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Torso and Hip Muscle Activity and Resulting Spine Load and Stability While Using the ProFitter 3-D Cross Trainer

Priyanka Banerjee, Stephen H.M Brown, Samuel J. Howarth, and Stuart M. McGill
University of Waterloo

The ProFitter 3-D Cross Trainer is a labile surface device used in the clinic and claimed to train spine stability. The purpose of this study was to quantify the spine mechanics (compression and shear forces and stability), together with muscle activation mechanics (surface electromyography) of the torso and hip, during three ProFitter exercises. Trunk muscle activity was relatively low while exercising on the device (<25%MVC). Gluteus medius activity was phasic with the horizontal sliding position, especially for an experienced participant. Sufficient spinal stability was achieved in all three exercise conditions. Peak spinal compression values were below 3400 N (maximum 3188 N) and peak shear values were correspondingly low (under 500 N). The exercises challenge whole-body dynamic balance while producing very conservative spine loads. The motion simultaneously integrates hip and torso muscles in a way that appears to ensure stabilizing motor patterns in the spine. This information will assist with clinical decision making about the utility of the device and exercise technique in rehabilitation and training programs.

Keywords: trunk, gluteal, gluteus medius, spinal loading

Rehabilitation and training goals are often met through the use of exercise equipment, yet these treatment methods are seldom scientifically quantified. Uses of labile surfaces, which include gym balls and other devices, have become quite popular. The ProFitter 3-D Cross Trainer (Fitter International Inc., Calgary, Canada) is a labile surface device typically used to develop proprioception, joint mobility, and muscular stabilization in addition to training skiing performance (Fitter International Inc., n.d.). For the injured back, improving motor patterns to optimize spine stability is one goal of rehabilitation (McGill et al., 2003). Clinicians hope that through this approach, perturbed motor patterns that compromise spinal stability can be addressed to improve spine stability, meanwhile producing minimal spine load. Athletic objectives include training specific muscle groups and finding equipment that allows the motor patterns of a sport to be mimicked. This investigation is directed toward quantifying the mechanics of the device for utility in clinical and possibly athletic-training settings.

Previous research documenting the benefits of using the device has not been conducted. However, there exists a body of research examining and outlining the benefits of stabilizing exercises for treatment of back pain (Saal & Saal, 1989, O'Sullivan, 2000, Hicks et al., 2005). Specifically, Saal and Saal (1989) reported higher return-to-work rates (85% of subjects) for patients with herniated intervertebral discs when stabilizing exercises were incorporated into their rehabilitation. While stabilizing exercises are scientifically beneficial, reducing spine compression and shear forces are also of key importance for patients who are sensitive to these types of loading. The manufacturer claims that the ProFitter enhances spine/core stability; however, there has been no research conducted to determine whether the device develops spine/core stability or rather whole-body stability.

The skiing motion associated with the device is used clinically, given the apparent hip challenge and stability component. This movement may also have implications for those interested in transitioning from rehabilitation to skiing training. Skiing training should focus on balance, coordination, and specific muscle strength and endurance (Leach, 1994). Several studies have investigated the mechanics of the various forms of skiing and the turns involved (Hintermeister et al., 1995, 1997, Berg & Eiken, 1999). Three skiing styles on the device include slalom skiing, giant slalom skiing, and downhill skiing. Hintermeister et al. (1995) reported leg, thigh, abdominal, and back muscle activation levels between 96% and 268% of maximal voluntary isometric

The authors are with the Spine Biomechanics Laboratory, Department of Kinesiology, University of Waterloo, Waterloo, ON, Canada.

contraction for slalom and giant slalom skiing. Hintermeister et al. (1997) also examined differences between wedge, parallel, and giant slalom skiing styles, in which they reported significantly different levels of muscle activation between the three skiing styles for biceps femoris, medial hamstrings, vastus lateralis, and external oblique. This formed the rationale for the second objective of this article: to compare different skiing styles that are performed in the clinic.

The purpose of this study was to quantify spine loading and stability, together with muscle mechanics of the hip and torso between three exercises performed on the device in a healthy asymptomatic population. This information may be useful for those wishing to use the device for skiing-type exercise. It was expected that the exercises would be suitable for some rehabilitative spine stability programs and that muscle activation levels and patterns measured during each exercise would warrant its use to enhance skiing performance. It was also hypothesized that the exercises would allow exercise progression, through a continuum in muscle activity and spine stability.

Methods

Sample Population

Nine male participants with an average age of 24 years (*SD* = 1.5 years), height of 181.8 cm (*SD* = 4.6 cm), and weight of 86.8 kg (*SD* = 9.6 kg) volunteered to participate in the study. Participants reported no current musculoskeletal concerns or preexisting back conditions. One participant reported previous experience using the device. Before testing, measures of each participant's hip and shoulder breadth were obtained (35.6 cm ± 3.0 cm and 40.6 cm ± 1.8 cm, respectively). All subject recruitment and data collection procedures were performed in accordance with the University Office of Research and Ethics guidelines.

