The Use of Real-Time Ultrasound Feedback in Teaching Abdominal Hollowing Exercises to Healthy Subjects

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Study Design: Randomized controlled trial.
Objectives: To determine if supplementing typical clinical instruction with real-time ultrasound feedback facilitates performance and retention of the abdominal hollowing exercise (AHE).
Background: Increasingly clinicians are using real-time ultrasound imaging as a form of feedback when teaching patients trunk stabilization exercises; however, there has been no justification for this practice.
Methods and Measures: Forty-eight subjects were divided randomly into 3 groups that received different types of feedback: group 1 received minimal verbal feedback, group 2 received verbal and palpatory feedback, and group 3 received real-time ultrasound, verbal, and palpatory feedback. If the subject performed 3 consecutive correct AHEs during the initial session, she/he returned for a retention test. The performance of 3 consecutive, correct AHEs was the criterion measure; the number of trials to criterion was also recorded during the initial and retention test sessions.
Results: The ability to perform the AHE differed among groups ($P<.001$). During the initial session, 12.5% of subjects in group 1, 50.0% of subjects in group 2, and 87.5% of subjects in group 3 were able to perform 3 consecutive AHEs. Group 3 subjects achieved the criterion in fewer trials than the other 2 groups ($P = .0006$). No differences among groups were found for the retention testing; however, low power due to fewer subjects precluded a strong interpretation of this finding.
Conclusion: Real-time ultrasound feedback can decrease the number of trials needed to consistently perform the AHE; however, the data are inconclusive with regard to retention of this skill. *J Orthop Sports Phys Ther 2005;35:338-345.*

Key Words: *motor learning, transversus abdominis, trunk exercises, trunk stabilization*

When learning trunk stabilization exercises, patients with low back pain (LBP) are taught to voluntarily contract the deeper abdominal and lumbar spine muscles while keeping the larger torque-producing trunk muscles inactive.[17,18,19,20] Trunk stabilization exercises have been purported to improve the timing and recruitment pattern of the deep abdominal and lumbar spine muscles[16,20] and, therefore, are often prescribed for people with recurrent and chronic LBP secondary to segmental instability.[17]

The initial trunk stabilization exercise that physical therapists often teach patients with LBP is an abdominal "drawing-in" maneuver[9] that has become known as the abdominal hollowing exercise (AHE). For correct performance of the AHE, patients are taught to contract the deeper anterolateral abdominal muscles, in particular the transversus abdominis (TA)[18,20] and internal oblique (IO) muscles,[15,16,17] without contracting the global abdominal or back muscles (external oblique [EO], rectus abdominis [RA], or erector spinae).[1] It has been demonstrated in individuals without LBP that while lying in a supine position and correctly performing the AHE, the IO muscle is preferentially activated over the RA muscle.[15]

Activating the deep anterolateral abdominal muscles in relative isolation appears to be particularly difficult for people with LBP. Recent studies of people with LBP have reported excessive use of the RA muscle[15,16] as well as altered TA muscle recruitment patterns.[8] Teaching the AHE is also a challenge for clinicians because the TA

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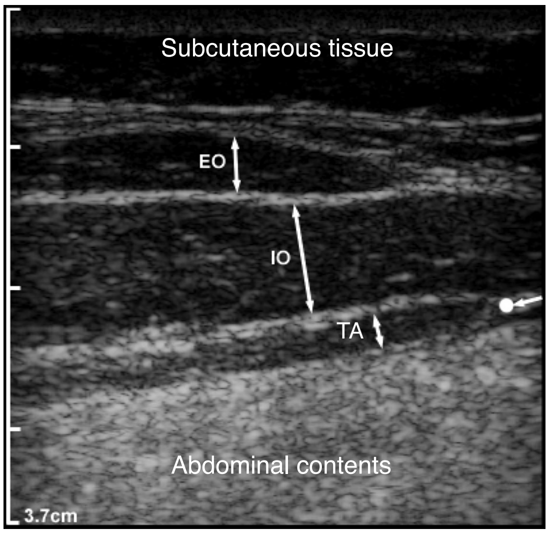

FIGURE 1. A transverse view of an ultrasound image of a subject's relaxed anterolateral abdominal wall. The single arrow and white-filled circle indicate the medial border of the transversus abdominis (TA) muscle where its fascia blends with that of the internal oblique (IO) muscle. The double arrows indicate the width of each of the abdominal muscles, TA, IO, and external oblique (EO), which are separated by fascial planes that appear as white lines on the ultrasound image. The scale on the left side of the ultrasound image indicates the depth.

