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The Kohnstamm Phenomenon: Involuntary Movement Followed by Sustained Muscle Contraction

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Abstract

The Kohnstamm phenomenon, a lightness sensation of the limbs and involuntary movement following sustained muscle contraction, is well documented. However, the physiological mechanisms behind this phenomenon are not well understood. This study investigates this phenomenon from the perspective of the muscles involved and the peripheral nervous system. This research examines the effect of shoulder position, muscle activation, external loading, hand position, and external electrical stimulation on the Kohnstamm phenomenon. We documented the presence and intensity of the Kohnstamm phenomenon from a sample of UNCA student volunteers by having subjects press against wooden stands with force plates attached, which allowed us to measure contraction force of the shoulder muscles at two different widths (1.00 m and 1.25 m). We also used electromyography (EMG) to record the electrical activity of the deltoid and supraspinatus muscles for a random subset of people in the study. Of the 39 subjects we tested, 33 experienced the phenomenon and 6 did not. For the majority of subjects who did experience the phenomenon, about 79% reported that the effect was greater when pressing against the narrower frame width. External loading (having the subject hold a weight in one hand) and applying an external stimulus with a transcutaneous electrical nerve stimulation (TENS) unit both decreased effects on the subjects' perceived intensity of the phenomenon. Although the deltoid is often attributed as the primary muscle involved with the Kohnstamm phenomenon, our initial results suggest that the effect is largely due to proprioception involving the deeper shoulder muscles of the rotator cuff.

Introduction

Sustained contraction of muscles often causes a sensation of lightness in the limb that persists after the contraction ends. A classic example is the Kohnstamm phenomenon, a well-known physiological phenomenon that occurs following the sustained static contraction of the muscles in the shoulders against an unmoving resistance.[1,2] The phenomenon occurs after a person pushes their straightened arms outward against a solid surface with the back of their hand and applies constant sustained muscular effort for 30-60 seconds. When the person stops voluntary contraction and relaxes their arms, the subject typically feels a floating sensation in their limbs and often finds their arms raising involuntarily. While this effect is widely documented, the physiological basis behind this phenomenon is still unknown.[3,4] This phenomenon is reported in about 75% of healthy participants, but it is unknown why it is negated in some participants.[5,6]

Although researchers often chose the shoulder muscles when conducting experiments on this phenomenon, this effect also occurs in the arm, wrist, ankle, knee, hip, and neck muscles.[7] Additionally, It has been reported that after-contractions occur more clearly in proximal joint muscles than distal ones. Past studies have shown the presence of a latent period between voluntary contraction and involuntary movement. The muscle is inactive during this period, and the limb remains intact. Although the duration of this period varies across participants, the study reported that it lasts an average of 1-3 seconds.

Interest in understanding the Kohnstamm phenomenon arises mainly due to the ease of demonstrating the effect and the lightness sensation it causes on the subjects. Additionally, acquiring deeper knowledge about the mechanism of this phenomenon can be beneficial in better-understanding diseases associated with involuntary movements of the body, including Parkinson's disease and Tourette syndrome.[8] The precise physiological mechanisms that cause this phenomenon to occur have yet to be fully understood. The most accepted hypotheses focus on ongoing muscle recruitment, unbalanced proprioceptive inputs, and activity of supraspinal brain structures.[6] As for the latter, a study showing that a motor post-effect can be elicited by simply imagining the effort necessary to move one's arm strongly supports the idea that higher brain structures may contribute to generating involuntary movements. This idea was further supported by another study that showed several brain areas being activated while involuntary contractions of muscles occurred.[6]

This study focused on exploring the underlying mechanisms of the Kohnstamm phenomenon by examining the involvement of the deltoid and supraspinatus muscles as well as the peripheral nervous system. One of our goals was to assess how ubiquitous this phenomenon is by having a sample of college students undergo the experiment, which is explained in detail in the Materials and Methods section. We aimed to evaluate the self-reported intensity with which they experienced the Kohnstamm phenomenon, and we hypothesized that the phenomenon is negated in some participants due to the lack of force exerted during the activity. Additionally, we strove to investigate whether the intensity of the phenomenon varies when changing the degree of abduction of the shoulder while pressing against wooden stands. We hypothesized that the intensity will be more significant when participants press against the narrow width compared to the wider width due to the increase in force exerted during contraction.

We also wanted to determine which muscle group (deltoid or rotator cuff) is the primary source of the phenomenon. To accomplish this, we experimented with different degrees of abduction of the shoulder and did an electromyography (EMG) analysis to record the relative recruitment of these muscles before, during, and after the activity. EMG encodes information about the active motor units in a detection zone. The properties of the muscle fibers that make up the motor units determine the shape and conduction velocity of the motor unit action potentials. These variables are responsible for forming the spectral properties in an EMG.[10] We hypothesized that the narrower frame, which has arms closer to the subject's side, recruits the supraspinatus muscle more heavily and, therefore, shows greater EMG activity of that muscle compared to the deltoid muscle. On the other hand, we thought that the wider frame, which has greater shoulder abduction, recruits the deltoid muscle more heavily than the supraspinatus muscle.

Furthermore, we had a subset of participants hold a 2.5-pound weight in their right hand while conducting the experiment. With this adaptation, we aimed to determine if the phenomenon could be negated using an external source. When subjects held a lightweight in their right hand, we hypothesized that the intensity of the phenomenon would decrease in their right arm, although it would still happen. In other words, we expected greater abduction of the left arm than the right arm, which held the weight.

