg)} }{QF} = QF \times k.
\]  

(4)

**Statistical Analysis**
Mean exercise heart rate was compared on each device, and then to the subjects’ mean predicted heart rate via a Wilcoxon signed-rank test. A repeated measures analysis of variance (ANOVA) was used to compare joint angles and the percentage of the gait cycle at which peak joint angles occurred. Repeated measures ANOVA’s also compared joint moments, the percentage of the gait cycle at which peak hip moments arose, and patellofemoral compressive loading. A Kolmogorov – Smirnov test using a Chi Square distribution compared the percentage of the gait cycle at which peak knee moments occurred. Significance was established at the 0.05 alpha level for all comparisons.
[Results]

Heart Rate
Mean target heart rates and exercise heart rate data for the 16 subjects on the Precor AMT and Cybex Arc Trainer are presented in Table 1.

<table>
<thead>
<tr>
<th>Target Heart Rate (BPM ± SD)</th>
<th>AMT</th>
<th>Arc Trainer</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>142.09 ± 3.64</td>
<td>142.13 ± 7.64</td>
<td>141.81 ± 5.86</td>
<td>N.S.*</td>
</tr>
</tbody>
</table>

* = Denotes non-significant differences between devices and between the devices and target heart rate

As indicated in the table, there were no significant differences between exercise heart rates on either machine and the prescribed target heart rate. Likewise, there were no differences in the exercise heart rates on the AMT or Arc Trainer. These data confirm that relative exercise intensity was effectively normalized across the two devices.

Kinematic Data
The normalized elliptical pathway of the AMT footplate is expressed as a percentage of total movement, and pictured graphically in Figure 1. The beginning and end of the movement cycle (0, 100%) occur slightly forward of the horizontal center of the ellipse. From there, movement progresses backward and upward until the pedal reaches the most vertical position, at roughly 35% of the movement cycle. Anterior horizontal displacement occurs until approximately 75% of the cycle, after which, the pedal begins a downward movement to complete the cycle.

![Figure 1. Normalized pedal displacement cycle of the Precor AMT. Movement is in a clockwise direction, as indicated by the arrows.](image)

The normalized pedal displacement pathway of the Arc Trainer is shown in Figure 2. Unlike the AMT, the initial and final positions of the pedals on the Arc Trainer occur at the rearmost point of motion. Motion continues forward and upward until the pedal reaches its highest point at 50% of the movement cycle, and then returns to the starting position along the same pathway.
Figure 2. Normalized pedal displacement cycle of the Cybex Arc Trainer. Movement path is indicated by the arrows.

Joint displacement during the normalized gait cycle, for the AMT, is displayed in Figure 3. As illustrated, the hip angle on the AMT rose to a peak of 47.86 ± 6.35 degrees of flexion at 54.44 ± 5.61% of the gait cycle, declining gradually through the end of the movement. The mean hip flexion angle for the complete, normalized gait cycle was 30.68 ± 11.44 degrees.

Figure 3. Mean hip and knee displacement (deg), over the normalized gait cycle, for the Precor AMT.

Knee flexion increased to a peak value of 91.43 ± 5.60 degrees at 45.13 ± 2.58% of the gait cycle, and then returned to a minimum value at the end of the movement sequence. The average knee angle, for the complete movement sequence, was 45.31 ± 26.58 degrees of flexion.

Hip and knee angles for the Arc Trainer, over the normalized gait cycle are presented in Figure 4. As illustrated, both joints followed similar displacement trends. After a brief period of extension, the hip flexed to a peak of 66.60 ± 4.07 degrees at 57.69 ± 1.01% of the normalized movement cycle. The difference in peak hip flexion angle, between the Arc Trainer and the AMT was significant (p< .001). Peak hip flexion on the Arc Trainer also occurred later than on the AMT. This difference was statistically significant (p< .03). The mean hip angle for the complete gait cycle was 38.07 ± 19.59 degrees. The mean difference of approximately 8 degrees, between the Arc Trainer and the AMT was also significant (p< .001).
Knee flexion on the Arc Trainer increased to a peak of 66.42 ± 4.32 degrees at 55.00 ± 1.46% of the normalized gait cycle. The difference in peak knee flexion, of almost 30 degrees was significant (p< .001). Likewise, peak knee flexion on the Arc Trainer occurred 10% later in the gait cycle. This difference was also significant (p< .001). Average knee flexion for the cycle was 44.01 ± 14.53 degrees. This value was not statistically different from the AMT (p< .482).