Data Collection

Tasks. Each participant performed a series of three exercises on the device. The device consists of footpads on a frictionless track that teeters as a user shifts his or her weight from left to right. The footpads are attached to adjustable tension cords to allow the user to control the resistance while exercising. The exercises performed were a slalom skiing task (Figure 1A), a giant slalom skiing task (Figure 1B), and a downhill skiing task (Figure 1C), which represent an order of increasing difficulty according to the makers of the device (Fitter International Inc., n.d.). Note that the task names describe the overall body posture rather than any attempt at specific ski training. See Figures 1D, 1E, and 1F for the exercise motion. The order of the exercise conditions was randomized for each participant. For the slalom skiing task, participants were instructed to keep their trunk upright, arms bent at 90°, knees slightly bent, and head up while transferring weight from side to side halfway across the track to a cadence of 80 translations per minute. The giant slalom skiing task was performed with the same posture as in the slalom skiing task, but the participants were instructed to slide as far as possible along the track of the device at a cadence of 66 translations per minute. Last, participants were instructed to perform the downhill skiing task in a "tuck" position by increasing knee flexion and flexing at the hips to maintain a neutral spine while sliding at a cadence of 66 translations per minute. Again, participants were asked to slide as far as possible along the track while performing the task. The exercise conditions were adapted from the manufacturer's recommendations (Fitter International Inc., n.d.). The downhill position, however, had to be modified to require less trunk flexion as it was seen as too difficult for participants (new users) to master. The positions do not necessarily replicate actual real-world skiing postures. If the proper posture was not achieved during a trial, a research assistant instructed the participant to correct their posture, and the trial was recollected.

Participants were given an unlimited amount of time before the data collection to familiarize themselves with each exercise. Participants were asked to practice until they felt comfortable doing each exercise. Though the time required by each participant was not measured, the participants learned to perform each exercise properly within a few minutes. Each exercise was performed three times, with each trial being 15 s long. Trials were performed with a metronome to standardize the cadence at which the exercises were executed. Participants were instructed to maintain a neutral lumbar spine posture while performing each of the exercise conditions. A neutral lumbar posture was encouraged because a standardized lumbar posture was needed during the trials. In addition, avoiding a flexed lumbar posture parallels considerations that would have to be made for low back pain patients, who may not be able to tolerate lumbar flexion. The participants were also asked to perform quiet standing trials on the floor as well as on the exercise track.

Instrumentation. Electromyographic (EMG) signals were collected bilaterally from the following muscles: rectus abdominis (RA), external oblique (EO), internal oblique (IO), latissimus dorsi (LD), thoracic erector spinae (longissimus thoracis and iliocostalis at T9; UES) and lumbar erector spinae (longissimus and iliocostalis at L3; LES). The activation profiles of these muscles were required as input to a biomechanical model of the lumbar spine (Cholewicki and McGill, 1996). Gluteus maximus (GMAX), gluteus medius (GMED), biceps femoris (BF), and rectus femoris (RF) were collected unilaterally on the right side. Additional muscle activities could not be examined since the researchers were limited by the number of channels available for collection. Thus, gluteus maximus, gluteus medius, biceps femoris, and rectus femoris were the muscles used to

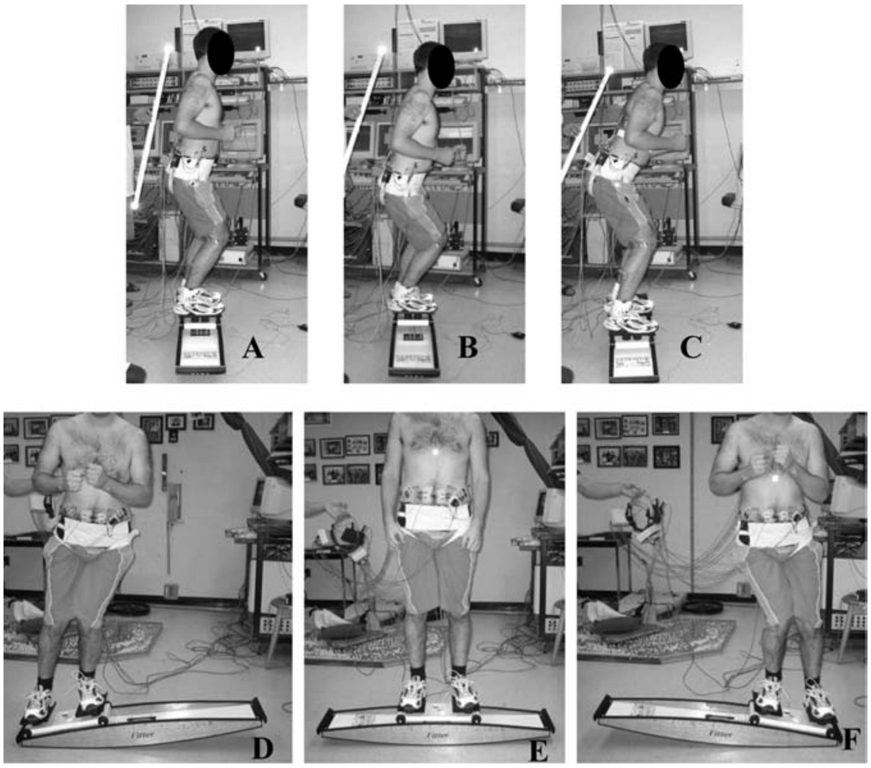


Figure 1 — The three different skiing tasks included slalom skiing (A), giant slalom skiing (B), and downhill skiing (C). The frontal plane view of a participant exercising on the ProFitter is shown in D, E, and F.

