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The role of head position and prior contraction in manual aiming

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ABSTRACT

We sought to determine if the asymmetrical tonic neck reflex influences the accuracy of self-selected arm positioning without vision and to ascertain if such accuracy is influenced by a pre-contraction of the prime movers. Participants reproduced an arm position using their abductors with the head in midline, rotated towards and away from the arm. Arm movements were made with and without a pre-contraction of the abductors. Twenty participants performed eight trials in each of the six different conditions. Compared to the midline position, participants undershot the reference position with the head turned away and overshot the position with the head rotated towards the arm. A pre-contraction caused undershooting regardless of head position. Results suggest that head position and pre-contraction may have significant and independent effects on arm positioning.

The asymmetrical tonic neck reflex (ATNR) is a coordinated movement response that occurs in most typically developing infants in response to head turning. The response consists of extension of the upper and lower extremities on the side to which the face is turned and flexion of the contralateral limbs (Fiorentino, 1981; Peiper, 1964; Silver, 1952). For example, when the head is rotated to the right, the right arm demonstrates elbow and wrist extension along with shoulder abduction, while the left arm extremity exhibits elbow and wrist flexion along with shoulder adduction. The ATNR has been theorized to play an important role in the normal development of human movement by facilitating early visual inspection of the hand, and thus hand eye coordination (Gesell, 1952). The somewhat obligatory nature of this coordinative structure usually disappears in infants by 6 months allowing rotation of the head independent of limb movement (Silver, 1952).

A hierarchical approach to neuromotor development posits that the reflex disappears because it is integrated by the development of higher center descending influences that suppress this primitive subcortical reflex, but that with central nervous system (CNS) pathology, the reflex may reemerge (Bobath & Bobath, 1972; Byers, 1938). There is however, a body of literature that shows that the ATNR is still present in adults without CNS pathology and can influence limb positioning under conditions of high stress (Hellebrandt, Houtz, Partridge & Walters, 1956; Waterland & Hellebrandt, 1964). For example, Hellebrandt et al. (1956) found that maximal wrist extension force was increased when the head was turned toward the wrist while wrist flexion force was increased with the head rotated away from the wrist. This difference in relative force production was accentuated with increasing fatigue. Tokizane, Murao, Ogata, and Kondo (1951) also found that in healthy adults, head turning facilitated activity of the extensor musculature, as indexed by electromyographical recordings, and inhibition of the flexor musculature in the extremity that the head was turned towards. The opposite pattern of facilitation was observed in the contralateral homonymous muscles. More recently, Shea, Guadagnoli, and Dean (1995) showed that head rotation influenced the accuracy of learned force production goals that required less than maximal levels of elbow extensor force production. In this work, the participants had to produce goals that coincided with 30%, 60% and 90% of maximal extension force. The researchers found that the tendency to undershoot or overshoot the force goal was predicted by the direction of head turning, consistent with the manifestation of the ATNR. Shea et al. demonstrated that with the head turned away from the experimental side participants were prone to undershooting the target force compared to when the head was turned towards the experimental side. Such findings suggest that the head position might play a role in the production of typical everyday motor activities and not just those requiring maximal force generation.

The cause of the asymmetrical limb response biases seen with head turning, whether they be at maximal or submaximal force levels, has traditionally been attributed to afference from the neck receptors

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(Curry & Clelland, 1981). Work by Gurfinkel and colleagues (Gurfinkel, Lebedev & Levick, 1992; Gurfinkel, Levik, Popov, Smetanin & Shlikov, 1988) has questioned this assumption however by showing that it is not the actual position of the head that causes response biases rather it is the perception of head position that is important. For example, when the head is held in rotation for 10 minutes, either passively or actively, the head is perceived to move back to midline although no actual movement takes place. When this perception of head return is realized, the response biases typical of the ATNR disappear. Furthermore, Gurfinkel et al. (1992) reported that when head rotation is induced hypnotically without any actual movement, response asymmetries could be seen. One can conclude from such findings that it is the internal representation of head position that causes such response asymmetries rather than the traditional explanation of reflex mediation.

Powerful response biases also frequently follow a sustained pre-contraction of the muscles involved in producing the response. This phenomenon was initially reported by Kohnstamm (1915) and Salmon (1916) who both described an involuntary response in the direction of a sustained pre-contraction along with a feeling of lightness in the now-relaxed limb. This involuntary potentiation, often termed the Kohnstamm phenomenon (KP) or after-contraction phenomenon, is thought to summate with voluntary efferent commands to bias subsequent responses. Hutton, Kaiya, Suzuki and Watanabe (1987) proposed that such potentiation results from a change in the relationship between afference and efference increasing the excitatory state of the neuromuscular system.

