Ultrasound Imaging as a Feedback Tool in the Rehabilitation of Trunk Muscle Dysfunction for People With Low Back Pain

Biofeedback training has been used in a variety of applications, including the treatment of different conditions (e.g., hypertension, drug dependency, bruxism, pain, fatigue, migraine, and tension headaches) and the improvement of performance (flexibility, sports performance, relaxation, meditation), with varying degrees of effectiveness. This commentary will discuss the use of rehabilitative ultrasound imaging (RUSI) as a biofeedback tool for enhancing motor performance and motor learning of selected trunk muscles in individuals with low back pain (LBP).

Biofeedback refers to external psycho-physiological, physiological, or augmented proprioceptive feedback that is used to increase an individual’s cognition of what is occurring physiologically in the body. Although definitions of biofeedback vary, the authors have used the following definition from Blanchard and Epstein, who state that biofeedback is “a process in which a person learns to reliably influence physiological responses of 2 kinds: either responses which are not ordinarily under voluntary control or responses which ordinarily are easily regulated but for which regulation has broken down secondary to trauma, disease, or injury.”

Using the above definition, there are 2 main goals for biofeedback training of the musculoskeletal system. One is to allow the central nervous system to re-establish appropriate sensory-motor loops under volitional control that may have been damaged by injury, disease, or surgery. In the context of this review, the goal of biofeedback would be to enhance the ability of an individual with LBP to preferentially activate trunk muscles, in particular, the transversus abdominis (TrA) and internal oblique (IO) muscles, during an abdominal drawing-in maneuver (ADIM) as well as the lumbar multifidus muscle during an isometric contraction. The second goal of biofeedback training is to assist in the development of greater cognitive awareness of confidence in, and increased volitional control over, a physiological process that has been previously considered “involuntary” or beyond the conscious awareness, such as activation of single motor units, volitional control over smooth muscles, or synergistic patterns of muscle activation. In the context of motor learning, increasing awareness of, as well as improving volitional control and preferential activation of, the deep trunk muscles for individuals with LBP may be an appropriate application of biofeedback training.

The ADIM is often the first exercise taught in a segmental stabilization exercise progression with the aim of teaching the individual to preferentially activate the deeper trunk muscles, in particular TrA and IO muscles without activating the more superficial abdominal or back muscles (external oblique, rectus abdominis, or erector spinae muscles). Teaching preferential activation of the lumbar multifidus muscles is also a key

SYNOPSIS: This commentary provides an overview of the current concepts and the emerging evidence related to rehabilitative ultrasound imaging (RUSI) for biofeedback purposes. Specifically, the role of RUSI to assess improvements in trunk muscle performance and motor learning will be discussed, highlighting the importance of retention and transfer testing to assess motor learning. The use of RUSI as an extrinsic (augmented) feedback tool and its ability to provide both knowledge of performance and knowledge of results information will be defined. An analysis of the limited available literature related to the role of RUSI as an augmented feedback tool to enhance motor skill acquisition related to the deep trunk muscles will be provided. Future research directions and priorities are recommended.

KEY WORDS: motor control, multifidus, therapeutic exercise, transversus abdominis

1Associate Professor, Department of Rehabilitation and Movement Science, The University of Vermont, Burlington, VT. 2Assistant Professor and Director, Center for Physical Therapy Research, US Army-Baylor University Doctoral Program in Physical Therapy, San Antonio, TX. Research Consultant, Spine Research Center and Defense Spinal Cord Column and Injury Center, Walter Reed Army Medical Center, Washington, DC. The opinions or assertions contained here in are the private views of the authors and are not to be construed as official or as reflecting the views of the Departments of the Army or Defense. Address correspondence to Dr Sharon M. Henry, Department of Rehabilitation and Movement Science, 305 Rowell Building, 106 Carrigan Drive, The University of Vermont, Burlington, VT 05405-0068. E-mail: Sharon.Henry@uvm.edu
component of a segmental stabilization program. Preferentially activating the anterior lateral abdominal and lumbar multifidus muscles appears to be particularly difficult for people with LBP and those injected with a hypertonic saline solution to experimentally induce pain.