Kinetic Data

Hip and Knee Moments

Figures 5 and 6 display hip and knee moments on the AMT and Arc Trainer through the normalized gait cycle. As presented in Figure 5, there is a relatively small external hip flexor torque on the AMT, until approximately 65% of the gait cycle, at which point it increases to a peak of 1.39 ± 0.51 N.M/Kg at 85.25 ± 4.44%. From approximately 10% until 35% of the movement cycle, a small external extensor torque is applied to the hip. The average external hip flexion torque on the AMT, for the complete gait cycle was 0.433 ± 0.48 N.M/Kg.

For the first 73% of the AMT gait cycle, there is an external flexor moment acting on the knee, remaining higher than the corresponding hip moment from 10% until 60% of the cycle. A peak knee flexion torque of 0.535 ± 0.26 N.M/Kg occurs at 53.63 ± 14.55% of the movement cycle. For the final 27% of the gait cycle, an external knee extensor moment is generated, peaking at 85% of the movement. The mean external knee flexion moment on the AMT, over the gait cycle, was 0.101 ± 0.301 N.M/Kg.

Hip and knee moments on the Arc Trainer are displayed in Figure 6. The majority of the joint loading occurs at the hip, where an external flexor moment is sustained throughout the movement, rising steadily from initiation until 69.38 ± 8.76% of the normalized gait cycle, where it reaches a peak value of 1.77 ± 0.37 N.M/kg. The difference in peak hip torque between the Arc Trainer and AMT (0.38 N.M/Kg) and the phase of the gait cycle at which peak hip torque occurred (15.87%) were both statistically significant (p< .001). The average external hip moment on the Arc Trainer (0.814 ± 0.548 N.M/Kg) was also statistically greater than the corresponding value on the AMT (p< .001).
External knee flexion moments on the Arc Trainer were shown to have a bi-modal distribution, with two peaks clustered around the 0%/100% phase of the gait cycle, corresponding to when the pedal was directly beneath the subject. Peak external knee flexion torque (0.407 ± 0.25 N.M/Kg) was similar to that of the AMT. The point at which peak occurred, however, was different between the two devices (p< .001), with peak on the AMT occurring at the mid-point of the cycle, and the two Arc Trainer peaks arising at the beginning and end, respectively. Mean knee torque on the Arc Trainer, 0.008 ± 0.11 N.M/Kg, was significantly lower than the corresponding value on the AMT (p< .005).

**Figure 5.** Mean hip and knee moments (N.M/Kg), over the normalized gait cycle, for the Precor AMT. Positive values indicate external flexion torques.

**Figure 6.** Mean hip and knee moments (N.M/Kg), over the normalized gait cycle, for the Cybex Arc Trainer. Positive values indicate external flexion torques.
Patellofemoral Joint Force
Patellofemoral joint force (PFJF) in Newtons/Kg, results from the interaction of knee joint angle, joint moment, and quadriceps force. These variables are presented in Table 2.