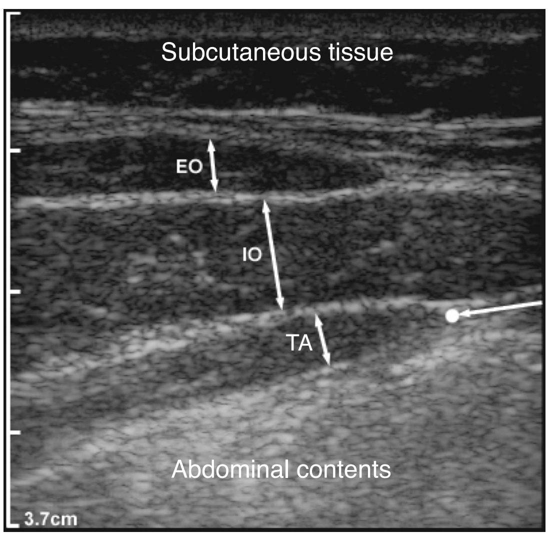

FIGURE 2. A transverse view of an ultrasound image of the same (as in Figure 1) subject's contracted transversus abdominis (TA) muscle (the ultrasound head was not moved after imaging Figure 1). The single arrow and white filled circle indicate the medial border of the TA muscle that has moved laterally compared to the medial border of the TA muscle in Figure 1. Also note that the thickness of the TA muscle and, to a lesser extent, the internal oblique (IO) muscle has increased with the subject's voluntary contraction, whereas the external oblique (EO) muscle has not changed thickness compared to the EO muscle in Figure 1. The scale on the left side of the ultrasound image indicates the depth.

muscle is deeply located and cannot be palpated in isolation; the IO muscle can only be palpated in a small window just medial to the anterior superior iliac spine. In addition, few people know how to voluntarily isolate these deeper abdominal muscles from more superficial abdominal muscles (RA, EO). Furthermore, the AHE is different from typical exercise programs in that only a very low-level isometric contraction is needed for correct performance.

To address the difficulties in learning and teaching the AHE, several physical therapy researchers and clinical instructors are advocating supplementing traditional feedback methods with the use of real-time ultrasound imaging techniques to provide augmented visual feedback.[5,6] The ultrasound images of the anterolateral abdominal wall can provide precise visual feedback and instantaneous knowledge of performance by displaying movement and thickening of the individual's deeper abdominal muscles on the ultrasound screen in real-time.

When an individual is lying supine and at rest, real-time ultrasound imaging of the anterolateral abdominal wall (~10 cm lateral to midline and halfway between the iliac crest and the inferior border of the rib cage) will reveal 3 distinct muscle layers (Figure 1): the EO, IO, and TA muscles. When an individual is proficient at contracting the TA/IO muscles relatively independently of the EO and RA muscles, a thickening of the TA muscle[14] and a lateral excursion of the v-shaped attachment of the TA muscle to the IO will be observed on the ultrasound image,[7] with minimal thickening of the EO (Figure 2) and RA muscles. While the reliability of measuring the thickness of the TA muscle has been established,[2] there have been conflicting reports about the correlation of changes in the TA muscle observed with ultrasound imaging and electromyographic recordings of that same muscle.[7,13]

Thus, the purpose of this study was to examine if augmenting the typical clinical instruction for teaching the AHE with real-time ultrasound feedback was effective at reducing the number of trials needed for an individual to consistently perform an AHE. In addition, the effect of using real-time ultrasound during the initial session on the subjects' ability to retain the correct performance of the AHE up to 4 days later was examined. Prior to the primary study, a pilot study was conducted to establish the author's ability to detect correct AHEs and common substitution patterns.