Consequently, researchers and clinicians have begun using RUSI during exercise to provide visual biofeedback to individuals with LBP about the amount of thickening of the anterolateral abdominal muscle layers as well as the lumbar multifidus muscle, with the goal of enhancing mastery of the ADIM and lumbar multifidus muscle performance. However, the examination of the appropriateness of using RUSI as a biofeedback tool for this purpose and the determination of which subgroups of patients with LBP that would most benefit have just begun.

We will briefly discuss motor learning versus performance and how motor learning is assessed. Studies using RUSI as a means to provide visual biofeedback to enhance selective activation of deep trunk muscles will be analyzed, and the limitations of, and potential future research directions for, this biofeedback tool will be discussed. In the context of motor learning, a discussion about the use of biofeedback to improve performance should include information about the stages of learning, the types of feedback, when they should ideally be used, as well as the transfer of learning. However, space constraints limit the inclusion of this information. The reader is referred to Magill for an overview of this topic.

**Motor Learning Versus Motor Performance**

According to Magill, it is important to distinguish performance from learning. Performance has been defined as an observable behavior or the execution of a specific skill. In contrast, learning cannot be observed directly but is inferred based on the person’s performance of the skill during a retention or transfer test, during which the permanence of change in performance was determined. To claim that an individual has learned a skill following practice of that skill, an individual must be able to demonstrate a relatively permanent improvement in an observable behavior (performance) during a retention or transfer test conducted without feedback. In the context of this commentary, the improvement and retention of performance during the ADIM and the preferential activation of the multifidus muscle are of interest.

Improvement, consistency, stability, persistence, and adaptability are observable aspects of motor performance used to characterize skill acquisition. Improvement has been defined as behavior that is advancing over time, whereas consistency has been defined as performance of the skill that is becoming more reliable. Further, stability of performance should increase with learning such that internal (eg, anxiety) or external (environmental context) variables do not alter the skill performance. Persistence refers to the person’s ability to maintain the improved performance over a longer period of time (in the absence of biofeedback) and adaptability reflects the person’s ability to exhibit the skill in different performance contexts. Persistence and adaptability can be assessed with retention and transfer tasks, respectively.

**How is Motor Learning Assessed Experimentally?**

Motor learning has been assessed by observing practice performance during retention tests (looking for the persistence characteristic) or transfer tests (looking at adaptability). To determine if an individual has learned the motor task, feedback should not be provided during either the retention or transfer tests. To date, RUSI has been used to assess performance of the ADIM, as reflected in an observable thickening and lateral movement of the TrA muscle with minimal thickening of the IO muscle. In addition, RUSI has been used to assess performance of preferential multifidus muscle activation by acquiring a parasagittal view of the muscle and examining changes in muscle thickness. In these studies, learning has typically been assessed through retention tests provided 2 to 7 days after the initial training session, but learning could also be assessed through transfer tests. An example of a transfer test would be if the person could perform the ADIM in a new context, such as in sitting or while walking after the individual had learned the skill in supine hook lying, or if the person was able to preferentially contract the lumbar multifidus muscle during a functional task such as walking, squatting, or lifting.

**Feedback to Enhance Motor Performance and Motor Learning**

Feedback has been defined as any sensory information that is available to an individual during or after production of a movement. The timing and mode of feedback, as well as the stage of learning during which feedback is provided, affect the success of learning and impact the effectiveness of the feedback provided to promote motor learning. When considering feedback, the characteristics of the skill being learned and that of the learner also must be taken into account. A brief overview about some parameters of extrinsic feedback is given for the purposes of providing a framework for critiquing the existing literature about the use of RUSI in people with LBP. The reader is directed to several textbooks that provide a review of extrinsic feedback and the parameters of feedback that can be manipulated to influence motor performance and motor learning.

