Trunk Muscle Activation Patterns, Lumbar Compressive Forces, and Spine Stability When Using the Bodyblade

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Background and Purpose

The objective of this study was to analyze the trunk muscle activation patterns, spine kinematics, and lumbar compressive forces that occur when using the Bodyblade, a popular tool in physical medicine clinics.

Subjects

The participants were 14 male subjects who were healthy and who were recruited from a university population.

Methods

With data collected from surface electromyography of selected trunk and shoulder muscles, video analysis, and a 3-dimensional lumbar spine position sensor, modeling methods were used to quantify L4–5 compressive forces and spine stability.

Results

Large-amplitude oscillation of a vertically oriented Bodyblade resulted in the greatest activation levels of the internal oblique and external oblique muscles (average amplitude=48% and 26% of maximal voluntary isometric contraction, respectively), which were associated with L4–5 compressive forces as high as 4,328 N. Instantaneous stability increased with well-coordinated effort, muscle activation, and compression, but decreased when subjects had poor technique.

Discussion and Conclusion

The way the Bodyblade is used may either enhance or compromise spine stability. Associated lumbar compressive forces may be inappropriate for some people with compressive intolerant lumbarspine pathology.

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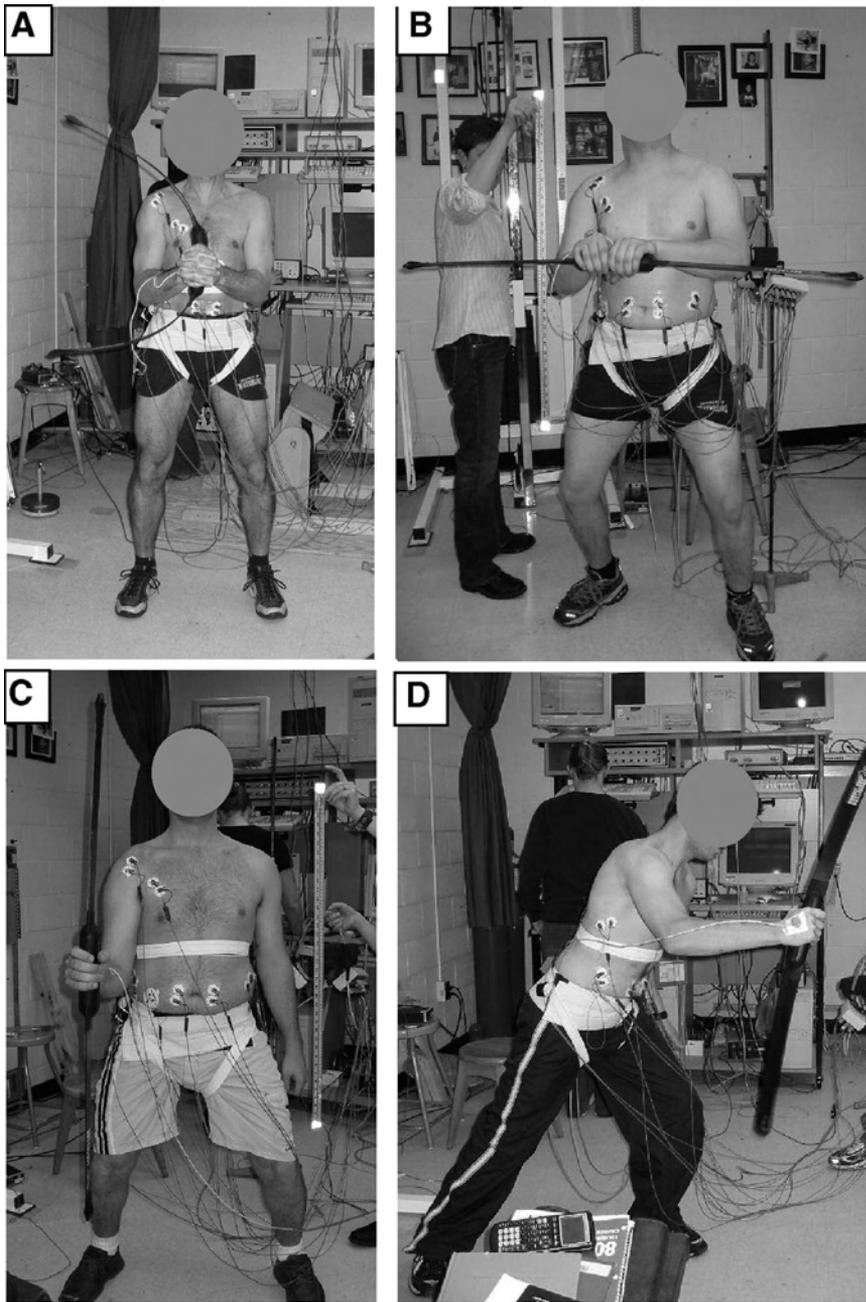
Figure 1.
Images of subjects using the Bodyblade in 4 orientations: (A) 2-handed, vertical; (B) 2-handed horizontal; (C) 1-handed, vertical; and (D) 1-handed, diagonal path.