METHODS

Operational Definition of a Correct AHE

The operational definition of a correct AHE used in the pilot and primary study included an observable thickening and more importantly, lateral movement of the TA muscle and thickening of the IO muscle, as verified by imaging the anterolateral ab-

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dominal wall with real-time ultrasound. Furthermore, the operational definition specified that none of the following 4 substitution patterns were observed: (1) no contraction of the EO muscle verified by an absence of muscle thickening on the real-time ultrasound image and by palpation of this muscle; (2) minimal to no movement of the pelvis in the posterior direction verified by visual inspection and palpation of the pelvis; (3) no increased weight bearing through the subject's heels which was verified by a scale under the subject's feet; and (4) no deep inspiration followed by breath holding as determined by visual inspection and palpation of the anterior thorax.

Pilot Study

Investigator's Ability to Detect Correct AHEs and 4 Common Substitution Patterns It was important to establish that the examiner (K.C.W.) could identify accurately and repeatedly a correct AHE and the 4 common substitution patterns. To establish the examiner's proficiency in this task, a physical therapist familiar with the segmental stabilization program was trained to simulate a patient performing a correct and incorrect AHE and the 4 substitution patterns. A skilled simulator has been used in a similar study examining the AHE[3] and the use of a simulator is a valid and reliable method to test clinical competence.[22]

To ascertain the correct performance of an AHE, K.C.W. observed the thickening and lateral movement of the TA muscle and thickening of the IO muscle using a Genesis II ultrasound machine (Biosound Inc, Indianapolis, IN) with a 7.5-MHz mechanical transducer. A second physical therapist (S.M.H.), skilled in the use of ultrasound and the AHE technique, simultaneously assessed the simulator's performance of the AHE and the ultrasound images. K.C.W. and S.M.H. compared findings after each set of 10 trials. In addition, K.C.W.'s ability to interpret correct versus incorrect AHEs on real-time ultrasound was established by video taping 10 different ultrasound images of the simulator's anterolateral abdominal muscles. K.C.W. later identified the ultrasound images as either a correct or incorrect AHE. The same video images were then played again but in a different order, and K.C.W. identified the images as a correct or incorrect AHE.

As stated earlier, the 4 common substitution patterns included (1) excessive EO muscle activity,[18] (2) posterior pelvic tilting,[3,4,20] (3) increased weight bearing through the heels,[20] and (4) breath holding.[3,4,18,20]

Contraction of the EO muscle was assessed by palpation and by using real-time ultrasound to ascertain whether or not the muscle thickened. The presence of EO muscle contraction was considered an incorrect AHE. The 2 examiners (S.M.H. and K.C.W.) then compared assessments. Recording the EMG signal from the EO muscle was an option; however, given that most clinicians do not have access to such equipment, EMG recordings were not used to determine absence or presence of muscle activity.

Posterior tilting of the pelvis was assessed using visual inspection and palpation of the pelvis that was then compared to kinematic data of pelvic motion acquired by a passive-marker system. Pelvic motion was analyzed using 2 Elite Plus motion analyzer TVC CCD cameras (Bioengineering Technology Systems, Corsico, Milan, Italy), sampling at 50 Hz. Reflective markers were placed on the patient simulator at the following locations on the mid axillary line: the greater trochanter, midway between the greater trochanter and the iliac crest, the iliac crest, and the trunk at the level of rib 10 and rib 7. Kinematic data collection was initiated at the start of the AHE and continued for 5 seconds for each trial. Individual markers were tracked and the angle between the pelvis and the trunk was calculated in degrees using Elite Plus 1.5 software (Biosound Inc, Indianapolis, IN). The magnitude of the peak angle change between the pelvis and trunk was determined using custom software written in Matlab (The Math Works Inc, Natick, MA). Variance of the baseline data was ±1°. Pelvic movement of greater than 4° was considered an incorrect AHE.[3]

Increased weight bearing through the heels was assessed by visual inspection and compared to any changes recorded by a bathroom scale placed under the patient simulator's feet. An independent examiner monitored and recorded the changes in weight on the scale during each exercise. A change of greater than 0.5 kg as measured by the bathroom scale was considered an incorrect AHE.

Inspiration followed by breath holding was assessed by visual inspection and palpation of the anterior thorax and compared to readings from a tape measure placed around the simulator's thorax at the level of the xyphoid process. An independent examiner monitored and recorded the changes in circumference of the thorax in centimeters. No decrease in rib cage circumference following a deep inspiration and subsequent exhale was considered an incorrect AHE.

