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The Effect of Visual Feedback on Lumbar Spinal Mobility in Subjects without Low Back Pain

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Introduction:

Mobility of the spine declines with age as the curve of the mid-lumbar spine begins to flatten, with the largest deficits being seen with extension.[5,8,18] Spinal mobility impairments are significant predictors of back problems and pain throughout the lifespan, with 52-91% of people with mobility deficits across all age groups reporting some sort of lasting issue with their back.[8] While the greatest decreases in spinal mobility begin at age 60, age is not the sole predictor of range of motion.[13] In fact, abdominal and paraspinal muscular weakness, hamstring tightness, and a fear of falling have all been linked to impaired mobility of the lumbar spine.[18] These deficits contribute to limitations with activities of daily living (ADLs), gait quality, and general musculoskeletal functions, such as lifting objects and bending over. To maintain or improve spinal mobility and prevent lasting impairments, it is crucial to perform strengthening, flexibility, and postural exercises to maintain the natural curve of the spine and preserve proper biomechanics in daily life, which would overall improve quality of life[32].

Low back pain (LBP) and dysfunction can cause severe disability, and patients with a lack of lumbar mobility are frequently seen and treated in the physical therapy clinic. According to the Treatment-Based Classification approach[24, 32], patients with LBP are classified into one of several different categories in order to tailor treatment to fit their specific needs. If a patient experiences pain stemming from their lack of spinal mobility, they would be classified into the Mobilization treatment category.[15, 21] The goal of treatment for patients in this category is twofold: to increase range of motion with a series of mobilizations and active mobility exercises designed to target their specific deficits and to improve proprioceptive awareness of their lumbar spines while in motion. Once mobility is restored, symptoms generally decrease, and the patient can maintain his or her newly gained lumbar range of motion with a prescribed and individualized home exercise plan. The home exercise plan should facilitate continued improvement of the previous deficits.

The Modified-Modified Schober Test is used to measure lumbar forward flexion range of motion. The test is initiated by making two midline marks on the participant's skin: the first at the level of their posterior superior iliac spines (PSIS) and the second 15 cm above the original first mark. The change in the distance between the two marks is used to determine maximum lumbar flexion motion. This test has been shown to have excellent intra-rater reliability (ICC=.95) and inter-rater reliability (ICC= .91) and was used to help compare the results of lumbar range of motion in quadruped[34].

One such active mobility exercise commonly used in the clinic is alternating posterior to anterior pelvic tilt in quadruped. Performed informally in exercise classes outside of physical therapy and known colloquially as "Cat" (posterior pelvic tilt) and "Cow" (anterior pelvic tilt). This exercise is a comprehensive and efficient method for facilitating improvements with lumbar mobility in untrained individuals. Originally adapted from a yoga pose, the cat/cow exercise in quadruped promotes mobility of the spine by unloading the lumbar region and removing the influence of hamstring restrictions. In addition to these benefits, performing this task in quadruped allows for the simultaneous use of several different types of biofeedback, such as using a webcam or laser pointer, which can help amplify motor learning and reinforce mobility goals.

Feedback is commonly given during exercise training in physical therapy and is crucial for quick and efficient motor learning.[15, 20] There are two basic types of feedback that are implemented when teaching a new motor task: intrinsic or extrinsic. Intrinsic feedback occurs within the patient as a natural result of movement, e.g., the feeling of balance while walking on a beam. Conversely, extrinsic feedback results from sensory cues that are not naturally received during the task, e.g., verbal adjustments given from a coach during a baseball game or visual adjustments like tracking a laser point.[15, 20] Either of these methods of feedback can be given during a task (concurrent) or after the task is completed (terminal).[15, 20] Extrinsic, concurrent feedback is best for preventing cognitive overload, and therefore enhancing the learning of new motor tasks.[15] Visual feedback is one of the most efficient methods for giving extrinsic, concurrent feedback during the initial stages of motor learning and has been utilized in previous research to improve posture, increase muscle activation, and increase range of motion in the lumbar, thoracic, and cervical spine.[16,17,22,23,26] The use of a laser pointer attached to a moving body part provides concurrent visual feedback and has demonstrated positive training outcomes in previous studies involving the hips, shoulders, and trunk, however the use of a laser pointer as a method to promote increased mobility of the spine has not previously been studied.[10,11,25]

The purpose of this study was to assess the effects of visual feedback provided by a laser pointer on lumbar spinal mobility in quadruped and to determine if this method of training would enhance effectiveness of lumbar mobility exercise training. A secondary aim of this study was to compare mobility assessed using the valid and reliable MMST to mobility measured indirectly using the laser pointer. We hypothesized that individuals receiving visual feedback from the laser pointer would have increased lumbar range of motion compared to individuals who did not receive visual feedback.