Spine stability is known to be dependant on the coordinated activity of many trunk muscles. Muscles that are anterior, posterior, or lateral to the spine must co-contract with varying amounts to create a "balanced" stiffness, ensuring stability under differing conditions of instantaneous position, velocity, and load placed upon the spine.[1,2] Some studies quantifying instantaneous spine stability have documented the necessity of many muscles, coordinated together, to create symmetric and balanced stiffness around the spine, which is necessary to ensure stability at that instant in time. For example, the obliques assist in forming the muscular girdle, and the latissimus dorsi muscle buttresses instability about all 3 orthopedic axes. Furthermore, the relative importance of different muscles to ensuring a stable spine continually changes as a function of the task or demand. Studies that have attempted to quantify the importance of specific trunk muscles with regard to spine stability have shown that no single muscle is dominant in ensuring the overall stability of the lumbar spine.[3,4] It is important, therefore, to choose spine stabilization exercises that require coactivation of numerous trunk muscles, while conserving the spine with tolerable loads, particularly when load tolerance is compromised with injury.[5] While proper coordination of muscles is paramount, spine stability is modulated by additional variables such as the ability to rapidly recruit and derecruit muscles, muscle endurance, and strength (force-generating capacity).[6]

The Bodyblade* is a 122-cm-long, 0.68-kg flexible foil with a natural frequency of 4.5 Hz (Fig. 1). This means that when the blade oscillates at 4.5 times per second, minimal additional energy is required to maintain this oscillation. The makers of the Bodyblade claim that it is "the most efficient core power training tool ever designed"[7] and list more than 100 universities and 60 professional athletic organizations in North America that use this rehabilitation tool. When using the Bodyblade, the posture of the user, the position and orientation of the blade, and the amplitude of the oscillations will determine which specific muscle groups are being targeted and their level of activation. The Bodyblade may be held in 1 or 2 hands, but to achieve oscillation at its natural fre-

quency, motion in the user's trunk and proximal arm must be minimized; excessive trunk or arm motion interferes with the coordination necessary to isolate reciprocal motions to the hand. Likewise, motion of the hand must occur in the plane perpendicular to both the length and the flat side of the blade; additional motion in other directions again will interfere with resonance. It would appear that, based on the requirement of minimizing trunk motion for adept use of the Bodyblade, it may be well designed for challenging the trunk muscles with regard to coordination, rapid recruitment or derecruitment, endurance, and strength. Considering the manufacturer's claims of core power training, the question arose as to exactly how this tool affects spine stability, together with the need to understand resultant muscle activation levels and spine load to guide clinical decisions. Specifically, do the manufacturer's claims have merit, and if so, are there ways to improve the utility of this tool with rehabilitation and performance training?

The purposes of this study were: (1) to analyze the trunk muscle activation patterns that occur with various positions, orientations, and amplitudes of Bodyblade exercises, (2) to estimate instantaneous spine stability and compressive loads associated with these exercises by means of a computerized model, and (3) to analyze the data for trends that help explain why some people are naturally adept at using the Bodyblade, whereas others find it extremely difficult to master. The full breadth of this information should enable clinicians to decide whether the Bodyblade is an appropriate rehabilitation tool for specific patients or clients.

The hypotheses were:

1. Coordinated use of the Bodyblade in various upright tasks will result

in activation levels of the trunk muscles that are comparable to or greater than those found in other spine stabilization exercises.[3,8–10]

2. L4–5 compression loads, when using the Bodyblade, will remain within the range deemed acceptable by recognized standards (eg, National Institute for Occupational Safety and Health [NIOSH][11]).

3. Instantaneous spine stability, as calculated during the exercise, will increase with coordinated use of the Bodyblade.

4. High-amplitude oscillations of the Bodyblade will result in higher levels of trunk muscle activation, L4–5 compression, and instantaneous spine stability than low-amplitude oscillations.

Materials and Methods

Fourteen recreationally trained men (mean age=28.14 years, SD=8.33; mean height=1.78 m, SD=0.05; mean mass=77.78 kg, SD=10.41) were recruited from the University of Waterloo population. All subjects were right-handed, healthy, and without current back or shoulder pain. Participants completed a written informed consent document approved by the University of Waterloo Office for Research Ethics. Of the 14 subjects, a subgroup of 5 subjects then repeated the trials at a later date, with the Bodyblade instrumented with 2 force transducers[†] to measure hand forces, enabling the process used to calculate spine load and stability.

Instrumentation and Data Collection

Exercises. After a brief instruction and practice session to ensure familiarity in use of the Bodyblade, participants were asked to oscillate the blade over a 15-second time period

[†] Transducer Techniques, 43178 Business Park Dr, Temecula, CA 92590.

in one of the following orientations: (1) a 1-handed vertical orientation of blade (medial-lateral oscillations), (2) a 2-handed vertical orientation of blade, (3) a 2-handed horizontal orientation of blade (up-down oscillation), and (4) a 1-handed, diagonal path, small-amplitude oscillation, whereby the participant moved the arm and blade through a diagonal pathway from lower right to upper left, similar to the direction used during a cable press exercise (Fig. 1). The order of the exercises presented to subjects was randomized. Exercises 1 through 3 were timed such that the first 3 seconds were quiet standing, the next 5 seconds were small-amplitude oscillations, and the final 7 seconds were ramped up to a large-amplitude oscillation. Exercise 4 was timed such that the forward press motion occurred over the first 4 seconds, with a return to the starting position over the next 4 seconds. These exercises were chosen from the Bodyblade Exercise Guide wall chart, which is shown on the manufacturer's Web site.[7] Specifically, we felt that they would be a fair representation of exercises aimed at challenging the core trunk muscles.

Electromyography. Surface electromyography (EMG) signals were collected bilaterally on each subject from the following trunk muscles and locations: rectus abdominis (RA), 3 cm lateral to the umbilicus; external oblique (EO), approximately 15 cm lateral to the umbilicus; internal oblique (IO), halfway between the anterior superior iliac spine of the pelvis and the midline, just superior to the inguinal ligament; latissimus dorsi (LD), lateral to T9 over the muscle belly; and erector spinae (ES) at T9, L3 and L5 (T9ES, L3ES and L5ES, respectively), located 5, 3, and 1 cm lateral to each spinous process. These surface electrode sites have previously been shown to be representative of the underlying muscle activity to within

15% root mean square of maximum voluntary contraction.[12] Electromyographic signals from the anterior deltoid muscle (AD) and the sternal portion of the pectoralis major muscle (PM) also were recorded on the right upper limb.

