Muscle utilization patterns vary by skill levels of the practitioners across specific yoga poses (asanas)

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KEYWORDS
Electromyography; Yoga pose; Asana

Summary
Objective: To compare muscle activation patterns in 14 dominant side muscles during different yoga poses across three skill levels.
Design: Mixed repeated-measures descriptive study.
Setting: University neuromuscular research laboratory, Miami, US.
Participants: A group of 36 yoga practitioners (9 M/27 F; mean ± SD, 31.6 ± 12.6 years) with at least 3 months yoga practice experience.
Interventions: Each of the 11 surya namaskar poses A and B was performed separately for 15 s and the surface electromyography for 14 muscles were recorded.
Main outcome measures: Normalized root mean square of the electromyographic signal (Nrm- sEMG) for 14 muscles (5 upper body, 4 trunk, 5 lower body).
Results: There were significant main effects of pose for all fourteen muscles except middle trapezius (p < .02) and of skill level for the vastus medialis; p = .027. A significant skill level × pose interaction existed for five muscles (pectoralis major sternal head, anterior deltoid, medial deltoid, upper rectus abdominis and gastrocnemius lateralis; p < .05). Post hoc analyses using Bonferroni comparisons indicated that different poses activated specific muscle groups; however, this varied by skill level.
Conclusion: Our results indicate that different poses can produce specific muscle activation patterns which may vary due to practitioners’ skill levels. This information can be used in designing rehabilitation and training programs and for cuing during yoga training.
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List of abbreviations

<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>EMG</td>
<td>electromyography</td>
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<tr>
<td>MVC</td>
<td>maximal voluntary contractions</td>
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<tr>
<td>NrmSEMG</td>
<td>normalized root mean square EMG</td>
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<td>Muscles</td>
<td></td>
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<tr>
<td>PECS</td>
<td>pectoralis major sternal head</td>
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<tr>
<td>DeltaANT</td>
<td>anterior deltoid</td>
</tr>
<tr>
<td>DeltaMED</td>
<td>medial deltoid</td>
</tr>
<tr>
<td>BB</td>
<td>biceps brachii</td>
</tr>
<tr>
<td>Tri</td>
<td>triceps brachii</td>
</tr>
<tr>
<td>TRAPUP</td>
<td>upper trapezius</td>
</tr>
<tr>
<td>TRAPMID</td>
<td>middle trapezius</td>
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<tr>
<td>RAM</td>
<td>rectus abdominis</td>
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<tr>
<td>ES</td>
<td>erector spinae</td>
</tr>
<tr>
<td>RF</td>
<td>rectus femoris</td>
</tr>
<tr>
<td>VM</td>
<td>vastus medialis</td>
</tr>
<tr>
<td>BF</td>
<td>biceps femoris</td>
</tr>
<tr>
<td>GastrocLAT</td>
<td>gastrocnemius lateralis</td>
</tr>
<tr>
<td>TA</td>
<td>tibialis anterior</td>
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Introduction

Yoga, originated in ancient India, integrates physical, mental, emotional, and spiritual dimensions to improve the holistic health. The benefits of yoga include: increased muscle strength and endurance,1-6 muscle power,7 anaerobic power,8 flexibility,9,10 balance and coordination,11,12 and pain attenuation.9,10 However, yoga is not without its detractors. Critics have argued that several poses may go beyond some practitioners’ capabilities and produce negative consequences, such as muscle strains and ligament rupture.11

Yoga postures comprise basic elements such as standing, sitting, forward and backbends, twists, inversions and lying. Each pose is expected to activate specific muscles. To our knowledge, only one study12 has examined muscle utilization patterns during specific yoga poses and no studies have quantified variations in muscle activity as practitioners’ skill levels evolve with practice. As yoga becomes more popular around the globe, understanding these factors may reduce injuries, provide guidelines for improved progression and cueing, and allow the design of pose sequences which can target needs related to specific sports, special populations and rehabilitation programs.