Primary Study

Subjects Forty-eight healthy volunteers (42 females, 6 males) between the ages of 18 and 60 years were recruited from the university and local communities for this study. Power calculations indicated that, with a sample size of 14 in each of the 3 groups, a 1-way ANOVA would have 80% power to detect a difference in the means at the 0.05 level, characterized by a variance of means of 16.67, assuming the common standard deviation is 8.00. The sample size was

increased by 2 subjects per group, for a total of 48, to account for a projected 10% drop-out rate. Volunteers were excluded if they had (1) a history of LBP or low back injury that interfered with activities of daily living or inhibited the individual from going to work or school, (2) spinal surgeries, (3) spinal deformities, (4) known neuromuscular or joint disease, or (5) a history of cancer. Any volunteers who were pregnant or had any prior experience with the AHE were also excluded from the study. Each volunteer gave his/her informed consent by signing a lay summary and consent form approved by the University of Vermont Institutional Review Board.

Procedure for Initial Testing All subjects admitted to the study completed a demographic data sheet and participated in an approximately 20- to 30-minute teaching session. All groups received the typical clinical instruction in how to perform an AHE, including a basic anatomical description of the abdominal muscles. The AHE was taught and tested with the subject in a supine position with hips flexed between 40° and 80° and knees flexed between 60° and 120° (Figure 3). The knee and hip joint angles of each subject were measured with a goniometer and recorded. At the beginning of each session, the weight of the subject's feet on the bathroom scale was recorded and monitored during the trials to detect any changes in weight bearing through the feet. During testing, the left anterolateral abdominal wall was palpated approximately 2.5 cm medial to the anterior superior iliac spine, in an attempt by K.C.W. to feel the tensioning in the TA and IO muscles as they contracted. A trial was classified as correct if the AHE was performed as per the operational definition and held for 10 seconds while normal breathing resumed. A 10-second hold is the duration of time often used clinically during the initial teaching sessions of the AHE.[17]

The subjects were randomized into 1 of 3 groups. Group 1, the control (CON) group, received only minimal verbal feedback from K.C.W. when she indicated that the specified performance criterion had been achieved; this is called bandwidth feedback because it is provided based on the individual's performance.[11,12] Group 2, the common clinical feedback (CCF) group, received common clinical feedback consisting of verbal descriptive feedback of any observed substitution patterns, verbal corrective feedback, and cutaneous feedback from palpation by K.C.W. and by the subject of his/her anterolateral abdominal wall. Feedback was given after the first trial and after every other trial thereafter. If the subject appeared to be having difficulty performing the AHE, then the verbal corrective feedback also included a rewording of the instructions to promote understanding. Group 3, the real-time ultrasound (RUS) group, received the common clinical feedback provided to the CCF group as well as visual feedback

FIGURE 3. Subject performing the abdominal hollowing exercise (AHE). The area palpated by the examiner and the subject is about 2.5 cm medial to the anterior superior iliac spine. To image the anterolateral abdominal wall and provide images shown in Figures 1 and 2, the ultrasound transducer is placed transversely midway between the iliac crest and the inferior border of the rib cage, with the medial border of the transducer about 10 cm from the midline. Note: In this figure, for photographic purposes, the equipment is not set up as described in the Methods section.

from the real-time ultrasound image generated from an ultrasound head placed on the left anterolateral abdominal wall approximately 2.5 cm inferior to the inferior angle of the ribs. The real-time ultrasound image was shown on a television monitor that was easily visible for the subject from the supine position (Figure 3). Before beginning the AHE, subjects were instructed to cough so they could see movement of their abdominal muscles on the monitor. Subjects in the RUS group received feedback regarding their performance as reflected by ultrasound image after the first trial and after every other trial thereafter. The investigator (K.C.W.) used the real-time ultrasound image to assess the subjects' performance in all 3 different feedback groups; however, only subjects in the RUS group were allowed to view the ultrasound screen as a form of feedback.

To examine the number of trials until the criteria for consistency of performance were achieved, all subjects participated in the teaching session for 20 to 30 minutes or until they performed 3 consecutive correct AHEs, which was chosen as the performance criterion because it is often used clinically. Subjects were informed when the performance criterion was reached and immediately performed 5 more practice trials while receiving the same feedback type and frequency, depending on their assigned group. A 20- to 30-minute time limit represents the length of time often available in a single physical therapy treatment session and is short enough to minimize subject fatigue. If the subject was unable to perform 3 consecutive correct AHEs during the first teaching session, his/her involvement in the study was terminated.