Pairs of silver-silver chloride surface electrodes were positioned with an interelectrode distance of 3 cm. The EMG signals were amplified to produce approximately ±2.5 V, then A/D converted (12-bit resolution) at 1,024 Hz. Electromyographic signals were full-wave rectified and low-pass filtered (low-pass Butterworth filter) with a cutoff frequency of 2.5 Hz and then normalized to maximal voluntary isometric contraction (MVIC) amplitudes. The MVICs were obtained during isometric maximal exertion tasks in the following way. For the abdominal muscles, each subject was in a sit-up position and manually restrained by a research assistant, who matched the effort so that very little motion occurred. The subject produced a sequence of maximal isometric efforts in trunk flexion, right lateral bend, left lateral bend, right twist, and left twist directions, but again with little motion occurring. For the extensor muscles, an isometric trunk extension was performed with the torso cantilevered over the end of the test table (Biering-Sorensen position). The MVIC for the PM was measured while subjects were positioned with the right shoulder flexed, abducted, and externally rotated with the elbow slightly bent. A research assistant resisted maximal isometric efforts of shoulder horizontal adduction, extension, and internal rotation. The MVIC of the AD was performed by resisting shoulder flexion at 90 degrees in the sagittal plane. For the shoulder MVICs, subjects were positioned supine on a thinly padded test bench.

Three-dimensional kinematics. Throughout all activities, the spine position was measured using an electromagnetic tracking instrument (3-Space ISOTRAK[‡], with measurements collected at a sampling frequency of 32 Hz and synchronized to the EMG and load cell data. This instrument consists of an electromagnetic transmitter that is strapped in place over the sacrum and one small receiver over the T12 spinous process to measure relative lumbar motion about the flexion and extension, lateral bend, and twist axes. Both components were held in place via elastic Velcro straps[§] that were securely fastened around the body. All lumbar angular measurements were made relative to the standing anatomical position. Consequently, at any instant in time during the required exercises, the instantaneous spine position could be determined in 3 planes of motion relative to upright standing.

Force data. Two load cells were taped to the Bodyblade, one to either side of the handle, to measure the forces exerted at the hand/blade interface. These signals were amplified and A/D converted (12-bit resolution over ±10 V) at 1,024 Hz. The larger handle size associated with the load cells made it difficult to coordinate the Bodyblade for some subjects, thus only 4 participants took part in this part of the experiment.

EMG Data Processing

A single 2-second window was chosen from each trial that best represented the concurrent activity of all muscle groups during the requested Bodyblade activity. The mean activation level then was calculated for

each window, and these calculations were averaged across all 14 subjects.

Stability and compression. Although a brief description of the modeling process is given here, readers who would like a more comprehensive description with mathematical rigor are recommended to read previous literature, which outlines the process in more detail.[6,13,14]

Static side-view photographs of each participant were used for hand digitizing body markers, using a computer software program that calculates the kinematic coordinates in the vertical and anterior-posterior directions. The medial-lateral coordinates were hand measured on each participant, assuming the body's midline to be the zero coordinate. These 3-D coordinates then were entered into a full-body linked-segment model to determine reaction forces and moments at the L4–5 joint. Together with the 14 channels of EMG and the 3-D spine posture and angles acquired from the 3-Space instrument, the information was input to an anatomically detailed computerized spine model representing 118 muscle fascicles as well as lumped parameter passive tissues, spanning the 6 lumbar joints (T12-L1 to L5-S1). Using the instantaneous spine position data obtained from the 3-Space instrument, the model partitions the motion to each of the lumbar vertebral segments, allowing muscle lengths and velocities to be calculated, based on their instantaneous position relative to the vertebrae. The orientation of the segments, together with the stress and strain relationships of the passive tissues, then was used to calculate the restorative moment created by passive tissues, including the spinal ligaments, disks, and the gut. The normalized EMG profile from each muscle, along with the calculated muscle length and velocity, is used to estimate individual muscle force

and stiffness values, as well as any passive contribution from noncontractile components. Total L4–5 compressive forces then were calculated as a sum of the compressive force measurements obtained from the linked-segment model (incorporating body mass and spine position) together with the compressive component of the muscle and passive tissue forces.

Spine stability was calculated using the potential energy approach, which states that stable equilibrium prevails when the potential energy of a system is at a minimum.[13] This theory is frequently used in biomechanics to calculate joint stability, as it is one of the only methods that assigns a quantitative value to the instantaneous stability of the system. For example, a ball resting in a deep bowl would require a large amount of additional potential energy (work) to move the ball up and out of the bowl. In its resting state, this system is stable and the ball is at a minimum potential energy state. If the ball were on top of an inverted bowl, minimal work would be required to cause it to roll off to a lower potential energy state. This system is said to be unstable. But a spine is a flexible rod that obtains potential energy from the stiffness properties of muscle when contracting ($PE = \frac{1}{2}kx^2$, where PE = potential energy, k = spring stiffness and x = deformed distance). The muscles are stiffness elements, or springs, that act like guy wires on a mast. Potential energy in this form is either enhanced or compromised by the arrangement of the supporting muscles, their stiffness modulated as a function of activation, their distance relative to the spine, and the symmetry and balance of these stiffness elements. In clinical terms, if the potential energy derived from the stiffness of the muscles, passive structures, and anatomical position of the spine are greater than the destabilizing work per-
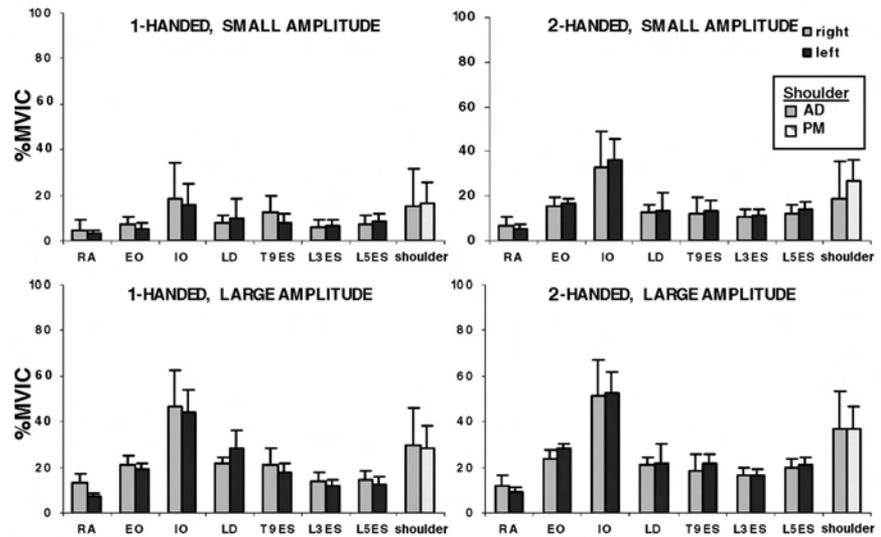
Figure 2.
Average (±SD) trunk and shoulder muscle electromyographic activity levels when Bodyblade is held in a vertical orientation, resulting in a medial-lateral oscillatory pattern. %MVIC=percentage of maximal voluntary isometric contraction. See Table footnote for explanations of abbreviations.