The purpose of this study was to quantify differences in muscle activity during different yoga poses by novices (NOV), advanced practitioners (ADV) and instructors (INST). Results can help yoga instructors choose appropriate postures based on students’ skill and fitness levels, allow practitioners to modify their practice to match their needs and capacities, and provide critical data for prevention and rehabilitation programs designed to treat the needs of athletes, the general community, and special populations.

Methods

Participants

Thirty-six Baptiste yoga practitioners using Vinyasa style participated in the study (9 men, 27 women; mean age ±SD, 31.6 ±12.6 years). Subjects were recruited through flyers and personal contacts at yoga studios and wellness centers. To be included in the study an individual must fall into one of three categories: NOV having practiced for 3–12 months; ADV who had practiced more than 3 years; or INST who possessed a yoga instructor certification. Additionally, subjects must have participated in yoga training for 1—1.5 h at least once per week for at least three months, must not have participated regularly in any other exercise program, and must have been capable of completing the study’s yoga sequence without assistance. Individuals with musculoskeletal and neurological impairments or unresolved injuries were excluded from study participation. Participants were informed of experimental procedures and completed a written consent approved by the University’s Subcommittee for the Use and Protection of Human Subjects. Participants’ characteristics are presented in Table 1. A power analysis using an effect size of 0.25, α of 5% and power of 95%, yielded a minimal sample size of 27.

Procedures

Participants arrived at the laboratory and completed the consent form and health questionnaire. They then warmed-up using surya namaskar (sun salutation) A three times and surya namaskar B twice at a self-determined pace. Next, electrodes were placed on the skin over the muscles of interest on participants’ dominant side (32 right-handed/4 left-handed). Fourteen muscles were randomly evaluated on two separate days. Surface electromyography (EMG) data were normalized across subjects and collection days, using EMG results from 3 s maximal voluntary contractions (MVC) targeting each muscle. Following preparation and normalization, each subject performed 11 Sun salutation poses (Fig. 1) maintaining each for 15 s. The pose sequences were randomized for each subject using a random number generator (Microsoft Excel, 2010; Microsoft Corp. Redmond, WA). Each pose was digitally recorded and evaluated by an independent group of yoga instructors blinded to the subjects’ skill level assignments, to confirm each subject’s skill level classification. Subjects were asked to avoid doing intensive

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Skill levels of the practitioners

<table>
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<tr>
<th>Characteristic</th>
<th>Sample</th>
<th>NOV</th>
<th>ADV</th>
<th>INST</th>
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<tbody>
<tr>
<td>N</td>
<td>36</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Gender (F/M)</td>
<td>27/9</td>
<td>8/4</td>
<td>11/1</td>
<td>8/4</td>
</tr>
<tr>
<td>Age (years)</td>
<td>31.6 ± 12.6</td>
<td>24.7 ± 2.7</td>
<td>36.3 ± 18.1</td>
<td>34.0 ± 9.4</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.66 ± 0.07</td>
<td>1.68 ± 0.07</td>
<td>1.66 ± 0.07</td>
<td>1.65 ± 0.08</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>60.7 ± 7.1</td>
<td>63.4 ± 6.5</td>
<td>57.8 ± 6.7</td>
<td>61.0 ± 7.6</td>
</tr>
<tr>
<td>Time practicing yoga (years)</td>
<td>5.53 ± 6.62</td>
<td>.45 ± .27</td>
<td>4.82 ± 2.22</td>
<td>10.87 ± 8.35</td>
</tr>
</tbody>
</table>

**Table 1** Demographics characteristics of the participants by skill levels (mean ± SD).

Fig. 1 The poses of sun salutation sequence. (a) Chair; (b) downward facing dog; (c) halfway lift; (d) forward fold; (e) high plank; (f) low plank; (g) mountain pose with arms up; (h) mountain pose with arms down; (i) upward facing dog; (j) Non-dominant side warrior 1 pose; (k) Dominant side warrior 1 pose. For detailed descriptions of each pose see the Yoga Journal Website at http://www.yogajournal.com/poses/finder/browse.

exercise 24 h before the tests. During the test, they were told to exert their maximal effort and perform each pose to the best of their abilities.