**Types of Feedback: Intrinsic Versus Extrinsic**

There are 2 broad types of feedback, intrinsic (via sensory systems within the
body) and extrinsic (augmented), which is supplemental feedback about the movement in addition to what was provided through intrinsic feedback. Typical types of augmented feedback used for improving motor performance include auditory, visual, verbal, and somatosensory. Augmented sensory feedback has been shown to facilitate muscle activation during the early stages of learning.47,28 Augmented somatosensory feedback for the anterolateral abdominal or the multifidus muscles has been described as static palpation or tapping by the physical therapist over the individual’s anterolateral muscle(s), both during and after an attempted ADIM.34 Alternatively, augmented somatosensory feedback has also been described by having the individual palpate his or her own muscle during an attempted contraction when feasible.34

Augmented feedback has been further subdivided into 2 broad categories of feedback: knowledge of results (KR) and knowledge of performance (KP). KR has been defined as presenting information to the learner about the outcome of the task or about the achievement of the goal, including information about the magnitude and direction of the error.22 An example of KR for preferential activation of the multifidus muscle would be to tell the individual the number of millimeters the muscle thickness increased during a preferential contraction.47 In contrast, KP is more related to information about the movement characteristics that contributed to a particular performance outcome.21 Having an individual watch the RUSI video in real-time or showing a video replay are 2 common and time-efficient means with which to provide KP for those with LBP.

There has been debate regarding how KR and KP influence skill learning. Most of what we know about providing augmented feedback comes from laboratory experiments in which KR was manipulated.22 Some researchers56,55 have suggested that KP is better than KR at facilitating skill acquisition, whereas others42 demonstrated the benefit of both KR and KP, each providing benefit for different reasons. Researchers that have assessed the use of RUSI to assess the anterolateral abdominal and lumbar multifidus muscles have used both KR and KP (TABLE). The reader is referred to other references22,37 for a more thorough discussion of KR and KP to facilitate skill acquisition.

Timing of Feedback
A question that remains unanswered has been, what is the optimal schedule for providing feedback to optimize motor learning? Is it better to provide concurrent augmented feedback (while the skill is still being performed) or terminal feedback (at the end of the attempt)? Terminal feedback has been found to be effective in almost any motor performance situation, whereas concurrent feedback appears to be most effective when the task-intrinsic feedback does not inform the learner about how to perform or improve the skill.22

When the augmented feedback has been given traditionally, there have been 3 time variables that are usually monitored with KR feedback.46 The first is the delay between the cessation of the skill and the provision of the augmented feedback (KR delay interval). The next temporal variable is the time between provision of the feedback and execution of the subsequent attempt of the task (post-KR delay). It has been assumed that during this interval the learner is processing the KR to improve the subsequent trial,46 at which time the physical therapist should remain quiet. The third defined variable is the intertrial interval, which is the total time between each attempt of the task. These intervals apply to any type of augmented feedback; however, to date the majority of research on motor learning has examined the effects of changing the intervals for KR feedback46 and to a lesser extent KP feedback. The timing of feedback in studies using RUSI feedback has not been addressed to date. Again, the reader is referred to Magill22 for a review of the literature regarding time intervals for providing feedback.

Frequency of Feedback
Researchers have suggested that learning is best promoted with less frequent feedback rather than feedback following each skill attempt,22 and that task complexity should influence the frequency at which feedback is provided. For a simple movement-timing task (such as moving a pointing finger from point A to point B), KR provided after every trial generally results in the best performance on subsequent trials. However, when a retention test was given and performance was compared, individuals that received summary feedback only after every 15 trials, as compared to after 1, 5, or 10 trials, demonstrated greater performance of the task during a transfer test.35 Similarly, Dunham and Mueller8 also demonstrated that greater amounts of feedback during learned affected performance positively but did not impact skill retention or learning. Schmidt36 and Lavery and Suddon20 demonstrated in separate studies that more frequent feedback during initial teaching affected performance positively but had a negative effect on retention tests used to assess learning. So even though KR provided after every trial can be motivational, it can also result in too much information for the learner or too much reliance on the augmented feedback by the learner, making the learner dependent on the augmented feedback at the expense of developing motor strategies that rely on available intrinsic feedback. The optimal frequency of RUSI feedback for various patient populations in learning different tasks has yet to be explored and only 4 studies to date have reported this information for RUSI feedback (TABLE).11,44,47,53

Precision of Feedback
Augmented feedback can be qualitative, quantitative, or both. Qualitative feedback would indicate only the direction of the response error or refer to some quality of the performance characteristic, whereas quantitative KR would include both direction and magnitude (often some numeric value) of the performance
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#### A Comparison Among the Published Manuscripts on Rehabilitative Ultrasound Imaging (RUSI) as a Form of Feedback for the Assessment of Trunk Muscle Function