Procedure for Retention Testing To assess permanence of performance or learning, all subjects able to perform 3 consecutive, correct AHEs during the initial teaching session were invited back for a retention test within 4 days. The mean (±SD) number of days between initial and retention testing for group 1 was 2 (±1.4) days; for group 2 it was 2 (±1.2) days; and for group 3 it was 2.5 (±1.2) days. Each subject was given 2 warm-up trials of the AHE, followed by 10 trials of the AHE, which were assessed as correct or incorrect by K.C.W. As 10 is a common number of trials in clinical use, it was chosen for this study. The instructions were repeated before every trial, but no feedback (verbal or visual from the ultrasound image) was given to any of the subjects after each trial.[11,12] The subjects' ability to perform an AHE was assessed by K.C.W., with the same methods used during the initial test (described previously): real-time ultrasound, palpation, a scale under the subject's feet, and inspection of the subject's abdomen. K.C.W. was blinded to the group to which the subject had been assigned for the initial teaching session. Subjects able to perform 3 consecutive correct AHEs on the retention test, as in the initial test, were considered to have retained the ability to perform the AHE correctly.

Data Analysis (Pilot Study)

Investigator's Ability to Detect Correct AHEs and Common Substitution Patterns Percent agreement values were calculated for the comparison among K.C.W.'s visual and palpatory assessment of an AHE, the simulator's list of correct and incorrect AHEs performed, and S.M.H.'s visual and palpatory assessment of an AHE. In addition, K.C.W.'s intrarater agreement value for identifying correct AHEs from videotaped ultrasound images was calculated. To test whether there was significant agreement beyond that expected by chance, the Cohen kappa statistic was performed to estimate interrater agreement on identification of the 4 substitution patterns comparing K.C.W. and S.M.H., and K.C.W. with the simulator.

Data Analysis (Primary Study)

Subject Characteristics Descriptive statistics (including age, mass, height, gender, and self-selected hip flexion and knee flexion angles) were calculated and examined for differences among groups by an analysis of variance (ANOVA) calculated for each characteristic individually.

Performance for the Initial Teaching Session Pearson chi-square analysis was performed to examine differences among groups in the proportions of subjects of each group that were able to meet the performance criteria. A Fisher exact test was used as a post hoc test to determine between which groups the differences existed. A time-to-response analysis, also referred to as a "survival analysis," was used to examine differences in the mean number of trials needed for each group to meet the performance criteria.[21] The time-to-response analysis also accounts for those subjects who did not succeed at demonstrating 3 consecutive correct AHE trials by including their results as censored data. Due to the fact that the experimental design had 3 ordered groups, a variation of the time-to-response analysis, a Tarone-Ware statistical analysis including the censored data,[21] was used to determine statistically significant differences among the groups based on mean number of trials to criterion.

Performance for the Retention Testing Session For the retention test a chi-square test was performed to examine the proportions of subjects in each group that were able to meet the retention criterion of 3 consecutive correct AHEs. The criterion of 3 consecutive correct AHEs was selected to represent maintenance of the performance level demonstrated during the initial teaching session.

For only those subjects who met the retention criterion, the mean number of correct trials out of 10 attempts was expressed as a percentage and used in an ANOVA to compare across groups the percentage of trials during which the AHE was performed correctly without any feedback. A 1-way ANOVA was also performed to examine differences between pairs of groups. The data were also tested for normality and homogeneity of variance.

All statistics were calculated using SPSS statistical software (SPSS Inc, Chicago, IL) and statistical significance was set at the 0.05 level.

RESULTS

Pilot Study

Investigator's Ability to Detect Correct AHEs and Common Substitution Patterns There was 90% agreement between K.C.W. and S.M.H., and between K.C.W. and the simulator, for identifying a correct AHE versus an incorrect AHE. The kappa statistic was 0.783 (P = .011), so the agreement between examiners or between K.C.W. and the simulator was not likely due to chance. For identifying a correct AHE from videotaped ultrasound images, K.C.W. achieved 100% agreement. K.C.W. achieved 90% agreement with both S.M.H. and the simulator for identifying an excessive EO muscle activity pattern (κ = 0.783, P = .011). K.C.W. also achieved 100% agreement in identifying the other 3 substitution patterns: (1) excessive posterior pelvic tilt (using motion analysis as the gold standard), (2) excessive weight bearing through the heels (using a scale as the gold standard), and (3) a breath-holding pattern.