**EMG measurement procedures**

The location of the electrodes for each muscle was determined using anatomical landmarks.\(^{13}\) The skin surface at each site was shaved, rubbed with light abrasive paper, and cleansed with alcohol to remove dead surface tissues and oil that might reduce conductivity. Disposable bipolar electrodes (Noraxon USA, Scottsdale, AZ) were then positioned parallel to the underlying muscle fibers, as determined by the muscles’ pennations.

Raw EMG signals were recorded using a wireless EMG telemetry system (BTS Bioengineering, Milano, Italy), and the quality of each muscles’ signal was examined visually throughout the data collection. The gain was set at 2,000 with band-pass filtering set between 1 and 500 Hz.\(^{13}\) Signals were sampled at a speed of 1,000 Hz, digitized using a 16-bit A/D converter, amplified (gain = 2000, CMRR > 110 dB at 50–60 Hz), and stored on a laboratory computer.

**EMG data analysis**

EMG signals from each muscle were analyzed using dedicated Labview Software\(^{®}\) (National Instruments, Austin, TX). The root mean square of the EMG signal (rmsEMG)
collected from the third to thirteenth second of the 15s pose period was used as a measure of average muscle activity for each muscle during that pose. Data were normalized (NrmsEMG) using the rmsEMG values collected during the middle 3s of each 5s MVC. MVCs were repeated three times for each muscle, with an intervening 30s passive recovery. The activities for obtaining the MVC for each muscle were established in previous studies: biceps brachii (BB), triceps brachii (Tri), anterior deltoid (DelANT), medial deltoid (DelMed), pectoralis major sternal head (PECM), upper trapezius (TRAPUP), middle trapezius (TRAPMD), erector spinae (ES), upper rectus abdominis (RAMUP), recus femoris (RF), vastus medialis (VM), biceps femoris (RF), gastrocnemius lateralis (Gastroc_LAT) and tibialis anterior (TA).

Statistical analyses

Data were assessed using a 3 (skill level) x 11 (pose) repeated-measures ANOVA for each muscle of the 11 poses. These analyses were designed to examine how differences in skill level and pose affected muscle utilization patterns. When significant main effects or interactions were detected, Bonferroni post hoc tests were used to determine the sources. Threshold significance was set at p < 0.05.

Results

Group demographics

No significant differences were detected across groups for any demographic characteristic with the exception of the time practicing yoga.

Main effect of pose

Significant main effects of pose were detected for all 14 muscles except the TRAPMD (Table 2), three showed significant main effects by skill level, and five showed significant pose by skill level interactions.

Upper body muscles

The TRAPUP post hoc analysis revealed significantly higher NrmsEMG values for Chr, DogDOWN and WarDOM compared to FFold and HLift (p < .003). Post hoc analyses for the BB showed significantly higher NrmsEMG values for Chr than all other poses except PinKhi, PinKLOW and DogUP (p < .043). The Tri showed significantly higher values for PinKLOW than all other poses except Chr, WarNON-DOM and WarDOM (p < .001) and for PinKhi and DogUP compared to HLift and MntDOWN (p < .021).

Core muscles

Post hoc analysis for the ES showed significantly higher NrmsEMG values for Chr, HLift, DogUP, WarNON-DOM and WarDOM than DoBDOWN, FFold and MntUP (p < .016).