<table>
<thead>
<tr>
<th>Henry et al</th>
<th>Worth et al</th>
<th>Teyhen et al</th>
<th>Van et al</th>
<th>Hides et al</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td>Non-LBP</td>
<td>LBP</td>
<td>LBP</td>
<td>Non-LBP</td>
</tr>
<tr>
<td><strong>Number of subjects</strong></td>
<td>n = 48 (16 per group)</td>
<td>n = 19 (10 in group 1, 9 in group 2)</td>
<td>n = 30 (15 per group)</td>
<td>n = 25 (13 in group 1, 12 in group 2)</td>
</tr>
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<td><strong>Study design</strong></td>
<td>Randomized control trial</td>
<td>Randomized control trial</td>
<td>Randomized control trial</td>
<td>Randomized control trial</td>
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<tr>
<td><strong>Muscles assessed</strong></td>
<td>Lateral abdominal muscles</td>
<td>Lateral abdominal muscles</td>
<td>Lateral abdominal muscles</td>
<td>Lumbar multifidus muscle</td>
</tr>
<tr>
<td><strong>Task</strong></td>
<td>ADIM</td>
<td>ADIM</td>
<td>ADIM</td>
<td>Isometric contraction</td>
</tr>
<tr>
<td><strong>Position</strong></td>
<td>Supine</td>
<td>Supine</td>
<td>Quadruped, sitting, supine</td>
<td>Prone</td>
</tr>
<tr>
<td><strong>Type of feedback</strong></td>
<td>Group 1: control group with minimal verbal feedback Group 2: verbal and tactile cues Group 3: same as group 2 with augmented RUSI feedback</td>
<td>Group 1: verbal and tactile cues Group 2: same as group 1 with augmented RUSI feedback</td>
<td>Group 1: clinical instruction and verbal cues Group 2: same as group 1 with augmented RUSI feedback</td>
<td>Group 1: none Group 2: verbal, tactile, and augmented RUSI feedback</td>
</tr>
<tr>
<td><strong>Precision of feedback (qualitative or quantitative)</strong></td>
<td>Qualitative</td>
<td>Qualitative</td>
<td>Qualitative</td>
<td>Quantitative</td>
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<tr>
<td><strong>Frequency of feedback</strong></td>
<td>After first trial, then after every other trial</td>
<td>After every trial</td>
<td>During every trial</td>
<td>During and after every trial</td>
</tr>
<tr>
<td><strong>Motor performance assessed</strong></td>
<td>Yes: more individuals receiving RUSI feedback met the performance criteria and in fewer number of trials</td>
<td>Yes: more individuals receiving RUSI feedback met the performance criteria and in fewer number of trials</td>
<td>Yes: no difference in performance between groups after initial training session</td>
<td>Yes: both groups improved their ability to perform the contraction. Those augmented with RUSI had a greater improvement</td>
</tr>
<tr>
<td><strong>Motor learning assessed</strong></td>
<td>Yes: retention test without feedback approximately 2 days after initial training. No difference noted on retention test between groups</td>
<td>Yes: retention test without feedback within 4 days after initial training. RUSI group reached performance criteria in a fewer number of trials. However, each group had the same number of patients consistently complete the task</td>
<td>Yes: retention test without feedback approximately 4.3 days later. No difference between groups</td>
<td>Yes: retention test without feedback approximately 1 week later was improved in the group with augmented RUSI feedback, while the other group’s performance decreased</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Small sample size for retention testing</td>
<td>Both groups were able to perform the ADIM at baseline, there may have been a ceiling effect</td>
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**Abbreviations:** ADIM, abdominal drawing-in maneuver; KP, knowledge of performance; KR, knowledge of results; LBP, low back pain.
or of the response error. Quantitative KR may promote better learning because more detailed information is provided to the learner; however, this can vary depending on the task and age of the learner. Both quantitative and qualitative KR provide benefit in early learning as they both contain information about the direction of error; however, quantitative KR provided in early learning appears to result in better performance later in practice. Thus, it appears that perhaps different types of KR information are used by learners at different stages of practice when solving a movement problem. Using different types of KR information from RUSI to promote the learning of ADIM or preferential multifidus muscle activation has not been addressed to date.