represent hip mechanics. The skin overlying the previously described trunk and hip muscle groups was shaved and cleansed. Pairs of Ag–AgCl surface electrodes (Blue Sensor, Medicotest Inc., Ølstykke, Denmark) were applied to the prepared skin with an interelectrode space of 3 cm. The EMG signals were amplified (CMRR: 115 dB at 60 Hz; input impedance: 10 GΩ; Model AMT-8, Bortec Biomedical Ltd., Calgary, AB, Canada) and A/D converted (12-bit) at a rate of 2048 Hz. Before testing, each participant performed a series of standardized maximum voluntary isometric contractions (MVCs), which were used for normalization of EMG signals (Kavcic et al., 2004b). In addition to the standardized MVCs, the reverse curl up was used to elicit maximal abdominal activation. Each participant lay supine with hips and knees flexed at 90° and was instructed to lift the pelvis off the ground followed by maximal right and left pelvic twist moment generation while being resisted by a research assistant. Maximal gluteus medius activity was elicited with resisted side-lying abduction of the lower limb while maintaining hip and knee flexion and also keeping the feet together (i.e., the clam; McGill, 2006, p. 269). To elicit maximal right biceps femoris activity, subjects lay prone with their right knee flexed to 60°. Participants were instructed, in this posture, to generate a maximal flexor moment at the knee and a maximal extensor moment at the hip while being resisted by a research assistant. Gluteus maximus was maximally activated in the biceps femoris, gluteus medius, or extensor MVC tests. Right rectus femoris was targeted with resisted knee extension combined simultaneously with hip flexion. While sitting and leaning back approximately 30°, participants generated a maximal knee extensor moment while also generating a hip flexor moment. Hip flexion was resisted manually by a research assistant, and knee extension was resisted by a strap around the participant's ankle that was attached to the table. For latissimus dorsi, participants depressed and retracted their shoulders while standing. Research assistants restrained the participant while the participant's arms were abducted (90°) and elbows were flexed in the frontal plane (90°).

Three-dimensional lumbar spine kinematics were measured using an electromagnetic tracking system (3Space Isotrak, Polhemus Inc., Colchester, U.S.A.) at a sampling frequency of 32 Hz. The transmitter was tightly secured with a custom harness over the sacrum and the receiver was tightly secured around the thorax over the T12 spinous process. Lumbar motion was measured as the motion of the ribcage relative to the sacrum. Each participant's upright standing posture on the floor was used as the neutral and reference posture for each of the subsequent exercise conditions

The kinematics of the device were recorded at a sampling frequency of 64 Hz using the Optotrak 3D motion measurement system (Northern Digital Inc., Waterloo, Canada). Infrared-emitting diodes (IREDs) were placed between the footpads and on each end of the ProFitter track to obtain kinematic information about the motion of the slider.

Data Analysis

EMG data were full-wave rectified and filtered by a single-pass, low-pass Butterworth filter at a cutoff frequency of 2.5 Hz to create a linear envelope. A cutoff frequency of 2.5 Hz represents the frequency response of torso musculature (Brereton & McGill, 1998). The linear envelope EMG signal was normalized to each participant's MVC for each of the 16 muscles. EMG and 3Space data of each 15-s trial was clipped to obtain two cycles of motion starting on the right side of the board. The start and end instances for the two cycles of motion were selected by determining the maximum frontal plane translation of the device slider from the markers placed on the slider. Some instrumentation noise was detected mainly in the gluteus maximus channels during the standing trials. This may have been due to greater thickness of subcutaneous tissues between the electrodes and the muscle, along with minimal muscle activation levels; consequently, the cleanest three subjects were used in the gluteus maximus muscle average scores. The signal-to-noise ratio was not an issue once exercise began and muscles became active.

Spine stability was calculated using the method documented by Cholewicki and McGill (1996), and involves a series of three interdependent models. A brief explanation of these models is provided along with a detailed flow chart of the modeling steps (Figure 2). The interested reader is referred to the works of Cholewicki and McGill (1996), McGill and Norman (1986), and McGill (1992) for a detailed explanation of each model. Whereas dynamic activities have been assessed in the past, this was a quasi static model.

First, an eight-segment linked model calculates reaction forces and moments at the L4/L5 joint using anthropometric data, external forces, and subject kinematics. A static approach is used here, meaning that inertial effects are not considered. The second model is the lumbar spine model, which uses three-dimensional spine motion to determine vertebral segment rotation, muscle lengths, and velocities. Ninety muscle fascicles are represented spanning six lumbar joints (sacrum-L5 to T12-L1). Stress/strain relationships of passive tissues are then used to calculate the restorative moments of spinal ligaments and discs. The third model utilizes the distribution moment approach (Ma & Zahalak, 1991), incorporating the normalized EMG profiles in conjunction with muscle length and velocity parameters to determine active muscle force and stiffness as well as any passive contributions due to parallel passive elastic tissues. The lumbar spine model then uses the muscle forces to calculate moments for each of six intervertebral joints. Muscle force and stiffness profiles are used in conjunction with the aforementioned reaction forces to calculate joint compression and shear forces and stability. Lumbar spine stability was determined by computing the eigenvalues of a Hessian matrix containing all second partial derivatives of a mathematical formulation of the spine's potential energy about six vertebral joints and three axes per joint. The smallest eigenvalue was used as the stability metric for the lumbar spine. A positive eigenvalue indicated stability, and a negative eigenvalue indicated instability. The specific computational procedures are described in detail by Howarth and colleagues (2004).