In a series of experiments, Shea and colleagues (Shea, Shebilske, Kohl & Guadagnoli, 1991) examined the effect of pre-contraction intensity on the magnitude and persistence of the KP. Participants were required to produce a target isometric force with elbow extension after various magnitudes of pre-contraction effort. The researchers found that as the intensity of the pre-contraction increased there was a concomitant increase in the magnitude of bias in the targeted forces. In a follow-up study, Shea et al. (1995) again examined response biases in force production due to the KP but this time they also examined how such biases interacted with those generated by the ATNR. In three experiments, subjects were required to make isometric elbow extension contractions at various percentages of maximal voluntary contraction after a pre-contraction. Head position during these targeted responses was an independent variable so that responses were made with the head in midline, turned toward, or turned away from the arm generating the response. The results demonstrated a strong effect for both the KP and the ATNR in generating responses biases. The biases generated by head position and pre-contraction did not statistically interact; the effects were additive. Head position then could combine with or counteract the influences of pre-contractions. The additive nature of the effects implies that each source of response bias was the result of an independent mechanism of motor control.

Shea et al.'s (1995) study is the only work to clearly show the combined effects of the KP and the ATNR on the accuracy of targeted isometric force production. The current experiment seeks to extend this work by examining whether the biases observed by Shea et al. may carry over to the production of submaximal isoinertial muscle contractions. In this work, the participants' goal now is not to produce a certain force; rather it is to produce a certain displacement of the arm. Participants were asked to first move the arm to a baseline position with head in midline and then to reproduce that position in a series of test trials that did or did not follow a sustained pre-contraction of the prime movers and that were made with differing positions of the head.

Though effects have been found on strength and movement patterns, no research has examined whether the ATNR can influence positioning accuracy. In the current experiment then, potential response biases that might result from the perception of head position and from the after-contraction phenomenon were examined independently and in combination to determine whether such biases might be additive or interactive in influencing the accuracy and variability of arm positioning.

1. Methods

1.1. Participants

Twenty (N = 20) students between the ages of 19 and 29 years (M = 23.1 yrs.) were recruited as volunteers to participate in the experiment. All signed informed consent prior to participation. All participants were naïve to the purpose of the study. If a participant self-reported any current musculoskeletal or neurological dysfunctions, they were excluded from the study.

1.2. Procedure

The participants were asked to stand with their shoulder blades in contact with a 4′ × 6′ white dry-erase board with their heels against the wall. The participants were instructed to keep their eyes closed throughout the trials. Participants held a marker in their non-dominant hand with a fist-like grip, with the marker tip projecting out of the back of the hand towards the white board, the shoulder being in neutral rotation. With the head in a neutral position and with their eyes closed, the participants were then asked to abduct their arm, keeping the elbow and wrist straight, until a horizontal arm position was perceived (90° of abduction). At this point, the participant made a small mark on the white dry-erase board behind them. This mark was then used by an experimenter to make a 30 cm horizontal line on the board with a spirit level at the height of the participant's mark. This line then served as the reference goal for the subsequent series of the six test trials in which head position and the presence of a pre-contraction were manipulated. The subjects were instructed to attempt to reproduce this subjective horizontal position each trial.

The three head positions were; midline, rotated away from the moving arm, and rotated towards the arm. All rotations of the head were made about the polar axis through the transverse plane. A maximal voluntary contraction (MVC) was performed before three of the trials while the other three trials had no prior contraction. An isometric MVC of the shoulder abductors was performed with the participant's hands placed inside of a looped gait belt. The gait belt prevented any movement while participants attempted to abduct both arms for 30 s. The gait belt held the arms in approximately twenty degrees of abduction.

The six test trials were randomly ordered with the exception that no more than two consecutive trials with a maximal pre-contraction were allowed. The six trials consisted of; head midline with no prior isometric MVC (just as in the original baseline movement), head in midline following a 30 s isometric contraction of the shoulder abductors, head rotated around the polar axis towards the moving arm with no pre-contraction, head rotated towards the moving arm following an isometric MVC of the shoulder abductors, head rotated away around the polar axis from aiming arm with no MVC, and head rotated away from the moving arm following a 30 s MVC of the shoulder abductors.

Each trial was separated by a 90-s interval. If the following trial did not entail a pre-contraction, all 90 s were rest. However, if the subsequent trial involved a pre-contraction, then the 90-s interval consisted of 60 s of rest followed by a 30-s pre-contraction of the shoulder abductors. This way the inter-trial interval was held constant.

Once all six trials were completed, the participant was given a two-minute rest period in which they were able to open their eyes and move out of the testing position. After the two-minute rest period, the participant then performed a new baseline trial to achieve a reference mark that they perceived to be horizontal. That mark was used to form a new reference position for the next six trials. Participants completed a total of four testing sessions on different days with testing days