



## Research Article

# Effects of neck muscle vibration on subjective visual vertical in an altered visual frame of reference

Christopher A Malaya\* and Charles S Layne

Center for Neuromotor and Biomechanics Research, University of Houston, Texas and Research Center, Parker University, Dallas, Texas, USA

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**\*Corresponding author:** Christopher A Malaya, Department of Health and Human Performance, Center for Neuromotor and Biomechanics Research, University of Houston, Texas and Research Center, Parker University, Dallas, Texas, USA, Tel: 512-827-7466; Email: christopher.malaya@gmail.com

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## Abstract

Rod and Frame Testing (RFT) has been used to investigate the effects of an altered visual frame of reference on subjective visual vertical. RFT requires an individual to align a luminous rod as best they can with true vertical. Their vision, however, is restricted by a rotatable square frame. Muscle vibration has effects on proprioceptive integration and appears to provide the illusion of muscle lengthening. This illusion leads not only to reflexive contractions of the stimulated muscle, but reflexive inhibition of its antagonist. We were interested in examining how the head orientation and perception illusions generated by ventral neck vibration would affect a participant's subjective sense of vertical in an altered visual frame of reference. A sample of 21 healthy individuals between the ages of 18 and 35 undertook RFT with concurrent, unilateral vibration over their sternocleidomastoid muscles. We found that RFT significantly influenced our participants even though their heads were stabilized in a chinrest, with or without vibration. Vibration alone was not significantly different from baseline. We believe this indicates the influence of the close visual frame of the RFT is independent of, or even primary over, relevant somatosensory information as it relates to subjective visual vertical.

## Abbreviations

RFT: Rod and Frame Testing; SCM: Sternocleidomastoid muscle; FRVL: Frame Right, Vibration Left; FRVR: Frame Right, Vibration Right; FLVR: Frame Left, Vibration Right; FLVL: Frame Left, Vibration Left

## Introduction

The human sense of vertical (subjective visual vertical) is strongly influenced by inputs from the visual, vestibular and somatosensory systems. Sensory information conveyed by each system is assigned a different "weight" that can vary depending on the individual, the environment, the availability of said information, the task, as well as from unanticipated or abrupt changes in the sensory input stream itself [1,2].

The rod and frame test (RFT) has been used previously to investigate the effects of an altered visual frame of reference on subjective visual vertical [3,4]. The RFT requires an individual to align a luminous rod as best they can with gravity (i.e.

true vertical). Their vision, however, is restricted by a square frame that can be rotated clockwise or counterclockwise. This provides the individual with an illusory visual frame of reference from which to base their estimation of vertical. Participants' subjective visual vertical (quantified as their error from true vertical) can provide insight into the role of individual sensory systems in perceiving vertical as well as individual participant's reactions to a visual illusion. Previous work has shown that participants' errors are generally in the direction of the frame's orientation [3-5].

Muscle vibration has noted effects on proprioceptive integration, and, by stimulating both primary and secondary muscle afferents, appears to provide the illusion of muscle lengthening [6-8]. Studies by Kawase, et al. and McKenna, et al. have examined the effect of neck muscle vibration on subjective visual vertical, albeit without the any close visual frame of reference. In Kawase, et al. researchers had participants with unilateral vestibular dysfunction sit in a darkened room and rotate a light bar until they perceived it as vertical while receiving vibration over their dorsal neck musculature. They

found vibration led to significantly larger error in aligning the light bar when it was applied to the side of dysfunction than when applied on the unaffected side [9]. In a similar experiment by McKenna, et al. researchers had healthy adults in a dark room align a laser line with gravitational vertical. Participants' heads were held at 30 degrees of lateral flexion (both to the left and right), as well as in an upright position. While the participants were able to align the laser to vertical under the upright condition, unilateral vibration of the dorsal neck musculature with opposite head tilt significantly affected subjective visual vertical: participants showed significant alignment change towards the direction of vibration [10].

In this study, we were interested in examining how the head orientation and perception illusions generated by ventral neck vibration would affect a participant's subjective sense of vertical in an altered (illusory) visual frame of reference. In this case, as our participant's heads rested on a chin piece, they were unable to move their head in response to the vibratory stimulus. While it is known that the illusory effects of muscle vibration can be diminished by light touch with a static object, we postulated that our participant's sense of vertical might still be affected by the vibratory illusion of self-motion, even without an overt ability to move their head [11,12]. In addition, by utilizing an RFT we provided an illusory close visual frame of reference which we believed might influence the effects of the neck vibration. In this way, we aimed to examine the effect of two sensory illusions (one visual modality and the other somatosensory) used in conjunction on an individual's subjective sense of vertical.

## Materials and methods

### Participants

A sample of 21 healthy individuals (38% female) between the ages of 18 and 35 (mean age: 26.4 +/- 2.9 years) volunteered to participate in the study. Participants had no known musculoskeletal, neurological or visual impairments. Written informed consent was obtained from each participant prior to the start of experimental procedures. Approval to conduct this study was granted by the Institutional Review Board at the University of Houston, in accordance with the Declaration of Helsinki.

