Undershothing of a Neutral Reference Position by Asymptomatic Subjects After Cervical Motion in the Sagittal Plane

Richard C. Hallgren, PhD,a,b and Michael T. Andary, MDa

ABSTRACT

Objective: The objective of this study was to determine if blindfolded, asymptomatic subjects undershoot or overshoot a self-selected neutral reference position (NRP) when performing a full-cycle, head repositioning accuracy test in the sagittal plane.

Methods: An asymptomatic group of subjects, consisting of 7 men and 5 women with no history of head and neck pain, were recruited for the study. Subjects, performing a full-cycle series of head/neck movements in the sagittal plane, attempted to return to a self-selected NRP, defined at the beginning of the movement sequence, without benefit of visual clues. Data were collected for each subject, and repositioning errors were calculated. The sign of the error was used to determine if undershooting or overshooting of the NRP had occurred.

Results: Subjects undershot a self-selected NRP at statistically significant levels (P < .01) when performing the head repositioning accuracy test while blindfolded. Subjects undershot the NRP 83% of the time when moving from flexion to the NRP and undershot the NRP 92% of the time when moving from extension to the NRP. A Fisher exact test showed no significant difference between the number of times subjects undershot the NRP when moving from either flexion to the NRP or from extension to the NRP. To our knowledge, neither undershooting nor overshooting of an NRP has previously been reported for asymptomatic subjects at statistically significant levels.

Conclusion: Knowing that asymptomatic subjects undershoot an NRP may help to direct treatment and rehabilitation of patients who have experienced whiplash-type injuries and are shown to overshoot the NRP when performing the same test. (J Manipulative Physiol Ther 2008;31:547-552)

Key Indexing Terms: Physical Therapy Modalities; Neck Pain; Whiplash Injuries; Kinesthesia; Proprioception; Outcome Assessment (Health Care); Spine; Cervical Vertebrae

The ability to characterize statistically significant differences in head positioning patterns between asymptomatic subjects and head and neck pain patients has the potential to direct and facilitate the process of rehabilitation for a number of patient populations, including those having whiplash-type injuries. Accurate positioning of the head depends upon the convergence of visual, vestibular, and neck proprioceptive input to the central nervous system (CNS). Imbalance or dysfunction in any one of these has the potential to impact an individual’s ability to perform normal, daily activities.1 Symptoms that are related to the pathologic condition may include vertigo, eye-head dyscoordination, dysequilibrium, and gait ataxia. When these symptoms persist, they can complicate the recovery process and contribute to long-term loss of functional independence.

Measurement of cervical range of motion (ROM) is a commonly used, easily administered,2 and inexpensive test that provides positional information related to specific motion restrictions. Individuals who have experienced a motor vehicle injury typically have less cervical ROM than control subjects, with sagittal plane movements being proportionally the most effected.3-6

Cervical kinesthetic performance has the potential to provide additional information beyond what may be obtained with ROM tests. Evaluation of kinesthetic performance typically is used to quantify a subject’s ability to return to a self-selected neutral reference position (NRP), without benefit of visual or verbal feedback related to accuracy, after moving their head and neck to a position that

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is equal to or less than the maximum active range of pain-free motion. Although some studies have found repositioning accuracy of some patients with head and neck pain to be significantly reduced when compared to control subjects, other studies have not observed this relationship. Revel et al. reported that head repositioning error was significantly less precise \((P < 0.01)\) in patients with the pathology than in control subjects. Rix and Bagust also reported that head repositioning error was significantly less precise \((P < 0.05)\) in patients presenting with neck pain than in control subjects. Heikkila and Astrom reported that head repositioning error was significantly less precise \((P < 0.007)\) in patients with whiplash injury than in control subjects. In sharp contrast to these reports, Armstrong et al. reported that they did not observe any significant position sense impairment \((P > 0.05)\) in the mildly disabled cohort of patients who had whiplash that they studied. This reported difference in outcomes might have resulted from methodological differences in the experimental protocols and/or from a multitude of confounding factors in the patient groups that might be related to the type of injury, the time since injury, intervention history, and the resulting pathologic condition. Studies agree that whiplash-type injury patients show either the greatest reduction in ROM and/or the greatest increase in the neutral positioning patterns in asymptomatic subjects. Because of the multitude of confounding factors related to the type of injury, the time since injury, intervention history, and the resulting pathologic condition in groups of head and neck pain patients, characterization of head and neck positioning patterns in asymptomatic subjects is considered to be worthy of study.

We hypothesized that there would be a significant difference between the number of times that blindfolded, asymptomatic subjects would overshoot and the number of times that they would undershoot a self-selected NRP when performing a full-cycle, head repositioning accuracy test in the sagittal plane.