Lower body muscles

The RF showed significantly higher NrmsEMG values for Chr, DoBDOWN, PinKhi and WarDOM compared to FFold (p < .022), and for DogUP and WarDOM compared to HLift (p < .039). PinKLOW and WarNON-DOM showed significantly higher NrmsEMG values than all other poses except PinKhi, DogUP and WarDOM (p < .001). The BF produced significantly higher values for Chr, PinKhi, PinKLOW, DogUP, WarNON-DOM and WarDOM than FFold (p < .032). Finally, the TA showed significantly higher NrmsEMG for Chr, DoBDOWN, PinKhi, PinKLOW and WarDOM compared to FFold and MntDOWN (p < .047), and for WarNON-DOM compared to all other poses except Chr, DoBDOWN and WarDOM (p < .043).

Main effect of skill level

A significant main effect of group was detected only in VM (p = .027; Fig. 2). Post hoc analysis revealed significantly higher NrmsEMG for INST compared to NOV.

Table 2: Significant main effects of pose in muscles without pose x skill level interaction in NrmsEMG.

<table>
<thead>
<tr>
<th></th>
<th>TRAPUP</th>
<th>TRAPMD</th>
<th>BB</th>
<th>Tri</th>
<th>ES</th>
<th>RF</th>
<th>BF</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chr</td>
<td>.976 ± .268</td>
<td>.463 ± .133</td>
<td>.292 ± .044</td>
<td>.366 ± .070</td>
<td>.320 ± .039</td>
<td>.360 ± .053</td>
<td>.182 ± .029</td>
<td>.591 ± .138</td>
</tr>
<tr>
<td>DogDOWN</td>
<td>.822 ± .193</td>
<td>.645 ± .319</td>
<td>.095 ± .019</td>
<td>.323 ± .039</td>
<td>.123 ± .023</td>
<td>.209 ± .027</td>
<td>.136 ± .022</td>
<td>.260 ± .049</td>
</tr>
<tr>
<td>FFold</td>
<td>.280 ± .047</td>
<td>.616 ± .450</td>
<td>.084 ± .029</td>
<td>.177 ± .069</td>
<td>.057 ± .011</td>
<td>.119 ± .018</td>
<td>.093 ± .012</td>
<td>.064 ± .008</td>
</tr>
<tr>
<td>HLift</td>
<td>.146 ± .030</td>
<td>.198 ± .043</td>
<td>.030 ± .009</td>
<td>.148 ± .035</td>
<td>.288 ± .027</td>
<td>.158 ± .014</td>
<td>.128 ± .021</td>
<td>.122 ± .024</td>
</tr>
<tr>
<td>PinKhi</td>
<td>.344 ± .082</td>
<td>.229 ± .055</td>
<td>.134 ± .048</td>
<td>.373 ± .037</td>
<td>.143 ± .069</td>
<td>.566 ± .117</td>
<td>.170 ± .025</td>
<td>.184 ± .023</td>
</tr>
<tr>
<td>PinKLOW</td>
<td>.786 ± .140</td>
<td>.575 ± .146</td>
<td>.151 ± .032</td>
<td>.741 ± .076</td>
<td>.258 ± .088</td>
<td>.719 ± .124</td>
<td>.205 ± .031</td>
<td>.159 ± .027</td>
</tr>
<tr>
<td>MntDOWN</td>
<td>.301 ± .101</td>
<td>.255 ± .060</td>
<td>.023 ± .008</td>
<td>.294 ± .010</td>
<td>.165 ± .016</td>
<td>.389 ± .144</td>
<td>.103 ± .014</td>
<td>.111 ± .020</td>
</tr>
<tr>
<td>MntUP</td>
<td>.842 ± .242</td>
<td>.405 ± .113</td>
<td>.117 ± .042</td>
<td>.294 ± .088</td>
<td>.094 ± .020</td>
<td>.237 ± .085</td>
<td>.159 ± .028</td>
<td>.129 ± .027</td>
</tr>
<tr>
<td>DogUP</td>
<td>.567 ± .168</td>
<td>.939 ± .445</td>
<td>.117 ± .042</td>
<td>.408 ± .061</td>
<td>.337 ± .058</td>
<td>.566 ± .133</td>
<td>.234 ± .038</td>
<td>.142 ± .022</td>
</tr>
<tr>
<td>WarNON-DOM</td>
<td>.801 ± .233</td>
<td>.352 ± .125</td>
<td>.137 ± .034</td>
<td>.344 ± .135</td>
<td>.212 ± .030</td>
<td>.576 ± .123</td>
<td>.284 ± .046</td>
<td>.481 ± .082</td>
</tr>
<tr>
<td>WarDOM</td>
<td>.926 ± .257</td>
<td>.641 ± .203</td>
<td>.105 ± .024</td>
<td>.394 ± .105</td>
<td>.244 ± .036</td>
<td>.470 ± .090</td>
<td>.224 ± .036</td>
<td>.282 ± .042</td>
</tr>
</tbody>
</table>