The movement time for the two clipped cycles of each trial and for each participant was normalized as a percentage of the total movement time (Winter, 2004). The vertebral joint forces, moments, and stability model outputs as well as the EMG and spine kinematic data were ensemble averaged to generate a series of representative profiles for each of the previously described exercise conditions.

One-way repeated measures analyses of variance were used to determine if differences existed between the three exercise conditions and two quiet standing conditions. The statistical analyses were performed on peak and average spine flexion, lateral bend and twist, peak normalized EMG (for each of the 16 channels of EMG), peak stability index, peak compression force, peak anterior-posterior shear, and peak absolute medial-lateral shear forces for a total of 26 independent ANOVAs. Where a significant main effect was detected (Bonferoni correction was used; $p < .003$), a least significant difference post hoc test was performed to assess significance between individual exercise conditions in a pairwise fashion.

Results

Upon visual inspection of the ensemble-averaged normalized electromyographic (NEMG) data, most muscles were activated at a constant level except for the gluteus medius, which showed phasic activation that was consistent with the sliding movement pattern (Figure 3). Participants tended to axially rotate the spine to the right while also moving to the right on the slider and subsequently also rotated to the left while sliding to the left (Figure 4). Spine stability and L4/L5 joint compression and both anterior-posterior and medial-lateral shear forces showed minimal variation throughout the cyclic motion. These patterns (amplitude of variables notwithstanding) were generalizable to all three of the skiing conditions: slalom skiing, giant slalom skiing, and downhill skiing.

The quiet standing condition while on the floor was no different from quiet standing on the device. As a result, Tables 1, 2, and 3 have been simplified to only show data for quiet standing on the device. The gluteal muscles showed the highest levels of activation, with the erectors being the second highest (Table 1). Left internal oblique, left latissimus dorsi, right and left

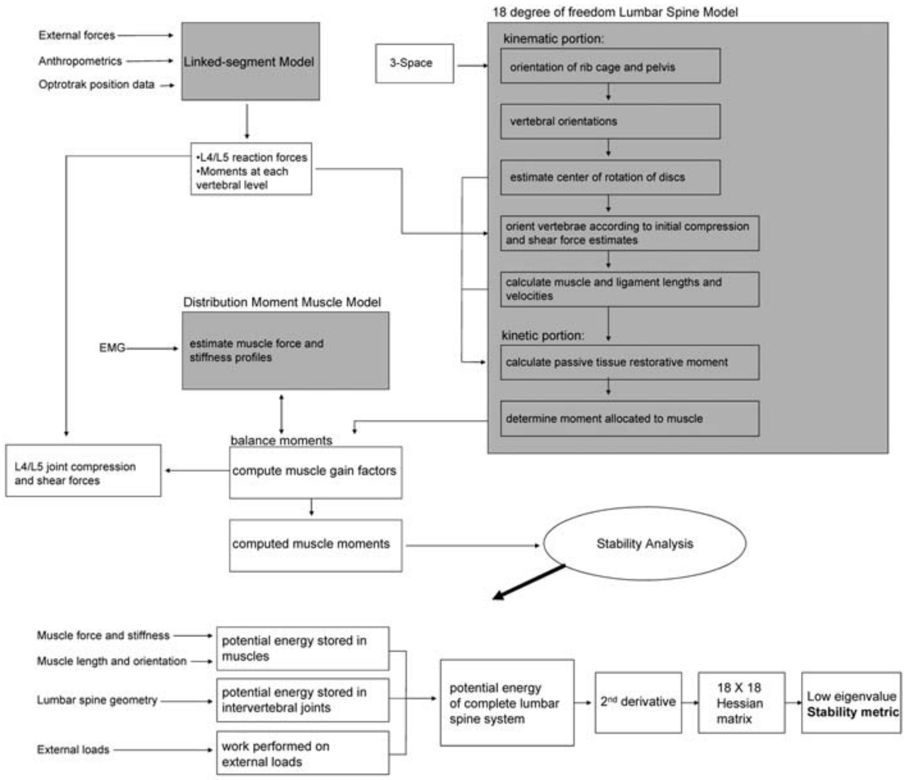
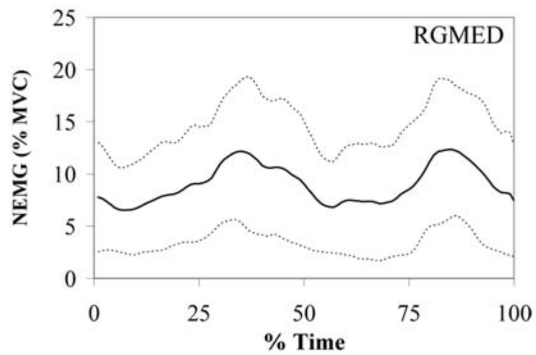


Figure 2 — Flow chart of the steps in the modeling analyses.