formed, then the spinal system is considered stable. Loss of stiffness in a stiffening element at any instant in time, sufficient to lower the potential energy at a specific section of the spine to values less than the applied work, puts the system at risk of buckling and subsequent injury.

The stability of the spine is indicated by the "eigenvalues," which are mathematically determined for each lumbar joint as a function of muscle and passive tissue stiffness, architecture, and so on. Because, in simplified terms, the eigenvalue is the difference between the residual potential energy and the applied work, a positive eigenvalue is indicative of a stable segment, and a negative eigenvalue indicates the potential for instability. The larger the number, the greater the stability. In this model, there are 6 lumbar segments, each with 3 axes of motion, resulting in 18 degrees of freedom, thus 18 eigenvalues, representing the segment levels and directions that are analyzed for stability. As long as the lowest eigenvalue is a positive number,

the system will be considered stable. In addition, the model also calculates a "stability index," which may be considered the average of all of the eigenvalues, thus more representative of the interplay of the multisegmental muscles that affect lumbar system stability.

Data Analysis

To assess the influence of the Bodyblade on muscle activation levels, lumbar compression, stability index, and lowest eigenvalue, a 2-way analysis of variance was conducted. Several methods of using the Bodyblade were compared, including a 1-handed vertical orientation, a 2-handed vertical orientation, and a 2-handed horizontal orientation. Where appropriate, least squares means testing was done as a *post hoc* test to determine the specifics of the amplitude × task interactions. A significance level of $P<.05$ was established for all analyses.
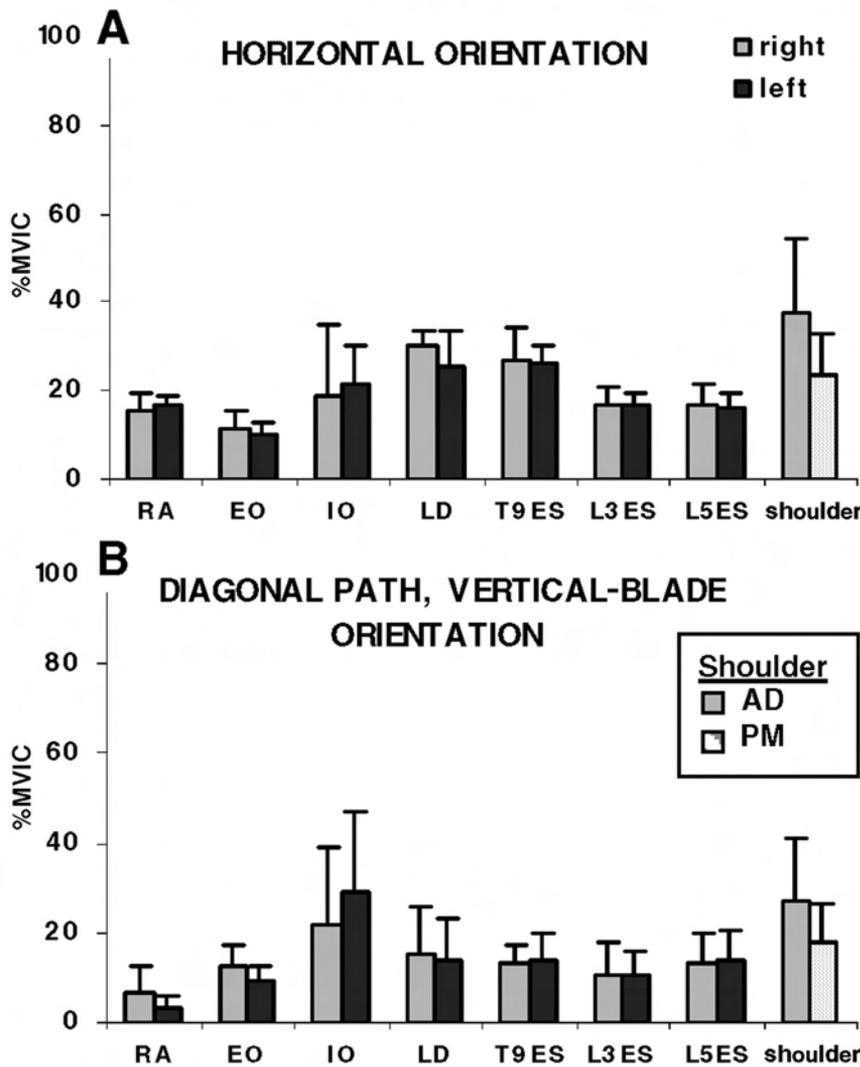
Figure 3.
Average (±SD) trunk and shoulder muscle electromyographic activity levels when the Bodyblade is held in: (A) a horizontal orientation (2-handed grip), resulting in an up and down oscillation, and (B) a 1-handed vertical orientation, but traveling along a diagonal path from lower right to upper left. %MVIC=percentage of maximal voluntary isometric contraction. See Table footnote for explanations of abbreviations.