A great deal of work needs to be done in the context of RUSI to begin to answer the myriad of questions regarding the various feedback parameters that can be manipulated to enhance performance of the ADIM or preferential activation of the multifidus muscle. How much practice time (not addressed in this commentary) should be suggested for optimal learning? When should the retention test be administered and what is the optimal retention or transfer task? Is the retention test for the ADIM administered on the next clinic visit assuming the individual has correctly completed the prescribed exercises? Or should the retention test consist of performance of TrA and multifidus muscle cocontraction while performing a functional task (ie, a transfer task)? These and many other questions will need systematic and careful investigation to maximize the potential that RUSI can contribute to our existing rehabilitation protocols.

**RUSI AS A FEEDBACK TOOL**

RUSI has been used as a biofeedback tool in attempts to improve preferential activation of the multifidus and TrA muscles in individuals with and without LBP. The goal is for the individual to gain the ability to preferentially activate these 2 deep trunk muscles simultaneously as part of the progression in a segmental stabilization protocol. The clinician’s goal should be to present biofeedback during training to foster preferential thickening of the TrA and multifidus muscles, so that at some point in the future the patient would be able to elicit preferential muscle activation of these muscles in the absence of RUSI feedback. RUSI has also been used to provide feedback to the physical therapist about an individual patient’s performance and to track outcomes. The following paragraphs review the existing literature about the use of RUSI as a biofeedback tool.

There are 5 studies that have examined the use of RUSI as a biofeedback tool to enhance the learning of how to preferentially activate the TrA and multifidus muscles in individuals with and without LBP (Table). Additionally, the positive influence of 1 of these rehabilitation programs on recurrence rates of LBP has been reported.

**Multifidus Muscle**

RUSI has been used to facilitate the learning of preferential activation of the multifidus muscle in an asymptomatic population (n = 25). Individuals were randomly assigned to 1 of 2 groups, both of which received clinical instruction in how to perform a preferential activation of the multifidus muscle, while 1 of the groups also received visual feedback of multifidus muscle contraction provided by RUSI followed by quantitative KR. Individuals who received the visual feedback and quantitative KR from RUSI imaging achieved greater improvements in the preferential activation of the multifidus muscle, as assessed by greater increases in multifidus muscle thickness. Retention tests conducted 1 week later without RUSI feedback assessed the learning of preferential multifidus muscle activation and demonstrated a greater improvement in the group that received the augmented RUSI feedback compared to the control group.

Hides et al also used RUSI to provide feedback about multifidus muscle activation to individuals with an acute, first-time episode of LBP (n = 41) who demonstrated a unilateral reduction in the cross-sectional area of this muscle on the side of pain. Using RUSI to facilitate a low-level multifidus isometric contraction, the cross-sectional area of the ipsilateral multifidus muscle was restored to match that of the contralateral side over a short period (10 weeks). The control group received no multifidus muscle training. Information about the feedback (nature, timing, frequency, or precision) was not addressed in the manuscript. Despite the increase in multifidus muscle cross sectional area with training, the study did not assess whether or not the subjects learned the preferential activation of the multifidus muscle or to what extent the use of RUSI might have facilitated learning of the muscle contraction, because neither a retention nor a transfer test was administered. Additionally, there was no exercise group that did not receive RUSI feedback to determine the extent to which the augmented feedback facilitated the outcomes measures. However, Hides et al found that the group that received the multifidus muscle training with RUSI feedback had lower recurrence rates of LBP at 1- and 3-year follow-ups.