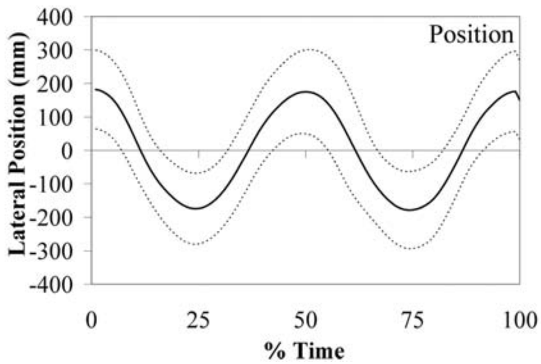


Figure 3 — Ensemble-averaged EMG of entire group for gluteus medius for two cycles of motion, starting with feet on the slider at the rightmost position. The data illustrates slalom skiing and dotted lines represent one standard deviation.

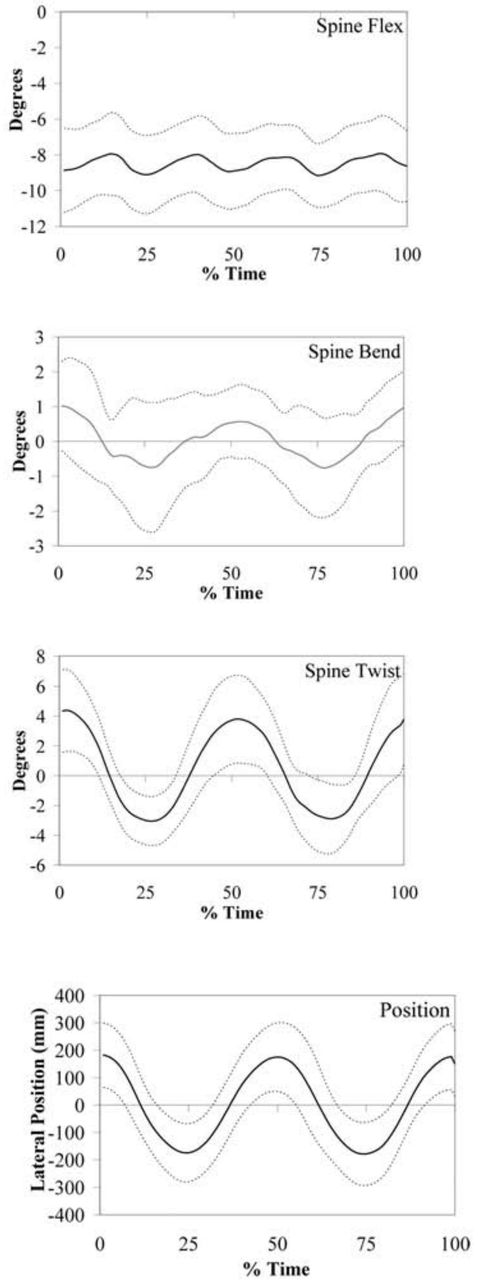


Figure 4 — Ensemble-averaged spine kinematics of entire group for two cycles of motion, starting with feet on the slider at the rightmost position. The data illustrates slalom skiing and dotted lines represent one standard deviation.

upper erector spinae, right and left lower erector spinae, and right gluteus medius had higher muscle activation than quiet standing conditions for all three exercise conditions ($p < .003$, Table 3). Similar activation levels were seen in the right latissimus dorsi and right rectus femoris between slalom skiing and quiet standing conditions (Table 3). Peak muscle activity for the left upper erector spinae increased from slalom (10.3 ± 4.4%MVC) to giant slalom (14.9 ± 4.8%MVC) to downhill skiing (22.4 ± 5.9%MVC, $p < .003$). Peak muscle activity was only higher in the downhill condition when compared with the giant slalom condition for left upper erector spinae (Table 3).

Peak compression and anterior-posterior (AP) shear forces on the L4/L5 joint increased in downhill skiing as compared with the other two skiing conditions ($p < .05$). L4/L5 joint compression exceeded 3000 N for downhill skiing (3118.3 N, Table 2). The level of lumbar spine stability did not differ between any of the three skiing conditions ($p > .05$, Table 3). However, these values were significantly different from quiet standing ($p < .05$, Table 3). In addition, all three skiing conditions showed similar medial-lateral (ML) shear force values.

Spine kinematics (peak and average spine flexion, bend and twist) for all three skiing conditions were significantly different than both quiet standing conditions ($p < .001$). Again, quiet standing on the floor was no different than quiet standing on the device ($p > .05$). Spine flexion (both peak and average values) significantly increased from slalom, to giant slalom to downhill skiing ($p < .001$, Table 4). The differences between slalom and giant slalom skiing for peak and average spine lateral bend and twist were significant ($p < .001$, Table 4). Average spine lateral bend was also significantly different between downhill skiing and slalom skiing ($p < .001$, Table 4), but not between downhill and giant slalom skiing styles ($p > .05$, Table 4). Spine kinematic values were all below the maximal range of motion for all the participants.

An in-depth example showed that the phasic activity of the right gluteus medius was more pronounced for one participant, who had previous rehabilitation experience with the device when compared with a less experienced participant (Figure 5). The experienced participant shows a patterned deactivation (to under 5% MVC) of right gluteus medius as he approached full left position on the slider. Cross-correlating gluteus medius NEMG data for two cycles of one giant slalom trial with two cycles of position data of the same trial yielded a high correlation ($r = .895$) for the experienced subject (Figure 5a). Right gluteus medius peak activation preceded the kinematic motion data in the right direction by 3% of a cycle. For the inexperienced subject, also for a giant slalom trial, right gluteus medius activation was weakly correlated with kinematic data ($r = .485$; Figure 5b).