Results
Muscle Activation

Trunk muscle activation patterns for 6 of the various positions tested are shown in Figures 2 and 3. Changing task resulted in significantly different activation levels for all muscles except the left LD (Table). Small-amplitude, 1-handed use of the blade in a vertical orientation (medial-lateral oscillations) resulted in the IO muscles having the highest activation levels (18% and 15% MVIC for right and left sides, respectively), followed by the right T9ES (12% MVIC) and left LD (10% MVIC). Changing to a large-amplitude oscillation caused the activation levels of all muscles to increase, with IO averaging around 45% MVIC.

Two-handed use of the Bodyblade altered the activation patterns such that bilateral IO and EO now had the highest activation levels of the trunk muscles with either amplitude (Fig. 2). Small-amplitude use resulted in IO levels averaging 35% MVIC, whereas the large-amplitude mean was 52% MVIC, significantly higher than the same task using a unilateral grip ($P<.05$). When comparing right and left sides, the 3 ES groups and LD all demonstrated near-equal activation levels side to side, with these levels being just slightly less than those of EO.

As shown in Figure 3, horizontal use of the Bodyblade resulted in LD and T9ES having the highest activation levels (bilateral average of 27% and 25% MVIC, respectively), with IO dropping down to approximately 20% MVIC, despite the large oscillation amplitude. The RA increased to its highest level of the trials, averaging 16% MVIC bilaterally. The magnitude of these changes was significant ($P<.05$) for all 4 muscle pairs, except the left LD.

The diagonal path, vertical orientation use of the Bodyblade (Fig. 3) required the participant to maintain a low level of oscillation while taking the right arm, trunk, and Bodyblade through a diagonal right-lower to left-upper path. Again, IO had the highest level of activation (28% and 21% MVIC, right and left, respectively). Of note are the even amounts of co-contraction that occurred in each of the pairs of back muscles, despite the fact that this was a unilateral activity. This differs from the previous upright stance trials, where a unilateral grip resulted in less equality of activation when comparing right and left sides.

Spine Stability and Compressive Forces

Changing task also significantly altered compression ($P<.0064$), stability index ($P<.0064$), and the lowest eigenvalue ($P<.0370$). The L4–5

Table.
Significant Main Effects by Muscle, Including F and *P* Values[a]

Muscle	Amp	F Value	*P*	Task	F Value	*P*	Significant Between-Task Comparisons (*P*<.05)
R RA	*	13.02	.0041	*	7.22	.0007	BH/BV, BH/UV
R EO	*	46.63	<.001	*	26.36	<.001	BV/UV, BV/BH
R IO	*	62.91	<.001	*	21.08	<.001	BV/UV, BV/BH, UV/BH
R LD	*	29.22	.0002	*	6.02	.0020	BH/BV, BH/UV
R T9ES	*	28.83	.0002	*	5.23	.0046	BH/BV, BH/UV
R L3ES	*	13.21	.0038	*	5.22	.0049	BH/UV
R L5ES	*	12.22	.0044	*	11.48	<.001	BH/UV, BV/UV
L RA	*	29.63	.0001	*	6.92	.0008	BH/BV, BH/UV
L EO	*	37.57	<.001	*	49.06	<.001	BV/UV, BV/BH
L IO	*	110.93	<.001	*	25.96	<.001	BV/UV, BV/BH
L LD	*	39.03	<.001		0.46	.7131	
L T9ES	*	37.87	<.001	*	10.43	<.001	BH/BV, BH/UV, UV/BV
L L3ES	*	17.70	.012	*	9.47	.001	BV/UV, BH/UV
L L5ES	*	8.33	.0127	*	10.0	<.001	BV/UV, BH/UV
R AD	*	43.40	<.001	*	5.11	.0048	BH/BV, BH/UV
R PM	*	60.20	<.001	*	7.21	.0006	BV/UV, BV/BH

[a] Amp=amplitude of oscillation variable (large versus small), Task=orientation and grip of the Bodyblade (B=bilateral grip, U=unilateral grip, V=vertical orientation, H=horizontal orientation). R=right, L=left, RA=rectus abdominis muscle, EO=external oblique muscle, IO=internal oblique muscle, LD=latissimus dorsi muscle, T9ES=erector spinae muscle at T9, L3ES=erector spinae muscle at L3, L5ES=erector spinae muscle at L5, AD=anterior deltoid muscle, PM=pectoralis major muscle. Asterisk indicates a significant main effect (*P*<.05).

compressive forces varied from an average of 1,670 N for the horizontal, low-amplitude oscillations to 4,328 N during the high-amplitude, bilateral grip, vertical orientation of the blade (Fig. 4). The lowest eigenvalue, a measure of segmental stability, varied between 85 and 113 N·m/rad. The stability index of the entire lumbar spine varied from 476 N·m/rad for the 1-handed, low-amplitude, vertical orientation to 1,368 N·m/rad for the 2-handed, large-amplitude, vertical orientation.

Amplitude of Oscillation

Changing from small to large amplitude of oscillation resulted in a significant increase in activation level for every muscle analyzed (Table), as well as a significant increase in compres-

sion and stability index (*P*<.0144 and *P*<.0137, respectively).