Table 2. Contributing factors to patellofemoral joint force; Precor AMT v Cybex Arc Trainer

<table>
<thead>
<tr>
<th>Variable</th>
<th>Device</th>
<th>Mean ± SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Knee Flexor Moment (N.M/kg)</td>
<td>AMT</td>
<td>0.535 ± 0.26</td>
<td>N.S.</td>
</tr>
<tr>
<td></td>
<td>Arc Trainer</td>
<td>0.407 ± 0.25</td>
<td></td>
</tr>
<tr>
<td>Peak Quadriceps Force (N/kg)</td>
<td>AMT</td>
<td>22.008 ± 10.81</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Arc Trainer</td>
<td>9.551 ± 5.46</td>
<td></td>
</tr>
<tr>
<td>Peak Knee Flexion (Deg)</td>
<td>AMT</td>
<td>91.430 ± 5.60</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Arc Trainer</td>
<td>66.420 ± 4.32</td>
<td></td>
</tr>
<tr>
<td>Peak PFJF (N/kg)</td>
<td>AMT</td>
<td>19.040 ± 9.19</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Arc Trainer</td>
<td>7.890 ± 4.59</td>
<td></td>
</tr>
<tr>
<td>Knee Angle at Peak PFJF (Deg)</td>
<td>AMT</td>
<td>65.59 ± 11.09</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Arc Trainer</td>
<td>35.19 ± 13.44</td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 2 and Figure 7, greater PFJF occurred while exercising on the AMT than on the Arc Trainer. The mean peak PFJF on the AMT, 19.04 ± 9.19 N/Kg, occurred at 60% of the gait cycle and at a knee angle of 65.59 ± 11.09 degrees. The mean peak joint force on the Arc Trainer was 7.89 ± 4.59 N/Kg, arising at 99% of the gait cycle, at a knee joint angle of 35.19 ± 13.44 degrees. Peak PFJF on the AMT was significantly higher than on the Arc Trainer (p< .001).

The mean PFJF, over the course of the gait cycle, on the AMT was 6.41 ± 4.07 N/Kg. On the Arc Trainer, the mean value was 2.10 ± 1.56 N/Kg. These differences were also significant at the .000 confidence level.

![Patellofemoral Joint Force](image)

Figure 7. Patellofemoral joint force (Newtons/Kg), over the normalized gait cycle, for the Precor AMT and Cybex Arc Trainer.
Here it was determined that peak patellofemoral joint forces on the Precor AMT were 141% higher than those on the Arc Trainer, while the average PFJF, across the entire gait cycle, was three times greater on the AMT, indicating a significantly greater degree of knee stress associated with the AMT.

The timing of peak patellar compressive loading was particularly interesting. A consistent finding in the research examining patellofemoral joint forces during various forms of gait, is that peak compressive loading arises during the stance phase of the movement cycle. This is true with the Arc Trainer, on which peak PFJF occurred toward the end of the movement, when body weight was aligned over the pedals.

On the AMT, however, peak PFJF occurred at 60% of the gait cycle, when the pedal was being moved horizontally, along the top of the ellipse. This is a point during the swing phase of normal gait, when there is typically no joint loading. Curiously, although little body weight can be applied to the AMT pedal at this point in the movement cycle, there is still a substantial compressive load on the user’s knee, as a result of the high external flexor moments generated at the knee while attempting to move the pedals in an anterior direction. Thus, while the movement pattern may appear to be normal (in terms of ambulatory gait), the kinetics are distinctively abnormal, and potentially stressful.

A Comparison with Other Activities

While only direct comparisons between the devices were made here, there is a fairly robust body of literature describing knee joint torques and patellofemoral joint forces, arising from a variety of different activities, against which these findings may be compared. These are summarized in Table 3.

Several studies have examined knee joint kinetics, for example, during walking, with moments ranging from 0.57 to 0.73 N.M/Kg (Brechter and Powers, 2002b) and patellofemoral forces from 9.0 to 13.4 N/Kg (Goudakos, et al, 2009; Brechter and Powers, 2002b). During stair climbing, knee joint moments may range from 0.4 (Costigan, et al, 2002) to 1.1 N.M/kg (Salsich, et al, 2001). Patellofemoral joint forces vary from 21.0 to 37.0 N/Kg (Goudakos, et al, 2009; Brechter and Powers, 2002a).