Values are mean ± SE.

*Significance level (p < .05). TRAPUP, upper trapezius; TRAPMD, middle trapezius; BB, biceps brachii; Tri, triceps brachii; ES, erector spinae; RF, rectus femoris; BF, biceps femoris; TA, tibialis anterior; Chr, chair; DoBDOWN, downward facing dog; DogUP, upward facing dog; FFold, forward fold; HLift, halflift; MntDOWN, mountain pose, arms down; MntUP, mountain pose, arms up; PinKhi, high plank; PinKLOW, low plank; WarNON-DOM, non-dominant side warrior 1 pose; WarDOM, dominant side warrior 1 pose.
Pose by skill level interactions

The 3 (skill level) × 11 (pose) ANOVA showed significant skill level × pose interactions for the PECS \(p = .030\), Delt\textsubscript{ANT} \(p = .011\), Delt\textsubscript{MED} \(p = .004\), RAM\textsubscript{UP} \(p = .030\), and Gastroc\textsubscript{LAT} \(p = .011\).

Upper body muscles
Post hoc analyses revealed significant differences among skill levels for each pose. For the PECS (Fig. 3a), NOV generated higher NrmsEMG INST in the Chr. For the Delt\textsubscript{ANT} (Fig. 3b), the values for INST were higher than NOV for FFold and War\textsubscript{DOM}. For the Delt\textsubscript{MED} (Fig. 3c), Chr and FFold produced higher NrmsEMG for INST than ADV and NOV, and for Dog\textsubscript{DOWN}, War\textsubscript{NON-DOM} and War\textsubscript{DOM}, values were higher for INST than for NOV.

Core muscles
For the RAM\textsubscript{UP} (Fig. 4a), although there was a significant interaction, post hoc comparisons revealed no significant differences.

Lower body muscles
For the Gastroc\textsubscript{LAT} (Fig. 4b), HLift and War\textsubscript{DOM} produced higher NrmsEMG for INST than NOV and ADV.

Discussion

The principle finding of this study was that different muscle groups can be targeted using specific yoga poses and activation levels are affected by skill levels.

Effect of pose

The targeting of the TRAP\textsubscript{UP} by Chr, Mnt\textsubscript{UP} and War\textsubscript{DOM} can be attributed to the flexing and external rotation of the shoulder and retraction of the scapula during these poses. The most effective exercise for targeting the TRAP\textsubscript{UP} is the shoulder shrug.\(^1\) Our results indicate activity levels of the TRAP\textsubscript{UP} during Chr, Mnt\textsubscript{UP} and War\textsubscript{DOM} poses (84.2–97.6% MVC) rivalled that reported for the shrug using external loading (119% MVC). The increased NrmsEMG during these poses without external loading allows improved performance while reducing injury potential during training progression.\(^1\)

The TRAP\textsubscript{MD}, Dog\textsubscript{UP}, where the shoulders retract with cervical extension, may be an effective strengthening exercise given its activation level (92.3% ± 44.6% MVC). Supporting the weight of the upper body and against the tonus of the

Fig. 2 Main effect of skill level for muscles where no skill level × pose interaction was detected. *Instructor significantly different than novice \((p < .049)\).