Primary Study

Subject Characteristics There were no significant differences in individual characteristics of subjects across the 3 groups (Table 1).

Performance on Initial Teaching Session There was a significant difference among the 3 groups in the proportion of each group able to meet the criterion as demonstrated by a Pearson's chi-square test ($P<.001$). Only 2 out of 16 subjects in the CON group, 8 out of 16 subjects in the CCF group, and 14 out of 16 subjects in the RUS group met the criterion of performing 3 consecutive correct AHEs (Table 2).

Significantly more subjects in the RUS group met the performance criterion than in the CON group as demonstrated by a Fisher exact test ($P<.001$). Statistical differences were noted also between the CON group and the CCF group (P = .027) and between the CCF group and the RUS group (P = .027).

There was a difference among groups in the mean number of trials until performance criterion was reached, as demonstrated by a Tarone-Ware analysis (P = .0006). The mean number of trials until criterion for the CON group was 14, the CCF group was 13, and the RUS group was 10 (Table 2).

Additional post hoc Tarone-Ware analyses were done for the 3 possible pairs of groups. The RUS group reached the performance criterion in a statistically lower mean number of trials than the CON group (P = .0007) and the CCF group (P = .0089). No significant difference in the mean number of trials to criterion was noted between the CON group and the CCF group (P = .2033) (Table 2).

Performance on Retention Testing Of the 24 subjects who returned for the retention test, 20 subjects met the retention test criterion: 100% of the CON group (2 of 2 subjects), 75% of the CCF group (6 of 8 subjects), and 86% of the RUS group (12 of 14 subjects) (Table 3). No differences were noted among feedback groups with regard to the proportions of subjects able to reach the retention criterion as demonstrated by a Pearson's chi-square test (P = .651).

For those subjects who met the retention criterion, the mean number of correct AHE trials out of 10 were examined. On average, 78% of trials for the RUS group, 67% of the trials for the CCF group, and 60% of the trials for the CON group were correct on the retention test (Table 3). The data were normally distributed (Shapiro-Wilk test, P = .191) and demonstrated equality of variances (Levene test, P = .074). Therefore, an ANOVA was performed and demonstrated no differences in the percentage of trials, during which the AHE was performed correctly across the 3 groups (P = .374).

Due to the fact that the CON group was so small (n = 2), an additional 1-way ANOVA was performed between the CCF group and the RUS group alone to look for differences in the percentage of correct trials. No significant differences between the CCF group and the RUS group were found (P = .248).

TABLE 1. Subject characteristics (mean ± SD). No statistically significant differences were found among the 3 groups ($P\geq.05$).

	CON Group (n = 16)	CCF Group (n = 16)	RUS Group (n = 16)
Age (y)	21.3 ± 5.0	21.9 ± 4.5	23.1 ± 10.1
Mass (kg)	64.0 ± 9.1	62.5 ± 9.2	63.9 ± 6.0
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Hip flexion (deg)	47.8 ± 5.2	47.6 ± 3.7	47.4 ± 3.7
Knee flexion (deg)	102.8 ± 9.4	102.7 ± 9.9	102.1 ± 6.7
Gender (% female)	81	88	94

Abbreviations: CON, control group; CCF, common clinical feedback group; RUS, real-time ultrasound group.

TABLE 2. Results for the initial testing session. Matching symbols represent statistically significant differences ($P<.001$).

Initial Test	CON Group (n = 16)	CCF Group (n = 16)	RUS Group (n = 16)
Number of subjects meeting initial criterion	2 (12.5%)*†	8 (50.0%)†‡	14 (87.5%)*‡
Mean number of trials to reach initial criterion	14§	13‖	10§‖

Abbreviations: CON, control group; CCF, common clinical feedback group; RUS, real-time ultrasound group.

TABLE 3. Results for the retention testing session. No statistically significant difference was found across groups.