Methods

Subject Selection

An asymptomatic group of subjects, consisting of 7 men and 5 women (mean age, 31.8 years; range, 18-52 years) with no history of head and neck pain, brain injury, whiplash-type injury, or cervical injury, was recruited from faculty, students, and staff at Michigan State University (East Lansing, Mich). Each subject was asked to read and sign an institutional approved informed consent form before proceeding with the study.

Data Collection System

A data collection/analysis system, based upon a personal computer, a frame-grabber board (Matrox Meteor; 640 × 480 pixels resolution; 256 gray levels, Matrox Electronic Systems Ltd, Dorval, Quebec, Canada), and a video camera (Sony XC-77, CCD; Sony Electronics, Los Angeles, Calif), fitted with a standard lens (VCL-16Y-M, f = 16 mm, F1.4), was constructed to measure cervical kinesthetic performance. The experimental design was patterned after Revel.
et al,7 Rix and Bagust,12 and Heikkila and Astrom.9 Subjects wore a modified bicycling helmet to which a lightweight, laser diode light source was securely attached with Velcro (Velcro USA, Manchester, NH) (total weight was approximately equal to 231 g) in such a way as to point in the direction of the subject’s gaze. The laser diode light source was used to project a spot of red light onto a translucent screen (Fig 1). The video camera was positioned behind the screen (Fig 2) so that the location of the projected spot of red light could be recorded without recording the face of the subject. The system was designed so that collection, storage, and analysis of image files would be a semiautomated process. The operator used embedded textual cues within the software to guide the subject through the experimental protocol.

To calibrate the camera image, nine 2.54-cm square blocks were drawn onto a calibration grid that was placed on the screen located 69 cm from the camera. The location of the corner of each block was digitized and the length of each side of each block in pixels was calculated from the digitized data. The mean of the 36 values (4 sides × 9 blocks) was found to be equal to 33.89 ± 0.79 pixels and corresponds to a screen resolution of 13.34 pixels/cm.

Previous work7 suggests that the relocating zone of control subjects with occluded vision, who are positioned at a distance of 90 cm from the screen, lies within an arc of 4.5°. An arc of 4.5° corresponds to a circle with a radius of 7.1 cm (94.7 pixels). A scaling factor was used in the software to scale measurements according to the actual distance between the screen and the subject, with a subject’s acromioclavicular joint being used as the common landmark. At a distance of 90 cm, the laser diode light source projects a spot with a radius equal to 2 pixels onto the screen.

As part of a calibration protocol, subjects performed a series of movement sequences, returning the red spot of the laser onto an operator-defined point on the screen. The subject’s vision was not obstructed in any way. The positioning accuracy was found to be equal to 0.16° ± 0.04°, a number that is consistent with the accuracy of equipment used in similar studies.3

### Data Collection

Data were collected by the principle investigator (RCH) for a period of 3 months at the Physical Medicine and Rehabilitation Clinic housed in the Michigan State University Clinical Center. A repeated measures protocol was used to quantify the ability of a subject to return their head to a perceived NRP without benefit of visual feedback after each of a predefined sequence of head/neck movements within the sagittal plane. The movement protocol was specifically designed to target those muscles in which atrophic changes have been reported21-24 in head and neck pain patients. These muscles provide proprioceptive feedback related to the position of the head and neck, primarily in flexion and extension, and have been implicated in dysfunction resulting from whiplash type injuries.25 Restricting movement of the head and neck within the sagittal plane is less likely to stimulate the vestibular apparatus than would a protocol involving rotation of the head.26 By obstructing the subject’s vision and limiting motion to the sagittal plane, we are better able to characterize the contribution of that component of proprioception that originates from within the musculoskeletal system and plays a role in determining a subject’s ability to return to an NRP.
Subjects were seated in an adjustable seat that provided support for the lumbar and upper torso, arms, and feet. If necessary, adjustments were made to the seat at the beginning of each test to ensure that the subject would remain comfortable for the 5-minute test period. Each subject was allowed to move their head until they believed that they had reached an NRP. The operator then adjusted the laser pointer so that the red spot of light was centered on the middle of the screen. Because the operator was required to touch the subject’s head to make this adjustment, the subject was once again instructed to assume a normal, relaxed sitting position, looking straight ahead. To quantify a subject’s ability to return to an NRP without benefit of any visual cues, subjects were effectively blindfolded by wearing ski goggles that had black paint sprayed onto the lens.