Literature Review:

Introduction

Adults at age 25 demonstrate maximum spinal mobility and stability, but these decline as age advances.[18] In fact, people over the age of 50 may experience a decrease of 20% or more in their mid-lumbar lordosis.[5] While mobility of the spine decreases in all planes, the most significant changes occur in the sagittal and frontal planes, with extension showing the greatest decline followed by flexion and lateral flexion.[8, 18] Studies have also shown that older adults have reduced sagittal plane lumbar mobility in a variety of positions, including quadruped, standing flexion, and standing extension compared to younger adults, measured via multiple methods such as Modified-Modified Schober (MMS), a 2D video analysis system, and EMG activity. Limitations in lumbar spinal mobility such as these can greatly interfere with activities of daily living (ADLs), contributing to decreased community interaction and a sedentary lifestyle.[7] Furthermore, maximum spinal mobility differs according to gender. Females have been shown to be more flexible than their male counterparts in all planes of motion and across all age groups, however mobility declines at the same rate.[13, 18] Based on the above research, it is important to recognize potential differences between genders and to minimize losses of lumbar mobility over time, especially in the sagittal plane, as it has been found to have the greatest decline in mobility[8, 18].

Measuring Spinal Mobility

Accurate measurement of spinal mobility is crucial for tracking change over time, and physical therapists use several different methods for this, including those based on three-dimensional motion analysis, goniometers, inclinometers, visual estimation, and tape measures. The universal goniometer has mixed evidence about whether it is a valid and reliable tool to measure spinal mobility in all planes.[9, 24] While it is a viable method for measurements in standing, the goniometer can prove to be cumbersome and less accurate in other positions due to its single hinge joint system which is so dissimilar to true biomechanical movement.[24]

Several three-dimensional measurement systems (Vicon, ViMove, Epionics SPINE) have been described as methods to assess spinal mobility during dynamic movement.[3, 6, 14] While these systems show promising reliability and validity, they are not used clinically as they are more cumbersome and expensive than other measurement tools. The use of a measurement grid in conjunction with a laser pointer to track mobility changes over time is an indirect method that has not yet been documented, however it may be useful for clinical purposes since it can track motion during commonly performed lumbar mobility exercises.

The bubble inclinometer is another popular spinal measurement tool that is widely used in the clinic due to it being relatively affordable, easy to use, and valid compared to radiographic studies. It has also been used to quantify spinal posture and straight leg raise.[2, 19] The simple bubble inclinometer has excellent clinical reliability (ICC >.90) for measuring lumbar lordosis and thoracic kyphosis in standing; however [2] a recent systematic review found the bubble inclinometer method is not a valid measure of lumbar flexion and extension mobility.. Furthermore, MMS is more reliable than the bubble inclinometer in measuring lumbar flexion and extension.

One of the most common clinical methods used to evaluate spinal mobility is visual estimation by the clinician. Although currently no studies have assessed reliability and validity of visual estimation in the lumbar spine, several studies have evaluated the cervical spine[15,29]. There is poor inter-rater reliability for measuring cervical flexion with visual estimation. However, cervical extension measurement was consistent, and this is supported by a systematic review of 32 articles[15]. Visual estimation is less valid than the goniometer for measuring cervical flexion and extension active range of motion. Based on the best current available evidence[34,40], MMS is the most valid and reliable method for measuring lumbar flexion range of motion.