Retention Test	CON Group (n = 2)	CCF Group (n = 8)	RUS Group (n = 14)
Number of subjects meeting retention criterion	2 (100%)	6 (75%)	12 (86%)
Trials correct on retention test for subjects who met retention criterion	60%	67%	78%

Abbreviations: CON, control group; CCF, common clinical feedback group; RUS, real-time ultrasound group.

DISCUSSION

It was important to establish the ability of K.C.W. to accurately assess a correct AHE and to identify the 4 common substitution patterns. Clinicians are required to make immediate assessments of their patients' performance in order to give accurate feedback regarding performance, thereby hopefully accelerating the learning process. In this study, K.C.W. needed to make an immediate assessment regarding the

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subject's performance in order to give feedback (CCF and RUS groups) and to determine if the subject met the performance criterion for a correct AHE within the 20- to 30-minute teaching session. One limitation of the method used to establish K.C.W.'s ability to assess a correct or incorrect AHE was that she practiced identifying each of the 4 substitution patterns individually. This differs from clinical assessments because patients learning the AHE may substitute with various combinations of patterns while trying to learn the correct maneuver.

Initial Teaching Session

This study demonstrated significant differences among the 3 feedback groups in both the number of subjects able to reach the performance criterion and the number of trials to reach the performance criterion within a 20- to 30-minute teaching session. Given there were no initial differences among the groups, these data suggest that variations in type of feedback can account for differences in performance observed across groups. First, a greater number of subjects in the CCF group reached the performance criterion compared to the CON group. Second, subjects who received real-time ultrasound feedback met the performance criterion in fewer trials and more of them reached the performance criterion compared to subjects in the other 2 feedback groups. The precise visual image produced by the ultrasound may have been a particularly beneficial form of feedback, given that both visual feedback[10] and precise feedback[23] have been shown to accelerate skill acquisition.

The previous recommendation[5,6] for the use of real-time ultrasound feedback to teach the AHE is supported by our data. The benefit of real-time ultrasound in learning the correct AHE was evidenced in the fact that the RUS group and the CCF group had the same feedback schedule (after every other trial), yet the RUS group still had a significantly greater proportion of subjects who achieved the performance criterion in significantly fewer trials, as compared to the CCF group. Additionally, there was not a significant difference in the mean number of trials until the criteria were met between the CCF group and the CON group. Thus, the use of real-time ultrasound feedback for teaching subjects the AHE appears to be beneficial in facilitating consistency of performance in a fewer number of trials, as compared to the current teaching and feedback methods used in most clinics today.

Retention Testing Session

The data from the retention testing must be interpreted cautiously due to the low number of subjects in the CON group (n = 2). The pool of subjects from the CON group used to compare the ability to retain the performance of a correct AHE was small (n = 2). With this study design, it was difficult to predict how many subjects would reach the criterion for a correct AHE during the initial testing, making a priori power calculations impractical for the retention phase of the study.

The results for retention testing suggest that there were no differences among feedback groups with regard to the proportions of subjects able to reach the retention criterion or the percent of correct trials performed on the retention test. One possible interpretation of these data is that once subjects were able to consistently perform the AHE during the initial test, the type and/or frequency of feedback provided during the initial teaching session did not affect their retention of this skill up to 4 days later. Another possibility is that once the performance criterion was met during the initial testing session, the amount of practice did not vary among groups (all subjects received an additional 5 practice trials). The equal practice time after the subjects received positive feedback for reaching the criterion during initial testing could contribute to the lack of a difference among groups during the retention testing. Future studies should systematically vary the amount of time between initial and retention testing, the type and/or frequency of feedback during the initial teaching session, as well as the amount of practice time after successfully reaching the criterion to examine the effects of these variables on the proportions of subjects who subsequently reach the retention criterion.

CONCLUSIONS

The use of real-time ultrasound feedback for teaching the AHE to subjects without LBP is a beneficial teaching tool for facilitating consistency of performance of the AHE as compared to verbal and cutaneous feedback, which are the teaching and feedback methods used in many clinics today. The effect of real-time ultrasound on retention of AHE performance is inconclusive based on this study. More research is needed to determine if people with LBP would also benefit from the use of real-time ultrasound feedback in learning the AHE. Lastly, studies must be conducted that examine if, and for which, subgroups of patients with LBP the AHE is beneficial in terms of pain reduction, functional improvements, and decreased number of recurrences.

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