Joint kinetics have been reported in traditional strength training exercises as well, such as squatting and lunging. Wallace and colleagues (2002) report a relatively low knee joint moment of 0.5 N.M/Kg, for a squatting exercise. Squats are also associated with patellofemoral joint forces between 0.89 and 43.0 N/Kg for knee ranges of motion between 0 and 60 degrees (Escamilla, et al, 2009), while compressive forces during lunging have been registered in a range between roughly 19 and 22 N/Kg (Escamilla, et al, 2008).

Clearly, the highest joint moments and patellofemoral forces are associated with activities such as step-ups, step-downs, and running, where compressive loads may be greater than 40.0 N/Kg, as noted by Chinkulprasert and others (2011) and Flynn and Soutas-Little (1995).

The Arc Trainer registered average peak knee moments of 0.41 N.M/Kg and mean peak patellofemoral joint forces of 7.9 N/Kg. These values are below those associated with walking, and are therefore considerably lower than stair climbing, squats, lunges, step-ups, and running.
In contrast, mean peak knee moments and patellofemoral joint forces on the AMT (0.54 N.M/Kg; 19.0 N/Kg), exceeded those incurred during walking, and were in fact, comparable to stair climbing, squatting, and lunging.

Of the activities for which knee moments and patellofemoral compressive forces are reported, clearly the various step-ups (step-downs) and running create substantially higher joint loads than either the Arc Trainer or the AMT. To this end, either device is a suitable alternative to limit exposure to those types of knee stressors. Nevertheless, if an option is available for a non-impact device, the one imparting the least stress would be favorable.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Activity</th>
<th>Knee Moment N.M/Kg</th>
<th>PFJF N/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brechter and Powers (2002b)</td>
<td>Fast Walking</td>
<td>0.73</td>
<td>13.4</td>
</tr>
<tr>
<td>Brechter and Powers (2002b)</td>
<td>Walking</td>
<td>0.57</td>
<td>9.5</td>
</tr>
<tr>
<td>Brechter and Powers (2002a)</td>
<td>Stair Climbing</td>
<td>1.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Costigan, et al (2002)</td>
<td>Stair Climbing</td>
<td>0.42</td>
<td>30.19</td>
</tr>
<tr>
<td>Salsich, et al (2001)</td>
<td>Stair Climbing</td>
<td>0.75 – 1.11</td>
<td>NA</td>
</tr>
<tr>
<td>McFadyen and Winter (1988)</td>
<td>Stair Climbing</td>
<td>1.0</td>
<td>NA</td>
</tr>
<tr>
<td>Andriacchi, et al (1980)</td>
<td>Stair Climbing</td>
<td>0.69*</td>
<td>NA</td>
</tr>
<tr>
<td>Chinkulprasert, et al (2011)</td>
<td>Step-up</td>
<td>NA</td>
<td>43.6</td>
</tr>
<tr>
<td>Escamilla, et al (2009)</td>
<td>Squatting</td>
<td>NA</td>
<td>0.89 - 43.0*</td>
</tr>
<tr>
<td>Wallace, et al (2002)</td>
<td>Squatting</td>
<td>0.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Novachek (1998)</td>
<td>Running</td>
<td>1.5</td>
<td>NA</td>
</tr>
<tr>
<td>Flynn and Soutas-Little (1995)</td>
<td>Running</td>
<td>NA</td>
<td>54.0</td>
</tr>
</tbody>
</table>

* = Value normalized to reflect 78 Kg body weight

**Total Integrated Work**

In addition to peak knee moments and patellofemoral forces, one can also determine the nature of joint loading by examining the total integrated work performed by each of the operating joints; in this case the hip and the knee. Total integrated work is an indicator of the effective overall contribution from a joint, per normalized gait cycle, and is expressed in Joules per kilogram. It is calculated for the hip and knee according to formula 5:
Work = \int T_\theta \cdot \Delta \theta \quad \text{(5)}

Where:  
\( T_\theta \) = moment of torque at a specified joint angle in radians  
\( \Delta \theta \) = change in joint angle in radians

Total integrated work at the hip, per gait cycle, is presented in Figure 8. As indicated in the figure, there was a three-fold greater hip contribution when exercising on the Arc Trainer as compared to the AMT (1.55 v 0.50 Joules/Kg). Mean hip total work on the Arc Trainer (0.554 ± 0.52 Joules/Kg) was significantly greater than total hip work on the AMT (0.125 ± 0.15 Joules/Kg; p< .001).