A tape measure can be used to measure spinal mobility as described with the Schober method and has reliability similar to goniometers for measuring spinal flexion. Issues with reliability, however, arise from the use of varying lumbar spinal landmarks for measurement[1,24] , and thus, several tape measure methods exist, including a fingertip to floor method and three variations on the Schober method. The fingertip to floor tape measure method has poor intra-rater reliability[6]. The original Schober (OS) method's landmark was 10 cm above the midpoint of the lumbosacral junction. The Modified Schober (MS) method was developed to account for more motion at the lumbosacral junction. The landmarks for this method are 5 cm below the lumbosacral junction and 10 cm above. MS has better intra-rater reliability than fingertip to floor and double that of inclinometry. It is more valid than OS when assessed via lateral radiographs. However, there is no significant correlation between lumbar range of motion (ROM) measured with MS and functional task lumbar ROM (return from bending and lifting), measured with 3D motion analysis[30].

The MMS method was developed to include more lumbar segments to account for all lumbar motion and to eliminate error associated with location of the lumbopelvic junction. The landmark for MMS is 15 cm above a line drawn between the posterior superior iliac spines. MMS has moderate-to-excellent intra and inter-rater reliability for measuring lumbar flexion and extension ROM. Compared to the gold-standard of radiography taken in the sagittal plane, MMS had moderate criterion validity[34]. Based on the current available evidence, MMS is the best method to measure lumbar mobility, based on its validity, reliability, cost effectiveness, and ease of clinical administration[34,40].

MMS Normative Values

There is currently only one study that has reported normative values using the valid and reliable MMS method. MMS flexion and extension were measured on 200 healthy males and females ages 21-40 years. Overall average values for lumbar flexion were 6.85±1.18cm. In the 21-30 age group, the average was slightly higher (6.94±1.16cm), and in the 31-40 age group, it was slightly lower (6.75±1.19cm), but the difference in lumbar flexion range of motion between the two age groups was not found to be statistically significant[19].

Visual Feedback

Various visual feedback systems have been shown to improve activation of the spinal and pelvic musculature as well as improve range of motion of the spine. When compared to controls receiving no visual feedback, individuals with their eyes open demonstrated greater trunk control and fewer postural deviations during standing and seated pelvic tilt tasks.[22, 23] In both studies, head and trunk rotations deviating from center of mass were minimized, resulting in higher success during balance and postural training.[22, 23] Park et al. and Ribeiro et al. analyzed the effects of visual feedback on range of motion in the cervical spine. Both studies concluded that neck ROM improved with various visual feedback methods (i.e. real-time smartphone inclinometer and mirror images) during rotation, extension, and lateral flexion by 2.4-3.5 degrees. Furthermore, compensations such as shoulder elevation and trunk lean were minimized with visual feedback, promoting more beneficial movement patterns.[16, 17] The use of a smartphone mirroring system to provide concurrent visual feedback has been shown to improve activation of core musculature during an arm and leg lift in quadruped in subjects with chronic low back pain.[26] When compared to trials in which visual feedback was not received, EMG activity of the internal oblique and erector spinae muscles increased, indicating improved dynamic stabilization of the trunk in quadruped. Axial rotation compensations of the pelvis were also minimized when visual feedback was applied, resulting in better quality of movement during the task.[26]

Visual feedback has also been shown to reduce low back pain. Participants with chronic nonspecific LBP reported a smaller increase in pain and a quicker time to ease when allowed to visualize their back with a mirror during standing lumbar flexion and extension movements. Patients receiving feedback treatment via a Webcam recording their back in real-time during anterior and posterior pelvic tilting in R and L side-lying for two weeks in addition to standard rehabilitation therapy showed statistically significant improvements in pain and sensation compared to the control group who received an equal number of sessions but only standard treatment[35].