### Experiment

During the experiment, participants stood in front of a modified version of Oltman's rod and frame apparatus (Oltman 1968) [13]. Each participant rested their chin on an ophthalmological chin rest that was adjusted to center their vision into a 24" long, 12" square tunnel. The tunnel rotated around a central axis and their peripheral vision was restricted such that the only reference and visual input they could use was the frame (tunnel) and a monitor at the far end of the frame. The monitor displayed a white rod on a black background that could be rotated using a wireless gamepad controller (Logitech F710 Gaming Controller) held at waist level. Participants were asked to use the controller to align the rod, as best they could, with gravity (i.e. true vertical) over the course of 16 different

trials. In between trials, participants were asked to close their eyes while the position of the frame was changed between 18 degrees clockwise, and 18 degrees counterclockwise, where the inclination of the frame has been found to elicit its greatest effect [14]. The starting position of the rod was either 18 degrees clockwise, or 18 degrees counterclockwise relative to the position of the frame, depending on the trial. Prior to testing, participants were provided an opportunity to interact with the gamepad controller to become familiar with the control features Figure 1.



Figure 1: RFT Apparatus.

During 8 of the 16 trials, participants experienced unilateral vibration over one of their sternocleidomastoid muscles (SCM). Participants had small linear motor drivers (Engineering Acoustics, Inc.) adhered bilaterally to their SCMs with medical tape. The linear drivers were controlled by a proprietary software (Engineering Acoustics Tactor SDK 2.10b) and operated with an amplitude of 0.8 mm at a frequency of 250 Hz.

The 16 trials were organized such that participants had 4 trials with a vertical frame without vibration ("baseline"), 4 trials with a rightward or leftward tilted frame and no vibration ("frame only"), 4 trials with a vertical frame and unilateral right-side or left-side SCM vibration ("vibration only", two trials each), and 4 trials with a combination of frame tilt and vibration ("combined"). The 4 combined trials were comprised of two trials with a rightward frame tilt and vibration on the right side or left side (frame right with left vibration: "FRVL"; and frame right with right vibration: "FRVR") as well as two other trials with a leftward frame tilt with right and left vibration ("FLVR" and "FLVL," respectively). The various conditions are identified in Table 1.

Each participant's final rod position and error was recorded by a custom Matlab program (Matlab R2018b:9.5.0.944444).

### Statistical analysis

Data normality was assessed using Shapiro-Wilk and Kolmogorov-Smirnov tests.

As data were not normally distributed, baseline, frame tilt, vibration and combined frame/vibration conditions were



examined using a related-samples Friedman's test. Post hoc analysis were conducted using Wilcoxon signed-rank tests with Bonferroni correction applied and all post-hoc tests were compared to an adjusted significance value.

## Results

There was a statistically significant difference in baseline, frame, vibration and combined conditions,  $\chi^2(2) = 109.212$ ,  $p < 0.001$  Table 2.

The vibration only trials were not statistically different from baseline: vibration on right SCM ( $p = 0.4$ ), vibration on left SCM ( $p = .398$ ). The combined frame/vibration conditions were not significantly different from the frame only conditions ( $p > 0.05$ ).

**Table 1:** The various Trial Conditions.

Trial #	Trial Condition	Frame Starting Tilt	Rod Starting Tilt	Vibration Location
1	Baseline	0°	18° CW	None
2	Baseline	0°	18° CCW	None
3	Frame Only	18° CW	18° CW	None
4	Frame Only	18° CCW	18° CCW	None
5	Frame Only	18° CW	18° CCW	None
6	Frame Only	18° CCW	18° CW	None
7	Vibration Only	0°	18° CW	Left SCM
8	Vibration Only	0°	18° CCW	Right SCM
9	Vibration Only	0°	18° CW	Left SCM
10	Vibration Only	0°	18° CCW	Right SCM
11	Combined (FRVL)	18° CW	18° CW	Left SCM
12	Combined (FRVR)	18° CCW	18° CCW	Right SCM
13	Combined (FLVL)	18° CCW	18° CCW	Left SCM
14	Combined (FLVR)	18° CW	18° CW	Right SCM
15	Baseline	0°	18° CCW	None
16	Baseline	0°	18° CW	None

CW = Clockwise; CCW = Counter-Clockwise. All values of Rod Starting Tilt should be added to the Frame Starting Tilt to be compared to true gravitational vertical. For example, in Trial 3 ("Frame Only"), the Frame Starting Tilt is 18° CW (this is 18° from true vertical). However, the Rod Starting Tilt is 18° CW from the original position of the frame (this is 36° from true vertical)

**Table 2:** Experimental Conditions with Pairwise Comparisons.

Condition	Deviation from Vertical (Median ± SE)	Deviation Direction
Baseline	0.25° ± 0.94	CW
VR	0.50° ± 0.25	CW
VL	0.25° ± 0.22	CCW
FR	7.00° ± 1.23**	CW
FL	5.75° ± 1.38**	CCW
FRVR	6.50° ± 1.27**	CW
FRVL	6.00° ± 1.26**	CW
FLVR	7.50° ± 1.43**	CCW
FLVL	7.00° ± 1.49**	CCW

Pairwise comparisons made to Baseline Condition: \* $p < 0.001$

Across all participants, in the frame only conditions, frame right was not significantly different than frame left ( $p > 0.05$ ). In the combined conditions, there was no significant difference between the side of frame tilt and the same side of tilt frame only conditions ( $p > 0.05$ ).