Individual Cases

In an attempt to determine why various participants found this activity difficult or easy to master, motor patterns of individual participants were analyzed. The following case study is very revealing of what distinguishes skilled performance versus poor ability, together with the substantial effect that coordination levels have on spine stability. Figure 5 shows the normalized EMG amplitudes of the IO and EO during a 4-second window of the 2-handed, large-amplitude, vertical orientation of the blade trial. Data are shown from 2 subjects: 1 subject who found the Bodyblade relatively easy to coordi-

nate (subject 10) and another subject who, despite ongoing practice, could not master the coordination necessary to achieve resonance (subject 2). The former subject demonstrated a clear antiphase pattern of the right versus left IOs, with relatively equal amplitudes of activation. Although the IO muscles of subject 2 also were in an antiphase pattern, there was much more variability in EMG amplitude, with the right side being dominant throughout most of the graph. The phase patterns of EO were less clear in both subjects; however, subject 2 clearly had the right and left EO activating in more of an in-phase manner, which would not be conducive to trunk stability with a rapidly oscillating right-to-left force being applied.
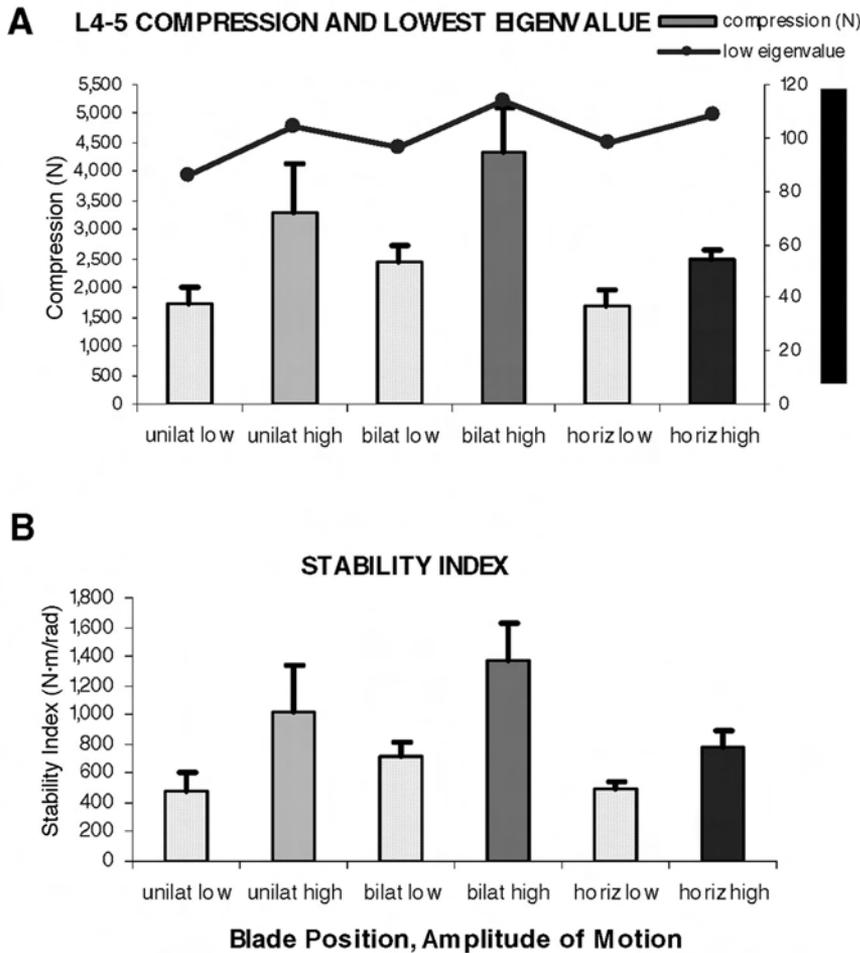
Figure 4.
(A) Average (±SD) L4–5 compression and the average lowest eigenvalue for 6 of the Bodyblade trials. (B) Average (±SD) stability index for the same trials. The lowest eigenvalue is indicative of unisegmental lumbar stability, whereas the stability index represents stability of the entire lumbar segment. Unilat=unilateral, bilat=bilateral, horiz=horizontal.

If perfect coordination were obtained, it would be expected that the ratio of right to left activity of either IO or EO would oscillate around a mean of 1, with activation levels being equal right to left. The right IO/left IO graph for subject 10 oscillated around a mean of 0.97, and the right EO/left EO graph oscillated around a mean of 0.71 (Fig. 5). Subject 2, however, again demonstrated greater variability in this ratio over the 4 seconds, but his IO ratio oscillated around a mean of 1.5 and his EO ratio oscillated around 0.5, indicating a tendency to be dominant in his right IO and left EO.

Figure 6 gives insight into the consequences that poor technique may have on spine stability. Here subject 2 is compared with a well-coordinated subject (subject 4) over a 15-second time line while performing 1-handed vertical-blade oscillations. Participants were asked to start with 3 seconds of quiet standing, followed by 5 seconds of low-amplitude oscillations, then approximately 5 seconds of high-amplitude oscillations. Subject 4 demonstrated 3 distinct regions, with an increase in measured force and spinal compression as the oscillation amplitude increased. His lowest eigenvalue

remained fairly constant around 100 N·m/rad. Subject 2, however, had much more variability in the force measured at the hand and blade interface. His lumbar compression changed little between the low- and high-amplitude oscillations, possibly indicating an inability to increase his trunk activation levels with high-amplitude oscillations. Of note are his lowest eigenvalues, which varied between 1.3 and 45.8 N·m/rad, indicating much less lumbar spine stability than the well-coordinated subject; in fact, he was bordering on potential buckling.

Discussion

The Bodyblade may or may not be a useful rehabilitation tool for improving spine stability. Training and coordination of the user appear to have a huge effect on the spine stability associated with its use. Because compression values vary greatly according to the position, amplitude, and coordination of the exercise, careful choice of these variables is necessary to optimize the benefits of the exercise, while protecting the underlying intervertebral structures.