Concurrent visual feedback with a laser pointer has proven to be a viable method for increasing muscle activation and control in various joints in the body. Maximum voluntary contraction of the infraspinatus increases by approximately 20% when concurrent laser pointer feedback is provided during an external rotation exercise.[10] The laser pointer was attached to the humerus of each participant and was used to visualize positioning of the arm during the activity, resulting in greatly improved body mechanics and EMG activation of the posterior rotator cuff.[10] When attached to the patella with a strap, a laser pointer has been shown to greatly decrease unwanted compensations during a squat. Hip internal rotation and dynamic knee valgus both decreased by an average of seven degrees, and EMG activation of the vastus medialis oblique muscle increased in comparison to the vastus lateralis.[25] While performing a supine bridge exercise, the use of the laser-assisted biofeedback improved EMG activity of the gluteus maximus and erector spinae muscles, resulting in a more level pelvis and fewer deviations from neutral.[11] The laser pointer allowed for real-time adjustments of body angles, thus increasing stability and muscle activation. EMG data also showed that the use of the laser pointer facilitated muscle activity before initiation of the exercise, suggesting an improvement in motor planning.[11] To our knowledge,the use of a laser pointer to improve or teach spinal mobility has not yet been documented. Motor planning improvements and increased muscle control, as described in the above studies, show promise for using the laser pointer in this way. Furthermore, no studies have yet evaluated the effects of visual feedback on lumbar mobility while in the quadruped position.

Summary

In summary, spinal mobility decreases over time, primarily after age 50 in the sagittal and frontal planes, and thus exercise may be needed to improve mobility. While visual feedback, in general, has been shown to be a viable method for increasing spinal mobility and muscle activation, studies have yet to observe the effects of a laser pointer as a concurrent feedback mechanism for spinal mobility tasks or training. However, the potential for this based on other joints is promising and more evidence is needed to determine effectiveness. Three-dimensional spinal measurement systems have been shown to have good reliability and validity when compared to radiographic studies, but they are expensive and not widely available. This indicates a need for a more objective and clinically feasible way to assess for changes in spinal mobility while providing concurrent feedback.

Study Purpose

The present study aimed to determine the effects of laser pointer visual feedback on sagittal plane spinal mobility in quadruped. A secondary aim was to evaluate the feasibility of assessing lumbar mobility using the transit of light from a laser pointer on the treatment surface with the patient in quadruped. The final aim of this study was to compare the laser transit method of assessing lumbar mobility to the MMS method.

Methods:

Subjects:

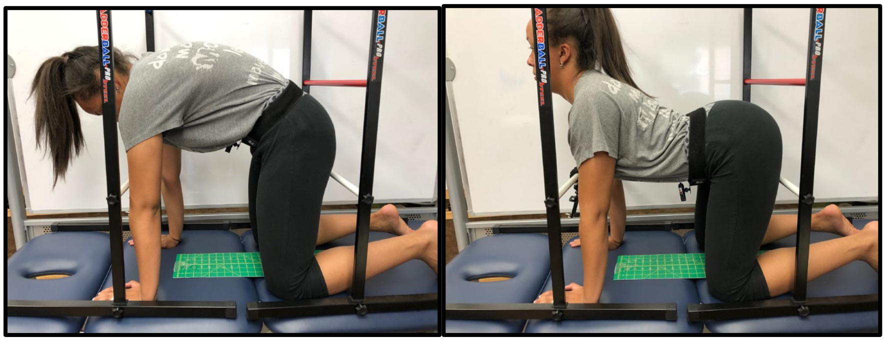
Sixty-Nine people, ages 21-80 years, with no low back pain in the previous year, no history of back surgery, and who denied current pregnancy and participation in regular spinal mobility exercises (i.e. yoga, Pilates, etc.) participated. Each participant also reported the ability to both maintain quadruped position for at least 5 minutes and see the beam of light produced by the laser pointer on the grid, and then provided written consent. Participants were further screened for waist circumference for further research. Screening and participant record keeping was handled by researchers not involved in video analysis, thus ensuring that later assessment of mobility outcomes was blinded.

Procedures:

Data collection took place over two sessions per participant. At the beginning of their first session, participants completed a demographic questionnaire and viewed a short instructional video, which described and demonstrated neutral spine positioning and the alternating posterior to anterior pelvic tilt exercise performed in quadruped (cat/cow). Participants then confirmed their understanding of the exercise and were asked if they had any additional questions prior to obtaining measurements.