## Discussion

This study found that participants were strongly affected by the position of a close visual frame when attempting to orient a rod to vertical. Consistent with previous work utilizing an RFT, their errors were most often made in the direction of frame tilt [3-5]. As several investigations have shown the effects of altered close visual frame of reference on subjective visual vertical to be robust through a range of different postures and body orientations, it is little surprise that our participants were likewise affected [3-5]. It is of note, however, that the RFT influenced our participants even though their heads were stabilized in a chinrest. This suggests that the influence of the close visual frame of the RFT is independent of, or even primary over, relevant somatosensory information from the ground and the chinrest as it relates to subjective visual vertical.

The lack of response to neck vibration was likely multifactorial. Malmstrom, et al. has previously shown a lower response to vibration applied to the ventral musculature as compared to dorsal, with stepping-in-place tasks [15]. However, the authors still saw significant change in task with both ventral and dorsal vibration, while the current experiment saw no effect.

It is possible that the haptic contact from the chin rest provided corrective somatosensory information as to offset or overcome the vibratory illusion. This is supported by a study by Bove, et al. which found that light finger touch of a stationary surface reduced body tilt from short duration, single-sided muscle vibration of dorsal neck musculature and the sternocleidomastoid muscle. Similarly, Lackner, et al. [12] reported that haptic contact with a stable bar attenuated center of pressure changes from vibration of the right peroneal tendons in heel-to-toe stance participants. However, Karnath, et al. found significant differences in participant's ability to align a laser pointer with their "subjective straight ahead," in spite of utilizing a chin rest [16]. This suggests the chinrest may not have been solely responsible for disrupting the vibration illusion.

Indeed, it is more likely that the rod and frame device provided enough of a structured visual context as to diminish the effects of the vibratory illusion. This is supported by previous work showing that proprioceptive vibratory stimulation was less impactful in a structured visual environment as compared to darkness [17,18]. This suggests that, in the context of the RFT (a structured visual environment), the vibratory illusion was diminished because, even though the close visual reference was conflicting with somatosensory inputs, it was still our participants' primary means of establishing verticality.

Gaerlan, et al. found that healthy adults primarily relied on their visual system for maintaining postural balance [19]. In a study of construction workers at elevation, all measured



sway parameters significantly increased *only* when they became distant enough from the ground to lose close visual reference [20]. It has been argued that “appropriate close visual references increase the ability to maintain balance” and that being elevated a distance from the ground removes some of the visual information needed to maintain postural balance [20]. While our study did not have an “appropriate” visual reference (that is, the frame did not accurately represent gravitational vertical), the simple task of standing during an RFT was not challenging enough to induce a fall in our participants and, as there was a close visual reference from the frame, the somatosensory input from the vibratory illusion was not upweighted to counter the conflicted visual input [21].

It is also possible that the somatosensory information from the neck, given altered visual input, was down weighted compared to somatosensory information from the feet. In the Simeonov, et al. study above, the authors found construction workers at elevation relied more heavily on input from the soles of their feet for maintaining balance. In our study, participants stood on a solid floor during the RFT; however, we did not collect any data on nor challenge the stability of our participant’s feet as they stood for the test. Future work should examine the possible differences between somatosensory input to the neck musculature and feet as it relates to close and far visual frames of reference.

Thalassinos, et al. [5] explored the differences in trained athletes versus untrained individuals as it related to Achilles tendon vibration during a two-dimensional, digital RFT. Interestingly, they found that trained dancers were more affected by tendon vibration and took longer to adjust to the illusion than untrained individuals. It has been argued that dance training shifts and individual’s sensorimotor dominance from visual to proprioceptive [22–34]. While we did not collect any information on the athletic background of our participants, it was the case in our sample that the visual system appeared to be the primary estimator of verticality. While this appears to be dependent on population, it is notable that the RFT used in Thalassinos, et al. [5] did not have a three-dimensional, physical frame. Instead, the rod and frame were displayed on a large screen. It is possible then, that the visual system retains primacy for establishing vertical unless that information stream is actually *absent*. In Thalassinos et al., the participants were affected by vibration due to the lack of a physical, close referenced frame. Comparatively, in this study, the presence a close visual reference overrode the vibratory illusion. Said another way, in the presence of altered, even incorrect visual information *in close reference*, the visuals will remain weighted most heavily. More work in this area is needed to examine these effects, however. In particular, future work on this topic should consider enlarging and distancing the frame, and removing any other close, structured visual references, and examining the effects of muscular vibration on subjective visual vertical.

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