For the knee, the opposite was true, as seen in Figure 9. In this case, total knee work on the AMT (0.67 Joules/Kg) was 16 times greater than that on the Arc Trainer (0.042 Joules/Kg). The mean value of 0.361 ± 0.27 on the AMT was also significantly greater than that of the Arc Trainer (0.023 ± 0.008 Joules/Kg; p< .001).

Figure 8. Total hip work (Joules/Kg), over the normalized gait cycle, for the Precor AMT and Cybex Arc Trainer.

It is also notable that mean total knee work exceeded total hip work on the AMT. The average difference of 0.236 Joules/Kg was significant (p< .001), suggesting that the AMT places greater emphasis on the knee joint. McFadyen and Winter (1988) note that in stair patterns the majority of the energy is generated at the knee. Although the movement pattern of the AMT is similar to running, the kinetic profile is more closely associated with climbing stairs. In contrast, mean total hip work on the Arc Trainer was significantly greater than total knee work (p< .001), indicating a greater concentration of effort at the hip, with off-loading of the knee.
These findings are significant when viewed from the perspective of typical usage patterns on non-impact cross trainers. Consider the fact that the AMT is predominantly a knee-focused exercise, as determined by the total integrated work at the hip and knee. One could argue that the patellofemoral joint forces on a step-up are considerably higher than the peak forces registered on the AMT (43.6 v 19.0 N.M/Kg). Thus, it’s more stressful to perform step-ups.

Someone doing step-ups, however, may follow an exercise regimen that includes three sets of ten to fifteen repetitions. In other words, over the course of a single workout, the user may complete up to 45 movement cycles with a higher patellofemoral joint stress. On the other hand, someone using a cross-trainer at 100 steps per minute, for 30 minutes, will complete 3000 movement cycles, and even with lower patellofemoral peak forces, may still be exposed to potential overuse syndromes.

According to Dye (2005), excessive intrinsic compressive loading of the patella may be a contributing factor to patellofemoral pain. The author purports that while high loading conditions, as in stair climbing or lunging, applied over a relatively brief period of time, may induce discomfort or pain, activities that involve lower loads may cause a “supraphysiological overload” if sustained for a longer period of time. The AMT generates compressive forces that are comparable to higher-force, strength based activities, and over a significantly longer period of time typically associated with cardiovascular exercise regimens.

[Conclusion]

There is an assumption amongst casual users of exercise devices, that the absence of impact on cross trainers somehow mitigates the kind of noxious knee stressors that may, in time, lead to overuse injuries, such as patellofemoral pain syndrome. While this study does not address nor predict injury occurrences, the data do not support the notion that all non-impact cross trainers are stress-free, but that patellofemoral stresses do exist, and that they are significantly greater on some devices than others.

It is also notable that the movement patterns associated with some devices, while kinematically similar to typical running or walking gait, do induce a much higher level of knee joint loading, thereby creating the potential for greater patellofemoral risk, especially in individuals with knee pain. According to
Chinkulprasert and colleagues (2011), “people with knee pain should be cautioned about exercises with higher patellofemoral joint loading.” Some of those exercises, as seen here, may involve non-impact cross trainers. Further exploration of the stresses imposed by these devices, especially at higher work loads, is certainly warranted.

[**Acknowledgements**]

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Christopher Powers, Ph.D, Musculoskeletal Biomechanics Research Laboratory and Department of Biokinesiology and Physical Therapy, University of Southern California, helped to establish the mathematical algorithm which was used to calculate patellofemoral joint stress.

[**References**]