Waist circumference was measured with a tape measure immediately above the iliac crest, with the tape measure pulled snug but not tight. Next the Modified-Modified Schober Test of maximum lumbar forward flexion was performed for each participant. The researcher made two midline marks on the participant's skin; the first at the level of their PSISs and the second 15 cm above the original first mark. Each participant was then instructed to bend forward as far as they could without bending their knees and the change between the two marks were recorded. Following the MMST, the participant was set up for the exercise portion. An elastic belt was affixed around the subject's waist in line with their anterior superior iliac spine (ASIS). The laser pointer was situated in midline using their umbilicus as the indicator. Researcher 1 was responsible for these tasks.

The participant was then asked to assume a quadruped position over a 44-inch grid used to measure the laser's transit.. The researchers adjusted each subject's position to ensure that hands were directly under the shoulders, and knees were directly under the hips. Neutral spine was assumed by the subject with verbal and tactile cueing from the researcher. Two barriers were then placed in front and behind the subject – one across their upper arm and the other behind their thigh – to prevent anterior or posterior movement of the trunk over the grid, to assure that the light coming from the laser pointer and moving over the grid would be moving as the result of only pelvic motion.



With the subject still in neutral lumbar spine position, the laser pointer was turned on, and then the grid was adjusted forward/backward until the "zero" on the grid was aligned with the laser light. A cell phone camera was affixed to the anterior barrier approximately halfway between the floor and the participants' shoulders and recorded the path of the laser's light on the grid during exercise.

Participants were then asked to demonstrate the exercise that they observed in the instructional video to further confirm that they knew how to perform the cat/cow task. If the exercise was performed incorrectly after watching the video, the researchers were responsible for instructing the participants on how to properly correct the motion before the recording began. The participant was then instructed that they would perform the cat/cow movements until signaled by the researcher to stop. Participants were instructed to perform to their maximum range of motion without any coaching throughout the exercise. Testing ceased once the researcher observed that the participant appeared to achieve maximal excursion of the laser transit anteriorly and posteriorly three times sequentially.

During the second session, 2-7 days later, each participant was asked to perform the same cat/cow task that they had completed during the previous session. A blindfold was placed over the participant's eyes during either the first or second session, depending on his or her group assignment. The order of interventions was randomized with a random number generator to assess for any order effect of the two conditions. Participants were assigned to one of three groups: control group (blindfolded during both sessions), intervention group A (blindfolded for the first session, visual feedback for second session), or intervention group B (visual feedback for first session, blindfolded for second session). Researcher 2 determined group allocation tasks via the random number generator.

Each video recording of the laser transit was named by Researcher 2 using a coding system in order to blind Researcher 4, who would be doing the video analysis, from each participant's group allocation. Researcher 4 then viewed each video at a later date in order to record the maximal anterior and posterior transit of the laser's light for each repetition of the cat/cow task. The motion of the light represented anterior and posterior pelvic tilt mobility.

Recordings were paused during each repetition and measurements were recorded to the nearest 1/8-inch. If the laser point was slightly lateral to the midline of the grid, the researcher would pause the video, zoom in and use a perpendicular straight edge to line up the point with the closest grid mark in midline. Videos that were deemed unreadable due to a blurry recording, a malfunction with the laser, or excessive lateral movement of the laser light were not included in data analysis.

Results:

A power analysis was not conducted because this research study was performed using a novel way of measuring lumbar mobility that has not been previously published. However, based on the central limit theorem approximately 30 subjects per group would be indicated. Ultimately, a total of 87 participants were randomized for this study, of which only 69 had complete data sets that were analyzed. Of these participants, 46 were female, and 23 were male, with an overall average age of 25.6 years old.

Each participant's anterior and posterior excursion of the laser light beam was documented for every repetition that was performed. The total lumbar excursion was calculated for the repetitions by combining anterior and posterior excursion. For each trial, the repetition with the largest total excursion was designated as the peak total excursion and these values were used for further statistical analysis.

To analyze the first question of whether visual feedback affected lumbar mobility, a two-way mixed model ANOVA was chosen to analyze both the between- and within-group differences for the data set. The control group's data was organized by their first and second testing periods, neither of which included visual feedback. The experimental group's data was organized by the condition of no visual feedback compared to visual feedback.