**TrA Muscle**

Henry et al demonstrated that augmenting typical clinical instruction with visual feedback of the anterolateral abdominal wall using RUSI reduced the number of trials needed for individuals without LBP to perform the ADIM correctly. The operational definition of a correct ADIM included, among other things, an observable thickening and lateral movement of the TrA muscle that was verified by RUSI of the anterolateral abdominal wall. This study included 2 groups of healthy individuals (n = 16 per group), 1 of which received typical clinical feedback with verbal and tactile cues only, while the other group received the typical clinical feedback and RUSI augmented feedback, and both groups received feedback after the first trial and after every other trial thereafter. If the individual was...
having difficulty performing the ADIM, the terminal, verbal corrective feedback was altered to include a rewording of the instructions to promote an understanding of what was being requested. A third group (n = 16), which served as the control group, received only minimal verbal feedback when the specified performance criterion had been achieved. Individuals were informed if they performed 3 consecutive correct ADIMs and immediately performed 5 more practice trials while receiving the same feedback type and schedule. All individuals who performed 3 consecutive correct ADIMs successfully on day 1 were tested again within 4 days to evaluate retention; thus, the subjects that were unable to perform the ADIM correctly during the initial training session did not return for the retention testing. During the retention test, the instructions were repeated for each trial but no feedback (including RUSI) was provided; thus, the study design was appropriate for assessing motor learning. Significantly more individuals in the RUSI group met the performance criteria, and did so in a fewer mean number of trials, compared to the group receiving traditional clinic feedback, indicating that the use of RUSI feedback did enhance the initial performance of the ADIM. On retention testing without feedback, a portion of each group performed the ADIM correctly: 75% (6 of 8 subjects) of the typical clinical feedback, 86% (12 of 14 subjects) of the RUSI group, and 100% (2 of 2 subjects) of the control group (minimal verbal feedback when performance criterion had been reached). However, no statistical differences among feedback groups were found on retention testing, suggesting that there was no superior effect of RUSI on the learning of the ADIM in healthy subjects. However, these results need to be interpreted with care due to the small sample numbers, which may not have been sufficient to detect a true difference.

A parallel study with a similar design was performed with individuals with LBP (n = 19), with the minor modification of providing feedback after every trial during the initial testing session. During the initial training session, significantly more individuals in the RUSI group reached the criteria for consistency of performance and had fewer trials to performance criteria, compared to the group receiving typical clinical feedback. During the retention test, individuals in the RUSI group reached the performance criteria in a fewer number of trials, thus providing preliminary support to the hypothesis that RUSI can enhance the learning of the ADIM in individuals with LBP.

Teyhen et al44 used RUSI as a feedback tool to assess its role in enhancing motor performance and learning of the ADIM in 2 groups of individuals with LBP (n = 30). The criterion assessed during the ADIM was an increased thickening of the TrA muscle layer captured on the ultrasound image to reflect improved motor performance. All individuals were provided verbal and tactile feedback to optimize preferential activation of the TrA muscle while performing the ADIM in 3 different positions (quadruped, sitting, and supine hooklying). Individuals in the RUSI group also received 5 minutes of visual feedback from the ultrasound image, which showed the individuals’ changes in TrA muscle thickness. Continuous RUSI feedback was provided over the 5-minute period. The RUSI group compared to the traditionally trained group did not demonstrate an enhanced ability to activate the TrA muscle, as reflected in an increased change in muscle thickness, either immediately after training or during a retention test 4 days later. The study was designed to assess motor learning, as the subjects did not receive RUSI during the retention test. Given that both groups were able to double the thickness of the TrA muscle prior to training, a ceiling effect may have occurred that could have obscured a potential superior performance effect resulting from the RUSI feedback.

None of the studies discussed above examined the effect of the 3 time variables (KR delay, post-KR delay, and the intertrial interval) usually monitored with KR feedback on performance of learning the ADIM or preferential activation of the multifidus muscle. These temporal variables have been described as important because the learner must have an opportunity to process his intrinsic analysis of his performance. For example, if terminal feedback is provided immediately or the next trial initiated too soon, the intrinsic analysis could theoretically be blocked. Thus, it will be important for future studies to examine these variables.