Fig. 3 Significant interaction between pose and skill level for the (a) pectoralis major sternal head; (b) anterior deltoid; (c) medial deltoid. *Instructor significantly different than novice. **Instructor significantly different than advanced and novice \((p < .05)\).
chest and abdominal muscles requires considerable activation of the TRAPmid. This pose offers an alternative to resistance training and is especially important for persons whose jobs require prolonged computer use or individuals whose postures are negatively affected by neuromuscular injury.

The PlnkLOW pose can effectively target Tri, since the Tri lifts the chest from the floor and stabilizes the elbows. Other poses where the arms supported a high percentage of body weight (PlnkHIGH, DogUP) the Tri activity levels were also higher than other poses. Our results showing an activity level of 74.1% MVC, compare favorably to those reported for the dangerous one-arm (78.7% MVC) and plyometric clapping (88.6% MVC) push-ups.

Activation levels of the ES were low for all poses with a relatively higher activity for the poses requiring trunk extension (Chr, HLift, DogUP) compared to neutral position or forward flexion (DogDOWN, FFold and MntUP). The RAMUP activity was similar to ES, most likely due to its co-contraction during stabilization of the spine.

For the RF, PlnkHIGH, PlnkLOW, DogUP and WarNON-DOM were effective activators and BF activation patterns, though low, mirrored those seen for the RF. This suggests a co-activation of knee extensors and flexors, as subjects held these poses and may offer a less stressful alternative for addressing anterior cruciate ligament (ACL) deficiencies while reducing the risk of ligamentous damage.

The Chr and WarNON-DOM targeted the TA, the dorsiflexor associated with fall probability in older adults. It is also a major muscle targeted during ankle rehabilitation following injury and is typically strengthened in programs designed to reduce ankle sprains and other injuries related to poor ankle stability. In the Chr, the dominant knee and hip are flexed as the toes lifted. This strengthens the TA and reduces the pressure on the metatarsals. Strengthening the TA and increasing dynamic range during dorsiflexion allows uniform weight distribution over the hallux during weight bearing. Reduction in plantar pressure is currently a therapeutic goal for reducing pain and tissue damage. Because the dominant side knee is fully extended with the foot flat on the floor, the co-contraction of the ankle musculature during this pose may also improve ankle stability.

Effect of skill level

Significant differences in VM activation were seen by skill levels (Fig. 2). Higher activation for INST versus ADV and NOV; therefore, ADV and NOV should concentrate on engaging this muscle during all sun salutation poses. Attention to the VM during these poses will increase the training effect on the lower body musculature. Cuing students to contract these muscles during support poses such as the PlnkLOW, PlnkHIGH, DogUP, and DogDOWN, will provide more balanced force distribution between the core and lower body. Additionally, weakness of the VM and strength imbalances between the VM and vastus lateralis (VL) are underlying mechanism for patellofemoral pain. The Chr and PlnkLOW can target the VM and potentially help correct VM/VL imbalances. VM activation patterns during the PlnkHIGH and PlnkLOW were also affected by skill level. INST and ADV demonstrated increased VM activities indicating better force distribution across upper, core and lower body musculature during arm-support poses.

Pose and skill level interactions

The interactions seen between pose and skill level for the PEC provide guidelines for using selected poses to target specific muscle groups at different skill levels. The analyses also expose neuromuscular inadequacies or ineffective recruitment strategies in less experienced practitioners, allowing guidelines for targeted cuing as practitioners’ skill and fitness levels increase.