Our first hypothesis was supported by the data: trunk muscle activation levels were comparable to, or in some cases greater than, those found in other spine stabilization exercises, when the blade was used in a vertical orientation and oscillating in a medial-lateral direction. These levels will vary, however, with the amplitude of oscillation. The IO activation levels of 52% MVIC were higher than most found in the exercise literature: unilateral activations of 57% MVIC with side-bridge exercises have been described, but these lowered to 43% MVIC when the right and left sides were averaged.[8] Bilaterally, abdominal curls[8] and press-ups[9] on a Swiss ball resulted in IO levels of 37% and 33% MVIC, respectively. The most challenging exercise—the 2-handed,

large-amplitude, vertical orientation—also required moderate co-contraction of all measured back muscles, averaging near 20% MVIC.

Previous research has shown more variability in activation levels, with bridge-style exercises resulting in average L5ES, T9ES, and L3ES activation levels of 23%, 8%, and 14% MVIC, respectively.[3] Four-point arm and leg lifts have been documented as producing lower mean ES levels, ranging from 13% to 34% MVIC.[8,9] Thus, it appears that vertical use of the Bodyblade results in relatively high activation levels of the oblique abdominal muscles, while simultaneously recruiting the ES and LD muscles to a moderate degree. This "hoop" architecture of muscles encircling the trunk helps to stabilize the spine.[6] Horizontal use of the Bodyblade tended to be the easiest of the oscillation patterns for most participants to master and shifted the focus of muscle activation to the upper back (LD and T9ES) and RA muscles (averaging 28%, 26%, and 16% MVIC, respectively). Previous reports in the literature claim that press-ups on a labile surface and abdominal curls both elicit approximately 31% MVIC of RA,[8,9] while abdominal curls on a Swiss ball resulted in 54% and 46% MVIC for lower and upper RA, respectively[10]; thus, any of these exercises would be preferable if specific RA strengthening is the goal. Diagonal path use of the Bodyblade also resulted in moderate amounts of co-contraction, despite the fact that this was a 1-handed, low-amplitude activity (Fig. 3), and could be useful for training the spine stabilizing muscles throughout a particular motion, as may be required in the workplace or in an athletic event.

The second hypothesis was partially supported by the data: at low amplitudes of oscillation, the L4–5 compressive loads associated with Body-
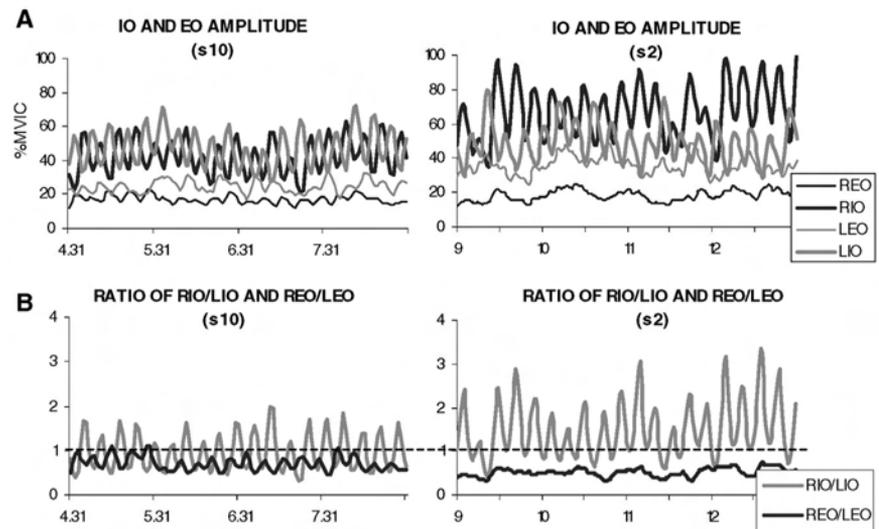
Figure 5.
(A) Amplitude of internal oblique (IO) and external oblique (EO) muscles over a 4-second time frame, comparing a well-coordinated subject (s10) with another subject who had great difficulty with coordination of the Bodyblade (s2). The subject with poorer coordination had more variability in the IO muscle activation levels, with the EO muscles exhibiting more in-phase behavior than the expected antiphase behavior. (B) Ratio of right (R) to left (L) muscle activation levels for the IO and EO muscles over the same 4 seconds. A dotted line is placed at "1," which the waveform should oscillate around if right and left muscles were activated to the same levels. %MVIC=percentage of maximal voluntary isometric contraction.

blade use were within an acceptable range, but they may become exceedingly high with large amplitudes of oscillation such that they would exceed the tolerance of many patients. From a rehabilitation perspective, the 4,328 N compression found with high-amplitude oscillations well exceeds the NIOSH action limit of 3,400 N.[11] In that this represents unusually high compression in the L4–5 vertebral segment, large-amplitude oscillations should be used with caution if there is measurable intolerance to compressive loading. Compression values associated with low-amplitude oscillations were in a preferable range, closer to 2,000 N, being less than those previously found in quiet sitting (2,853 N), bridging (2,864 N), or abdominal curls (3,422 N).[3]