Discussion

Based on the results, it is unlikely that the device is useful for high-performance training of stability. However, it may be used as a rehabilitative aid for improving stability and retraining of sport-specific motor patterns since sufficient stability was achieved during the exercises. However, using the device to progressively increase spinal stability using the three different exercises may not be warranted. Spinal loading is conserva-

Table 1 Average Peak Muscle Activity for Quiet Standing on the ProFitter (QSF), Slalom (SL), Giant Slalom (GS), and Downhill Skiing (DH)

	QSF		SL		GS		DH	
	% MVC	*SD*	% MVC	*SD*	% MVC	*SD*	% MVC	*SD*
RRA	3.5	1.8	4.0	2.3	5.0	3.7	5.0	3.8
REO	3.4	1.6	4.8	1.5	6.7	1.8	6.2	2.2
RIO	5.4	1.4	8.0	3.1	10.3	3.4	9.4	4.0
RLD	1.8	1.6	7.1	4.1	9.1	5.0	11.6	7.8
RUES	5.6	2.3	12.4	5.3	17.1	9.0	23.3	10.3
RLES	4.8	3.3	12.6	4.7	17.1	6.9	21.7	7.5
RGMED	4.2	2.8	16.5	8.7	29.6	15.4	35.5	16.7
RGMAX	3.9	1.7	14.4	19.2	14.7	10.4	24.9	19.8
LRA	2.6	1.0	3.0	1.1	4.2	2.5	3.5	1.5
LEO	3.1	2.1	4.7	2.5	6.1	2.2	5.9	2.9
LIO	5.8	3.4	9.8	4.6	11.5	4.1	9.7	2.4
LLD	1.8	0.9	5.2	2.6	8.2	3.3	9.9	5.3
LUES	4.4	2.8	10.3	4.4	14.9	4.8	22.4	5.9
LLES	4.7	1.4	13.7	6.9	19.6	9.0	24.7	7.2
RBF	1.7	0.8	6.6	3.7	10.3	6.7	10.5	6.2
RRF	1.1	0.3	7.7	4.2	14.4	12.7	20.3	13.9

Table 2 Average Peak Spine Load for Quiet Standing on the ProFitter (QSF), Slalom (SL), Giant Slalom (GS), and Downhill Skiing (DH), Together with the Stability Criterion of Lowest Eigenvalue

		QSF	*SL*	*GS*	*DH*
Low Eigenvalue	**N·m/rad/rad**	228.9	528.0	579.0	622.6
	SD	206.3	39.8	35.7	44.2
Compression	**N**	1747.0	2396.2	2748.0	3188.3
	SD	377.8	357.9	698.0	356.8
AP Shear	**N**	131.3	170.1	201.9	288.1
	SD	24.7	28.6	32.9	60.9
ML Shear	**N**	57.1	97.2	120.6	115.4
	SD	24.6	23.8	27.9	35.5

Note. Compression and shear forces are in newtons, negative AP shear values correspond to the superior vertebrae shearing backward on the inferior, and ML shear values are absolute values.

tive while using the equipment, suggesting it may be suitable for patients with some, but not full, compressive load intolerance. Furthermore, the movement patterns while exercising on the device may partially be driven by phasic gluteus medius activity, especially when skilled technique is used. Training of proper gluteal activation may be desirable for many patients. Other muscles involved in lateral movements may also drive the movement on the device, but they were not examined.

Although no comparative data on the use of the ProFitter 3-D Cross Trainer exists, a few of the findings may be evaluated with respect to previous scientific works. The low isometric abdominal and increased erector spinae activity in conjunction with the lowest eigenvalue criterion provides evidence that sufficient stability is achieved (Cholewicki & McGill, 1996, Cholewicki et al., 1997) while using the device. Abdominal bracing may be recommended if further improvements in lumbar stability are desired (Grenier & McGill, 2007). The increasing activation of the upper and lower erectors from slalom to downhill skiing likely contributes to the trend of increasing spine stability (although statistically insignificant) seen between the conditions. It is generally accepted that as muscle force increases, muscle stiffness increases, subsequently stabilizing the joints (Stokes & Gardner-Morse, 2003). In addition, muscle activity has been shown to be a primary factor in determining stability (Kavcic et al., 2004a). Other exercises on labile surfaces that do not involve sitting may fulfill the need to have a continuum for stability rehabilitation (Vera-Garcia et al., 2000, Drake et al., 2006). Gluteus medius activation helps drive the whole-body mechanics of the exercises on the

Table 3 Pairwise Comparisons of Conditions From a Least Significant Difference Post Hoc Test

	RRA	REO	RIO	RLD	RUES	RLES	RGMED	RGMAX	LRA	LEO	LIO	LLD	LUES	LLES	RBF	RRF	Stability	Compres.	AP-Shear	ML-Shear
DH-GS													*					*	*	
GS-SL		*					*					*	*							
DH-SL					*	*	*					*	*	*		*		*	*	
SL-QS		*	*		*	*	*				*	*	*	*			*	*	*	
SL-QSF					*	*	*				*	*	*	*	*		*	*	*	*
DH-QS		*	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*
DH-QSF		*	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*
GS-QS		*	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*
GS-QSF		*	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*
QS-QSP																				

The asterisks indicate significant differences according to the least significant difference post hoc test ($p < 0.05$).