For the Chr, NOV produced higher activity than INST for the PEC, indicating that NOV PEC are weaker or have lower localized endurance than INST since increases in mean amplitude are common marker of increased recruitment due to lower specific muscle force or fatigue during submaximal isometric contractions. Yoga teachers can use this information to correct NOV posture during this pose.
The Del_TA, NrmSEMG (Fig. 3b) for INST during the War_DOM and FFold were significantly higher than for NOV. For the War_DOM pose, reflects INST tendency to incorporate more shoulder flexion, abduction and external rotation than NOV. For the FFold, INST activate the Del_TA draw the torso deeper and increase flexibility in the lower back and hamstring, as the trunk bends deeply forward accomplished in part by the Del_TA bringing the arms forward in coordination with the core and lower body musculature. The Chr and FFold were effective activators of the Del_MED (Fig. 3c); however, only for INST and ADV. This selective benefit for INST and ADV also held true for the Dog_DOWN, War_DOM and War_DOM. The Del_MED is a synergist for Del_TA during poses requiring shoulder flexion and horizontal abduction, such as Chr, FFold, War_DOM and War_DOM. The high NrmSEMG of the Del_MED for INST during the Dog_DOWN is likely due to its function as a stabilizer. The low activation levels for NOV may indicate an inability to effectively activate this muscle which may lead to shoulder injuries if these poses are offered at too high a volume early in yogic training.

The trunk muscles are crucial for transferring force from the lower to upper body and reducing lower back pain. For training the RAM_UP (Fig. 4a), the PInK_Ht is the most effective pose, however, activation levels are modest (27% MVC). The trend toward NOV producing greater activity than ADV and INST during post hoc analysis for the Chr, may be attributed to greater lumbar flexion rather than extension in the NOV compared with INST. Based on these findings, yoga instructors can provide specific cues for practitioners to concentrate on lower back extension.

For the Gastroc_LAT (Fig. 4b), INST generated higher NrmSEMG in the HLIFT and War_DOM than NOV and ADV. This is needed for ankle stabilization during forward bends and lunges. In the War_DOM, the dominant front knee is bent; the foot is flat with ankle joint at 90°. The greater activity by INST allows enhanced forward position and deeper knee flexion.

In Chr, FFold, PInk_LOW, HLIFT, Dog_DOWN, War_DOM and War_DOM which produced significant pose x skill interactions, INST generated higher NrmSEMG than NOV, and the Del_MED and Gastroc_LAT than NOV and ADV. This indicates that these poses present greater neuromuscular challenges for less skilled or conditioned practitioners compared to other poses in the sun salutation sequences. This implies that program modifications allowing longer adaptation periods for these poses than less challenging poses. Yoga teachers may modify the poses sequences, placing a series of lower intensity poses between these poses allowing greater recovery so students can achieve proper performance.

Our results provide information that muscle activation levels vary during different poses and are affected by practitioners’ skill levels. Although subjects were asked to exert maximal efforts during each pose, this could not be guaranteed. Differences in skill level may have affected joint angle and muscle length and therefore muscle activation levels. Cresswell et al. suggest that decreases in NrmSEMG may be due to a reduced central drive to the shortened muscle via impaired neuromuscular transmission, or via reduction in neuromuscular facilitation of the motoneuron pool. For example, increased knee flexion and decreased muscle length could increase NrmSEMG in the gastrocnemius. Both kinetics and kinematics should be employed in future studies to examine the biomechanics underlying our electromyographic analyses. We also suggest that EMG frequency analyses using wavelets be used to assess fiber recruitment patterns and fatigue levels across sequences among yoga practitioners with different skill and fitness levels.

Conclusion

Understanding the differences in muscle utilization patterns across skill levels can help instructors focus students’ attention on proper alignment during specific poses and help the instructor to understand the muscle weakness profiles that may be delaying students’ progress and increasing injury potential. Additionally, intervention programs for prevention and rehabilitation of musculoskeletal injuries, improving neuromuscular performance specific to different sports or disease states, and improving strength, posture and balance in specific populations such as older individuals or persons with chronic joint instability can be designed based on our findings. Finally it is our hope that these results will provide information which allows more effective program design enabling greater progress and more effective interventions across fitness levels for populations ranging from athletes to persons with specific disabilities or disease states.

Conflict of interest

The authors confirm that there are no known conflicts of interest.

Acknowledgement

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References


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