Our third hypothesis also was supported by the results of this study: coordinated use of the Bodyblade

enhances instantaneous spine stability, as is shown by the increasing values of the stability index and eigenvalues. High-amplitude, vertical-blade exercises elicited a peak stability index as high as 1,363 N·m/rad, which at times was higher than those found with side-bridging (1,292 N·m/rad) or bridging (1,031 N·m/rad)[3]. Although there are few other studies with which to compare these stability numbers, previous authors[3,15,16] have reported that increasing levels of coordinated muscle activity result in an increase in instantaneous spine stability. However, the magnitude of the index cannot be interpreted in an absolute manner, only that a larger number indicates higher stability. Nonetheless, the near-zero values observed in the poorly coordinated subject is an indicator of buckling risk.[17] It therefore appears that using the Bodyblade in a coordinated manner poses minimal risk to spine stability. How-
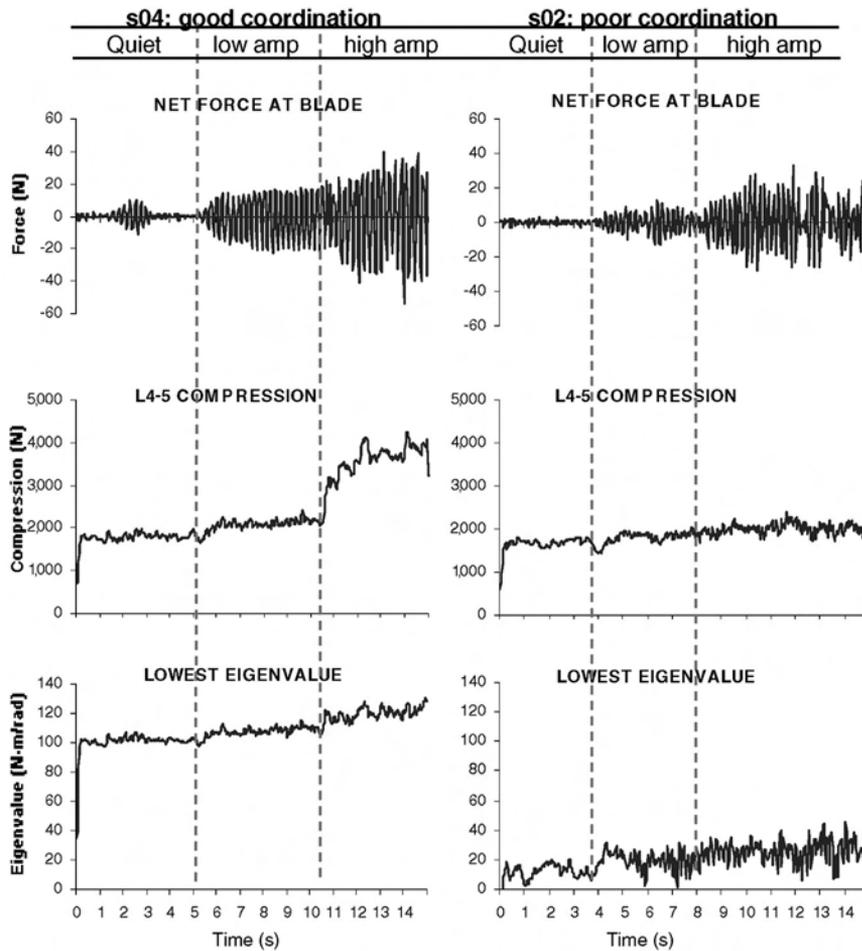
Figure 6.
A time line of 2 subjects: 1 well coordinated (s04) and 1 demonstrating poor coordination with the Bodyblade (s02) during a 1-handed, vertical orientation trial. Net force at the hand and blade interface, L4–5 compression, and the lowest eigenvalue are displayed for each subject. The first few seconds were to be quiet standing, the next 5 seconds were low-amplitude (low amp) oscillations, and the last segment was high-amplitude (high amp) oscillations.

ever, as the oscillation amplitude and stability increase, so do the L4–5 compressive forces, thus requiring judgment on the part of the therapist as to the preferred amplitude of oscillation. It is important to remember that subjects who have difficulty coordinating the Bodyblade may have a very small margin of safety regarding spine stability, given the instantaneous eigenvalues approaching 0 N·m/rad, as seen in subject 2 (Fig. 6). Therefore, large-amplitude oscillations should be used with caution until coordination is achieved.

Finally, given the results of this study, the fourth hypothesis also can be accepted: as discussed in the previous paragraphs, increasing the amplitude of the oscillations when using the Bodyblade significantly increased muscle activation levels, L4–5 compression, and instantaneous spine stability. Although amplitudes in this study were classified as "high or low," a continuum of amplitudes should be used in a clinical setting, with the cost-benefit ratio for each of the variables being carefully consid-

ered, based on the above-mentioned findings.

Several limitations exist as to the interpretation of data in this study. Because the computer model used to calculate stability and compression was written to accommodate a male body shape and size, all of our subjects were male, relatively fit, and from a university population. Consequently, the specific values of the compression and stability may be different for female or unfit male individuals. The use of mathematical modeling to calculate intervertebral loads and stability is based on well-accepted, validated protocols[18] and is a very useful tool for comparing these variables over different exercises and positions, because exact in vivo measurements are not possible. However, the numerical outcomes for stability should be considered in the context of relative amounts, not exact numbers. Finally, we cannot exclude the possibility of EMG crosstalk affecting our EMG signals, especially in the oblique muscles, which lie atop each other in the anterior abdomen. Every precaution was taken, however, to ensure clear representation of each individual muscle, based on recommended electrode sites as determined in previous studies.[12,19]

This study analyzed a few specific upright exercises, which are aimed at spine stabilization. Future studies should consider use of the Bodyblade in other orientations, such as 3-point kneeling or unsupported sitting, to test the effect that changing the body's position has on muscle recruitment, spine stability, and lumbar compression. In addition, the resultant shear forces in the spine should be determined with these varying positions, to better enable clinicians to choose positions and amplitudes of exercise most appropriate for their patients.

Conclusions

Depending upon the orientation, amplitude of oscillation, and specific technique, use of the Bodyblade may either enhance or compromise spine stability. Associated lumbar compressive forces may be inappropriate for some people with compressive intolerant lumbar spine pathology. However, specific techniques appear to be very effective for recruiting the entire abdominal wall, LD, and ES, all important spine stabilizers. Finally, it is not simply a matter of "doing the exercise" with the Bodyblade. It is a matter of doing the exercise in a way that grooves symmetrical stiffness and coordinated muscle activation patterns, with minimal hand and torso motion, that enhances spine stability.

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