Parametric testing was performed to ensure the proper assumptions would be met for ANOVA testing. Six outliers were present in the control group's data of the most recent study, violating an assumption of normality. After the outliers were removed, the assumption of normality was not met. ANOVA testing continued due to the robustness of the testing. Overall, this ANOVA determined that there was not significant within groups differences ($p = 0.106$, $p = 0.681$), and there was no significant difference between the two groups at any time period ($p = 0.258$).

To further explain, the within groups analysis assessed for differences between all the participants' two testing periods. In the control, the difference of lumbar mobility between the first testing period compared to the second which resulted in a value of $p=0.106$. In the experimental group, there was no significant difference of lumbar mobility with no visual feedback compared to visual feedback ($p=0.681$). The between group analysis assessed for differences in results of the control group compared to the experimental group, which resulted in a significant value of $p=0.258$. This suggests that there was not a significant difference in lumbar mobility depending on group allocation.

The following results are a sub-analysis done on the most recent iteration's data that included a total of 33 subjects (21 females, 12 males) with an average age of 26.9. Each subject's lumbar flexion was measured using the MMST before participating in the exercise portion of data collection. A Pearson's interclass correlation was performed to see if there was a correlation between a subject's Modified-Modified Schober measurement of standing lumbar flexion and his/her maximum lumbar flexion excursion in quadruped as indicated by the transit. All subjects were included in this analysis and maximum quadruped lumbar flexion values from the first trial were used. Parametric testing was performed to ensure the proper assumptions were present. Upon visual inspection of the data, one outlier was found. Once removed, normality was verified as indicated by a Shapiro-Wilke value > 0.05. Overall, a small to moderate correlation was found between maximum quadruped lumbar flexion and MMST lumbar flexion values ($r = 0.318$).

To investigate whether or not subjects' MMST measurements for lumbar flexion had an influence on the performance of the quadruped flexion portion of the task based on the intervention, a "Between-Between-Within" (BBW) three-way mixed model ANOVA was performed. Subjects were stratified into a "high" or "low" MMST group based on whether their standing flexion measurement was more or less than the group average of 5.85 cm. Average quadruped lumbar flexion values were taken from the second trial for the control group and the trial in which the subjects received visual feedback for the experimental group. Parametric tests were run to ensure proper assumptions were made before running the analysis. Normality was confirmed when data was split by between-subjects' factors for all groups resulting in a Shapiro-Wilke value of $p > 0.05$ except in the "high MMST, control". An outlier was detected in the "high MMST, control" group, and once removed the assumption of normality was still not met. The BBW three-way mixed model ANOVA analysis continued due to robustness of the test. A statistically significant three-way interaction was found between visual feedback MMST grouping, and group assignment by ($p = 0.045$). This significant p-value is not clinically relevant however due to the fact that no simple two-way interactions existed between any of the groups, there was no way to delineate where the significance was found.

Discussion:

This study was a continuation of a previous study aimed at assessing if visual feedback provided via a laser pointer had an effect on lumbar flexion and extension mobility in quadruped. A secondary purpose was to see if the quadruped lumbar flexion results were related to baseline lumbar mobility assessed via MMST. Our final purpose was to determine if a correlation existed between the degree of subjects' quadruped lumbar flexion and MMST values. Our hypothesis was that visual feedback would improve lumbar ROM during the quadruped lumbar flexion/extension activity compared to no visual feedback. Overall, the results were consistent with the last iteration which found that visual feedback does not produce significant changes in lumbar mobility. Neither the control nor the intervention groups' lumbar mobility changed significantly over the course of the study. This is inconsistent with our hypothesis that visual feedback with a laser pointer would increase effectiveness of lumbar mobility exercise. These results contrast with several previous studies which suggested that the use of visual feedback can have significant positive effects on increasing range of motion, stability, and muscle activity in other areas of the body, namely the cervical and thoracic spine[10,11,16,17,22,23].

Sub-analyses did find a couple interesting points. Firstly, there was a small-to-moderate correlation between subjects' MMST and peak lumbar quadruped flexion performance. The MMST already has normalized values and has proven to be a reliable measure of assessing lumbar mobility. As such, it's difficult to make any sort of inferences regarding QLF's ability to assess lumbar mobility, especially given the small correlation to an already established and easily administered measure. Secondly, the BBW three-way mixed-model ANOVA found significance only when all three variables – visual feedback, MMST grouping, and control versus experimental allocation – were considered. As further analyses yielded no significant two-way interactions, the results from the three-way mixed-model ANOVA regarding its clinical application suggests that all three variables must be factored into an assessment of the subjects' performance.