Table 4 Average and Peak Spine Flexion, Lateral Bend and Twist for Quiet Standing on the ProFitter (QSF), Slalom (SL), Giant Slalom (GS), and Downhill Skiing (DH)

	QSF	SL	GS	DH
Peak Spine Flexion	0.91° ± 1.61°	−10.1° ± 2.12°	−15.74° ± 3.74°	−29.06° ± 8.02°
Peak Spine Lateral Bend	0.65° ± 0.43°	2.83° ± 1.39°	3.97° ± 1.39°	3.48° ± 1.26°
Peak Spine Twist	1.27° ± 1.07°	6.06° ± 2.06°	7.61° ± 1.92°	6.86° ± 2.06°
Average Spine Flexion	0.59° ± 1.54°	−8.48° ± 2.08°	−13.3° ± 1.92°	−26.66° ± 8.0°
Average Spine Lateral Bend	0.50° ± 0.39°	1.16° ± 0.61°	1.69° ± 0.60°	1.70° ± 0.67°
Average Spine Twist	1.29° ± 1.22°	2.99° ± 0.85°	3.80° ± 0.83°	3.35° ± 1.12°

Note. Values are in degrees. Negative spine flexion indicates flexion of the spine. Lateral bend and twist values are absolute values.

device, which may be desirable for some patients to groove stabilization patterns (Akuthota & Nadler, 2004, Cynn et al., 2006).

The minimal abdominal activation while performing skiing exercises is consistent with the reported findings of studies by Hintermeister et al. (1995, 1997). Dominant erector spinae muscle activity during the skiing-type exercise on the device is also consistent with Hintermeister et al.'s (1995, 1997) studies of elite skiers. However, peak muscle activation levels while skiing on the device are far less than peak activations seen in previous EMG studies of skiing (Hintermeister et al., 1995, 1997). Performing skiing exercises on the device produced maximal muscle activation that was less than 35% MVC for all muscles measured in this investigation. It has been suggested that muscle activations at these levels likely do not offer strengthening advantages in healthy individuals (Souza et al., 2001). The discrepancy between these values may be explained by the different populations studied (elite skiers on actual skiing hills versus nonelite males in this study) in addition to the fact that the device postures do not necessarily replicate actual skiing postures or incline and wind conditions. Results of Hintermeister et al. (1997) indicate that during elite skiing, activation levels are generally over 100% isometric MVC. Quadriceps (rectus femoris) were not highly activated by the device, as they often are in elite skiing (up to 163% MVC in giant slalom skiing; Hintermeister et al., 1995). Only giant slalom and downhill skiing on the device activated right rectus femoris beyond quiet standing levels to approximately 14.4% MVC and 20.3% MVC, respectively. High activation of this muscle group is desirable in ski training to develop strength (Leach, 1994). Thus, the device may not be suitable for the quadriceps strength training often sought by elite skiers (Leach, 1994).

Hintermeister et al. (1995) also examined differences in muscle activation between slalom skiing and giant slalom skiing. In their study, they found the two skiing types to be very similar in muscle activation profiles, with external oblique activation being the only trunk muscle that was significantly higher in peak activation during giant slalom skiing (Hintermeister at al, 1995). During ProFitter skiing, right external oblique was significantly higher in GS skiing when compared with SL skiing. In addition, while skiing on the device, gluteus medius, left latissimus dorsi, and left upper erector spinae show higher activation. Thus, differences in muscle activity between slalom and giant slalom skiing are potentially more often seen on the device than in actual skiing (Hintermeister, 1995). Other differences (between giant slalom skiing and downhill skiing or between downhill skiing and slalom skiing) have not been examined in the literature. While performing exercises on the device, other consistent patterns in muscle activation differences were not seen.

Shear and compressive forces on the L4/L5 joint resulting from the three exercises seem to provide a reasonable margin of safety for users who are sensitive to compressive or shear loading. Compressive values are under the NIOSH action limit of 3400 N of spine compression (Waters et al., 1993), suggesting that the device may be beneficial for patients with sensitivity to compressive loading. Similarly, the peak anterior-posterior shear forces of the three tasks fall below the proposed 500-N action limit for anterior-posterior shear forces (Yingling and McGill, 1999). These findings, however, should be interpreted with caution as inertial forces were not accounted for. It is also interesting to note that spinal compression and anterior-posterior shear forces are greater in downhill skiing only, when compared with slalom and giant slalom skiing. No differences were seen in these variables between slalom and giant slalom skiing. The only difference between downhill skiing and the other conditions is posture (increased spine flexion), suggesting that body position may independently have an effect on spinal compression and anterior-posterior shear forces.