We chose an experimental protocol similar to that used by Feipel et al13 and Dvir et al5 that requires subjects to perform a full-cycle movement sequence, with the subject moving their head from an NRP into flexion (or extension), then moving back through the neutral position into extension (or flexion), and then returning to the NRP. Earlier studies have used a half-cycle protocol,7,8,11,12 where the term “half cycle” refers to a motion sequence that starts with the head in an NRP, moves to either flexion or extension, and returns to the NRP. These earlier studies typically averaged the results of 10 trials. Recent studies have found that 4 trials provide reproducible results.4,13

For each of the 4 trials, subjects were instructed as follows (see Table 1 for the full set of instructions): “Without moving your shoulders,...” After each of the 4 trials, when the subject indicated that they had returned to the NRP, the operator would instruct the computer to capture the position of the red spot of light projected onto the translucent screen. This position would then define the location of the NRP for the next trial. Each trial was repeated in succession. No feedback was given to the subject regarding position accuracy, and the operator did not touch the subject or alter the setup once the test was started.

**Table 2. Repositioning error measured in degrees for blindfolded subjects**

<table>
<thead>
<tr>
<th>Motion Trial</th>
<th>SMH</th>
<th>MTA</th>
<th>NLW</th>
<th>JDC</th>
<th>SSW</th>
<th>JAR</th>
<th>MCH</th>
<th>LED</th>
<th>PAI</th>
<th>MKJ</th>
<th>PAS</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. FEF</td>
<td>−2.55</td>
<td>−0.12</td>
<td>−3.41</td>
<td>−5.42</td>
<td>−0.46</td>
<td>−2.50</td>
<td>−0.53</td>
<td>−0.71</td>
<td>−2.42</td>
<td>−0.11</td>
<td>0.72</td>
<td>−0.76</td>
</tr>
<tr>
<td>2. EFE</td>
<td>−5.14</td>
<td>−5.10</td>
<td>−3.95</td>
<td>0.99</td>
<td>−0.50</td>
<td>−4.54</td>
<td>−4.39</td>
<td>−4.13</td>
<td>−3.68</td>
<td>2.46</td>
<td>−1.40</td>
<td>−0.76</td>
</tr>
<tr>
<td>3. FEF</td>
<td>−6.65</td>
<td>−0.55</td>
<td>−0.86</td>
<td>−2.53</td>
<td>−1.58</td>
<td>−1.37</td>
<td>−0.80</td>
<td>0.79</td>
<td>−2.88</td>
<td>−3.32</td>
<td>−1.44</td>
<td>−0.40</td>
</tr>
<tr>
<td>4. EFE</td>
<td>−6.48</td>
<td>−1.19</td>
<td>−1.21</td>
<td>0.47</td>
<td>−0.71</td>
<td>−2.78</td>
<td>−7.71</td>
<td>−2.41</td>
<td>−4.83</td>
<td>0.91</td>
<td>−3.08</td>
<td>−2.52</td>
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</table>

A negative number indicates undershooting of the NRP, a positive number indicates overshooting of the NRP.

**Table 3. Summary of incidences of under/overshooting of the NRP for blindfolded subjects**

<table>
<thead>
<tr>
<th>Motion Trial</th>
<th>SMH</th>
<th>MTA</th>
<th>NLW</th>
<th>JDC</th>
<th>SSW</th>
<th>JAR</th>
<th>MCH</th>
<th>LED</th>
<th>PAI</th>
<th>MKJ</th>
<th>PAS</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. FEF</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>U</td>
<td>U</td>
<td>U</td>
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<tr>
<td>2. EFE</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>U</td>
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<tr>
<td>3. FEF</td>
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<td>U</td>
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<td>U</td>
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<td>O</td>
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<tr>
<td>4. EFE</td>
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</table>

U indicates undershooting; O, overshooting.

A power analysis predicted that a sample of 12 would give a power of 0.76 with an α of .05. Because of the small sample size, statistical analyses were performed using a binomial test and a Fisher exact test. Calculations were performed using SigmaStat for Windows, versions 2.03 (Systat Software Inc, San Jose, Calif).

**RESULTS**

Repositioning errors for each of the 4 trials were calculated for each of the 12 subjects (Table 2). Table 3 shows a summary of incidences of undershooting and overshooting of an NRP.

We used a binomial test to analyze the data and assumed that there would be an equal probability that a subject would either overshoot or undershoot the NRP. We determined that there was a statistically significant difference between the number of times that blindfolded subjects undershot the NRP and the number of times that they overshot the NRP at a level of $P < .01$.

We observed that blindfolded subjects undershot a self-selected NRP 83% of the time when moving the head and neck from an extended position back toward the NRP and undershot a self-selected NRP 92% of the time when moving the head and neck from a flexed position back toward the NRP. A Fisher exact test showed no significant difference between the number of times subjects undershot the NRP when moving from flexion to the NRP and the number of times that they undershot the NRP when moving from extension to the NRP.

**DISCUSSION**

This study reports that blindfolded, asymptomatic subjects undershot a self-selected NRP for final motions of both flexion and extension at statistically significant levels when
performing a full-cycle, cervicocephalic kinesthetic performance test. To our knowledge, neither undershooting nor overshooting of an NRP has previously been reported at statistically significant levels by asymptomatic subjects who were performing a goal-directed, head positioning test.