The authors from the previous study noted limitations in their study that we accounted for in this iteration: a young, small sample size; a short transit grid which wasn't able to capture the true excursion of a sizeable number of their subjects; and a lack of privacy that the authors hypothesized prevented some participants to go through their full range of motion.

As previously mentioned, a potential ceiling effect existed due to a young average age and small number of subjects in our sample. In general, younger populations have a greater available range of motion, with lumbar mobility peaking at age 25 and slowly declining until the age of 50.[18] Therefore, young, healthy participants demonstrate decreased potential for significant improvements in range of motion because they were not likely to have been limited in the first place. While we attempted to recruit older individuals to create a more diverse spectrum of subjects – the average age of the subjects from this study was 26 years-old, and average MMST measurements of both the control and experimental groups were within 1 standard deviation of the norm – younger participants from the areas which we recruited (primarily on campus) were those most likely to commit to our study. Combining the data sets from this and the previous study yielded no significant differences as well, further implicating the ceiling effect existent in this population.

Extension of the grid was hypothesized to contribute to the ceiling effect noted in the previous study. Even with this ability to capture subjects' true excursion values, no significant differences were noted in lumbar mobility with and without visual feedback. Additionally, we accounted for the possibility that providing subjects with some privacy would enable them to move more comfortably and without hesitation through their full range of motion. This was done by having subjects perform the activity in a private room as opposed to in a hallway with more traffic. However, we cannot say conclusively that this change had any effect on their performance since the transit grid used in this study was longer than the previous study's grid.

Although adjustments were made to improve the methodology of this study, several limitations were noted. With the laser transit system, subjects in the intervention group were asked to look at a laser along the transit as they move between quadruped lumbar flexion and extension. Given the nature of the movements, the natural tendency of the head & neck when moving into quadruped lumbar flexion and extension is cervical flexion and extension, respectively. Moving the head into cervical extension would eliminate the hypothesized benefit of providing visual feedback via the laser. Even maintaining the neck in neutral when moving into quadruped lumbar extension would limit the subject's ability to view the laser point as it would be oriented posteriorly. This means that subjects might have retained their head in a flexed position, which could have limited the degree to which they were able to move into quadruped lumbar extension further confounding the results. Future renditions of this study should restrict movement to the lumbar flexion component to utilize visual feedback appropriately.

The abdominal girth of participants whose waist circumference exceeded or were within a few centimeters of the established limitations affected the transit of the laser light. As some subjects of greater abdominal girth performed the task, their abdominal mass would shift the intended direction of the laser, rendering their results invalid or at least difficult to record and accurately measure. The waist circumference limitations should be strictly followed for future research despite that it could limit the number of people able to participate.

Another limitation was lack of multiple camera angles for better viewing purposes. While the resolution of the video camera was enough to get accurate readings, to ensure better readings (specifically of quadruped lumbar extension) it would have been advantageous to add a camera looking at the transit system from the rear. This might affect subjects' comfort level when performing the task as the rear camera would be placed in a more provocative position, ultimately producing a similar limitation noted in the previous iteration of this study.

Lastly, the demographic of our subjects were similar to the last group's – 26 years old and with no back pain. Future iterations of this study should make more of an effort to recruit more older subjects and/or those with back pain and mobility deficits.

There is little existing research assessing effectiveness of visual biofeedback techniques for improving quadruped lumbar mobility, and this study provides a foundation for future studies regarding the use of a laser light as a novel form of biofeedback. Although visual feedback with a laser pointer did not increase peak lumbar mobility in pain-free individuals during quadruped lumbar flexion and extension, this question is still relevant to those who have decreased lumbar mobility and/or low back pain. Further investigation is warranted to find more conventional methods of measurement for linear lumbar mobility transit in correlation to lumbar mobility measurements. While no statistical significance was observed when using our novel laser transit system, neuromuscular training utilizing biofeedback may still be useful for helping patients gain more control and mobility of their spine.

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