The progressive increase in spine flexion during skiing conditions suggests a greater need for increasing back musculature activation. However, since spine flexion was always below maximum range of motion, load would not be transferred from the musculature to the passive tissues and thus likely would not qualify as a potential injury mechanism (O'Sullivan et al., 2006; Callaghan and Dunk, 2002). Spine twist and lateral bend

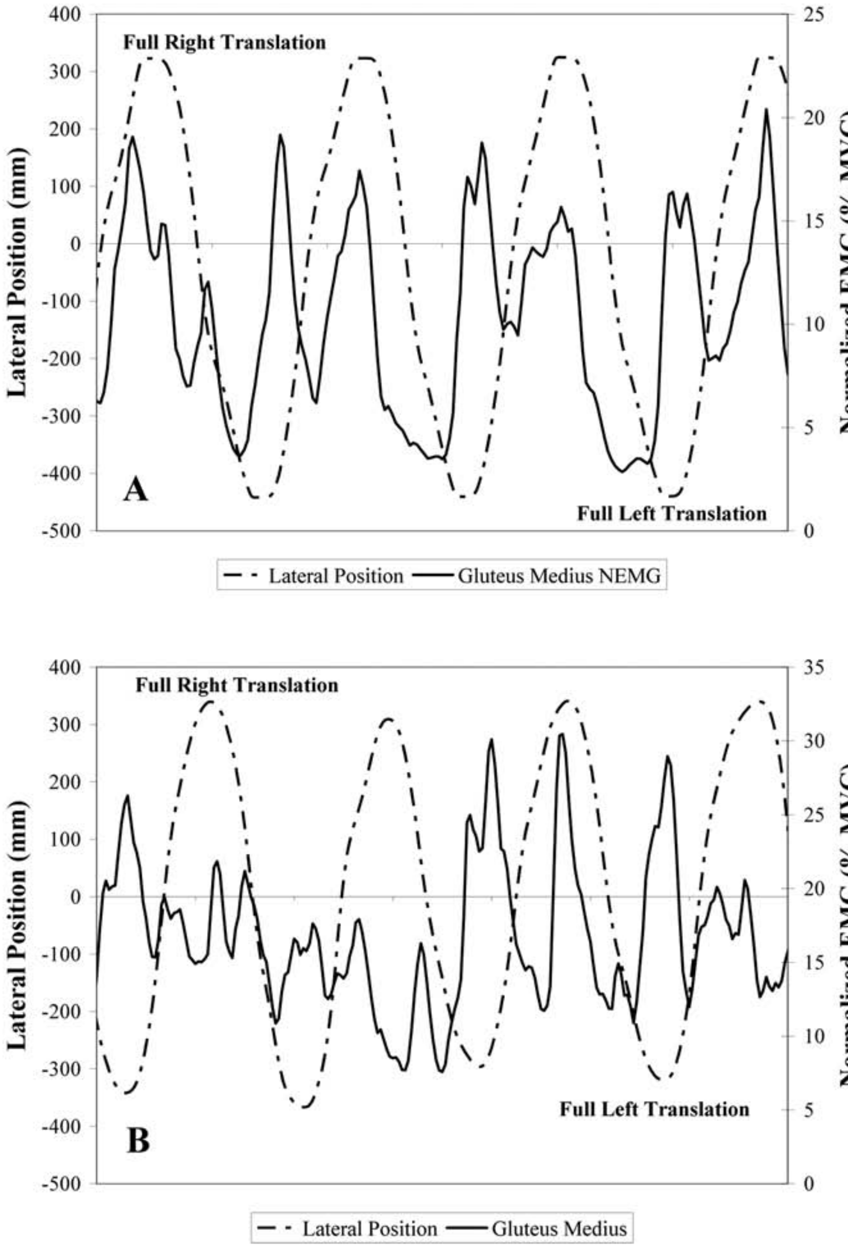


Figure 5 — Normalized electromyographic data for gluteus medius with respect to the position of the participant on the ProFitter 3-D Cross Trainer for both an (A) experienced participant, and a (B) inexperienced participant. Motion toward the right is indicated by more positive position values.

were minimal (Table 4); thus, the consistent increase between slalom and giant slalom skiing, although significant, would have little clinical implication.

Interpretation of the results may be limited by the small sample size recorded. Furthermore, the findings of this research are specific to the male population and may not be generalized to the female population. The sample population of males had to be used because the anatomical models used for computing lumbar spine loads and stability were based on 50th percentile male anatomy. Further investigation is required to understand the mechanics of the device that may change when used by a more variable population. Another recognized limitation of the study is that participants may have needed more time to practice motions on the device. Thus, some participants may not have been able to sufficiently master the motion and motor patterns needed to use the device. As a result, the entrained pattern of gluteus medius was not as pronounced in participants without previous experience.

Based on the results of this study, sufficient stability was ensured while participants used the device, which suggests that using the device may be suitable for some patients as a training aid for enhancing lumbar spine stability in a rehabilitation program. It must be noted that inertial body effects, which were not considered here due to the constraints of the potential energy-stability theory, would potentially produce an additional destabilizing component to the spine. In addition, the ProFitter exercises examined in this investigation can be performed maintaining a neutral spine posture, and produce spinal loads that can be considered safe for some patients. This is especially important when considering the use of the device for patients with low back pain that might be caused by excessive compressive loading. The use of the device as a strength training tool for competitive skiing is not well supported by this investigation. However, the device may help train gluteal muscle activation patterns (especially of gluteus medius) and other sport-specific motor patterns. As with all training and rehabilitation aids, it is not simply a matter of completing the exercise, but performing the exercise with optimal technique, which requires vigilance on the part of the clinician. This information will assist in clinical decision making when utilizing labile surface devices.

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