In contrast to our findings, Revel et al\textsuperscript{7} reported a tendency for patients with whiplash injury to overshot the NRP 60\% of the time. Rix and Bagust\textsuperscript{12} and Heikkila and Astrom\textsuperscript{9} both reported a statistically significant overshooting of the NRP when head and neck pain patients moved from flexion to neutral. Feipel et al\textsuperscript{13} reported a statistically significant overshooting of the NRP when patients with whiplash injury moved from extension to neutral. Overshooting of the NRP by some patients with whiplash injury may be a consequence of diminished or altered proprioceptive output from muscles that have been damaged as a result of whiplash-related injury.\textsuperscript{7,9,12,25} Atrophic changes in suboccipital muscles, quantified from magnetic resonance images, have been reported in some patients who have tension-type headaches\textsuperscript{21} and in some patients who have head and neck pain resulting from whiplash-type injuries.\textsuperscript{22-24} In some cases, this atrophy has been shown to be neurogenic in nature.\textsuperscript{23} Atrophy of these muscles would be expected to result in altered patterns of proprioceptive activity. The specific muscles affected are the rectus capitis posterior minor and the rectus capitis posterior major. Although these 2 pairs of muscles can be functionally classified as extensors, their small size, relative to larger muscles that act in parallel with them, minimizes their contribution to motion.\textsuperscript{27,28} A parallel muscle combination (PMC), that is, short muscles acting across joints in parallel with much larger muscles, occurs often in humans. The smaller muscles of PMC combinations have an average of 3.76 times as many spindles per gram of tissue as do their large counterparts, with the greatest absolute value of spindle density occurring in the smaller muscles of PMC combinations in the upper cervical spine.\textsuperscript{29} In addition to stabilizing the respective joints around the neutral position, it has been suggested that these small muscles function to provide significant proprioceptive feedback to the CNS, related to position and motion of the head.\textsuperscript{30} Because accurate head orientation in 3-dimensional space relies in part upon cervical proprioception, it is significant that some individuals within 2 groups of head and neck pain patients share a common pathology and that this pathology impacts the functionality of significant proprioceptive elements located within muscles of the upper cervical spine. Taylor and McCloskey\textsuperscript{31} have concluded that afferent activity from cervical proprioceptors contributes more to positioning accuracy of the head in relation to a target than does vestibular input. Karlberg et al\textsuperscript{13} have argued that a mismatch of proprioceptive and vestibular information within the CNS may result in a sensation of dizziness or vertigo. Brunagne et al\textsuperscript{13} have concluded that precise muscle spindle input from the paraspinal muscles is essential for accurate positioning of the pelvis and lumbrosacral spine in a sitting position. We suspect that neurogenic atrophy of suboccipital muscles, resulting from whiplash-type injuries, may result in both a decrease in repositioning accuracy and changes in head and neck positioning patterns and that these may contribute to head and neck pain syndromes.

Although there was no evidence that the outcome was biased by the specific population criteria of the study (small sample and relative young sample in contrast to other studies), it may be difficult to generalize the results to a larger, more heterogeneous population. It would be interesting to see if a study with an average subject age of 60 years might result in a different outcome.

At the present time, clinical use is limited. However, if future studies show an association between overshooting of an NRP by head and neck pain patients and the presence of atrophic changes in their suboccipital muscles, clinical use would be significantly improved.

**Conclusions**

Identification and treatment of injury-related dysfunction in patients with whiplash-type injury is an essential part of a rehabilitation strategy. Therefore, it is noteworthy that head positioning patterns from our study of asymptomatic subjects are significantly different from head positioning patterns reported in the literature for whiplash-injury patients. The functional implications of neurogenic atrophy of suboccipital muscles, resulting from whiplash-type injuries, are unknown, but we suspect that alterations in proprioceptive activity from these muscles may account for both a decrease in head and neck repositioning accuracy and changes in head and neck positioning patterns. Additional work, investigating the incidence and etiology of suboccipital muscle atrophy in patients with whiplash injury who are experiencing head and neck pain, needs to be initiated.

**Practical Applications**

- This study reports that asymptomatic subjects, with no history of head and neck pain, brain injury, whiplash-type injury, or cervical injury, undershoot a self-selected NRP for final motions of both flexion and extension at statistically significant levels when performing a full-cycle, cervicocephalic kinesthetic performance test in the sagittal plane.
- Overshooting of an NRP has been reported at statistically significant levels in some patients who have experienced whiplash-type injuries.
- Knowing that head and neck movement patterns of asymptomatic subjects are significantly different from head and neck movement patterns for some patients with whiplash injury may aid in the identification and treatment of injury-related dysfunction in this subgroup of patients.
ACKNOWLEDGMENT

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REFERENCES