It appears that RUSI may be more beneficial in some subgroups of patients than others.44,53 Teyhen et al44 reported a negative result for the use of RUSI to enhance ADIM performance in a group of individuals with a LBP history of less than 3 months, whereas Worth et al53 reported enhanced motor learning of the ADIM with RUSI in a group of individuals with a LBP history greater than 76 months. In both of these studies, a retention test was administered without providing RUSI feedback; thus both adequately assessed motor learning. However, it is unknown how the chronicity of LBP may influence how readily individuals can learn the ADIM and, therefore, how beneficial the addition of RUSI can be. This factor, in addition to lack of training stimulus (eg, practice time), may account for conflicting results about RUSI imaging in studies enrolling individuals with LBP and should be examined further. Alternatively, the results of Teyhen et al44 also suggested that RUSI did not enhance performance beyond traditional training, either because the training stimulus was too brief or because RUSI was given concurrently with performance (as opposed to post-performance). Some researchers have suggested that concurrent feedback is ineffective for stimulating learning because it theoretically blocks intrinsic performance analysis.

In summary, the results of 3 of the foregoing studies suggest that RUSI is a beneficial tool for providing augmented...
feedback that facilitates consistency of initial performance of the ADIM and activation of the multifidus muscle in a population with and without LBP. While the initial performance of the ADIM seemed to be improved with concomitant use of RUSI feedback, the benefit of RUSI in subjects without LBP for improving the retention of the ADIM performance was inconclusive and supported only preliminarily for activation of the multifidus muscle. There was 1 preliminary study that supported the use of RUSI to enhance motor learning of the ADIM in individuals with LBP but the subject number was low (n = 19).

Future Research Directions
Researchers need to examine the relationship between various quantifiable RUSI parameters and electromyographic recordings in different populations so that RUSI can be further validated as a noninvasive tool for quantifying muscle function. Rehabilitation protocols implemented with and without RUSI must be tested to determine the extent to which this type of visual feedback results in superior performance and clinical outcomes. In addition, the appropriateness of RUSI during the different stages of motor learning has yet to be evaluated. From a technical standpoint, the individual's ability to interpret the ultrasound image could potentially be improved through image processing techniques that decrease the complexity of the image, but this technology has yet to be investigated.

Another major issue to consider in using RUSI feedback to enhance motor performance and motor learning of tasks that involve the trunk muscle is the fact that the principles of biofeedback training paradigms are based largely on studies that used upper or lower extremity tasks. There are differences in the descending control systems, the size of motor units, and the available intrinsic feedback for the extremities versus the trunk muscles. The implications of these differences for the use of RUSI to train trunk muscles include the need to establish whether the practice schedules and feedback parameters that were effective for precise upper or lower extremity movements transfer to isometric muscle activations of the trunk muscles. For example, given the difference in the accuracy of control and intrinsic feedback available to the trunk muscles compared to extremity muscles, individuals attempting to learn preferential activation of trunk muscles may need a longer post-KR interval and more augmented feedback because of the lack of intrinsic feedback available.

Various parameters can be derived from RUSI, such as static measures of muscle morphology (muscle shape, size, and pennation angle) and dynamic measures of muscle behavior (changes in pennation angle, muscle shape, or fascicle length). These types of measures are affected by numerous factors, including the type of muscle contraction, forces created by adjacent structures (including activity of other muscles), as well as the fascicle arrangement within the muscle. The degree of correlation between these dependent measures and changes, positive or negative, in muscle performance are just beginning to be established. Which of these parameters derived from RUSI should be used to best enhance individual motor learning and reflect true improvements in motor performance need to be explored, established, and validated. Although it has been demonstrated that feedback training can help enable muscles to more effectively fire, it is not known if these changes reflect changes in firing rates, the number of motor units that are recruited, or in synchronization of active motor units or if the changes observed reflect increased motivation and compliance that accompanies biofeedback training. Additionally, if RUSI is used as a feedback tool to enhance motor learning and thus performance, the relationship between enhancement of muscle performance and any short-term or long-term clinical outcomes requires further investigation.

CONCLUSION
Only preliminary work on the use of RUSI as a feedback tool has been performed in those with LBP and pelvic floor dysfunction. However, the potential applications for this method of feedback are far-reaching. In designing research protocols, attention must be paid to the effect of pretraining, as well as the timing, type, and amount of feedback, as these factors affect skill acquisition. In future studies, investigators must be explicit about operational definitions of improved performance, parameters used to determine improved performance, as well as the amount and type of feedback provided. Through careful, systematic manipulation of research paradigms, we can elucidate the optimal ways to use RUSI as a feedback tool for the benefit of our patients.

REFERENCES
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