Lastly, we had a subset of participants repeat the experiment while transcutaneous electrical nerve stimulation (TENS) units were used to stimulate the insertion area of the right shoulder. TENS units are commonly used as a safe, noninvasive method for pain management and to mask signals from the sensory nervous system.[9] Comparing the EMG and TENS results helped us determine if the primary source of the phenomenon is attributed to the sensory nervous system or the result of ongoing stimulation of the muscles by the motor nervous system.

Materials and Methods

A total of 39 volunteer subjects, all students enrolled at the University of North Carolina Asheville (n=14 male; n=25 female) participated in this study. Participants were asked to read and sign an informed consent form before data collection.

General procedure. To assess muscle force while pushing against the frame, we constructed two wooden stands, each equipped with holes to accommodate force plates. This allowed for customization to fit the height of individual participants. These stands were positioned on either side of a door frame and secured in place using tape to prevent movement. A force plate [Vernier FP-BTA] was hung on each stand to quantify the muscle force of the left and right arms during the experiment. Both force plates were marked with an “X” in the center to define where participants should place their hands when pressing against them (Figure 1).

Participants were instructed to stand upright between the door frames and exert force against the wooden stands by pushing with their elbows straight and the back (dorsal) side of the hands against the force plates. Participants were instructed to give their maximum sustainable effort, continually for 30 seconds. As motivation, participants could see their force readings during the experiment. Following the exertion, participants were directed to step back into the hallway and relax their arms, and pay attention to any sensation that was coming from their shoulders. Subsequently, subjects were asked about any sensations and involuntary movements they experienced. Volunteers conducted the procedure twice at door frames of different widths: wide (1.25m) and narrow (1.0m). The order of trials (wide/narrow) was randomized. Participants were given a rest period of 3-5 minutes between trials. After performing the activity in both widths, they were asked to subjectively rank which door frame setup (wide or narrow) produced the greatest effect.

Figure 1. (A) Wooden stands with a force plate attached enabled recording of force generated during the experiment. (B) Subjects pressed against force plates with the back (dorsal) surface of the hands.

Muscle force and fatigue. We used Logger Pro 3.16.2 software to record and quantify the force with which the subjects pushed against the frame. We calculated the average force throughout the hold and the force integral (area under the force-time curve) over the 30 seconds for both the right and left arms. Additionally, the effort and degree of fatigue experienced by the subject were calculated by dividing the average force values over the first 5 seconds of the trial by the average force generated over the last 5 seconds of the trial.

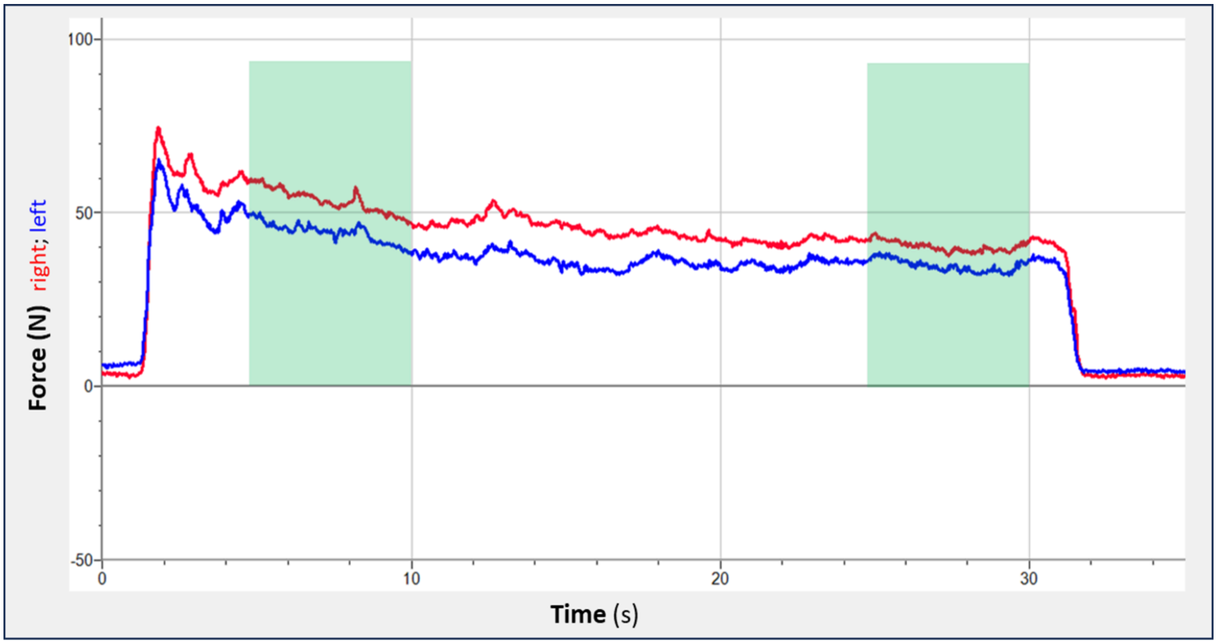

Figure 2. Force (N) recordings for right and left limbs, with beginning and end hold periods highlighted.

Muscle electrical activity. To quantify patterns of motor unit recruitment, a random subset of participants (n=15) had surface EMG electrodes affixed to their supraspinatus and deltoid muscles on their right shoulder while they conducted the trials. We chose these muscle groups because past studies have shown that they greatly contribute to shoulder abduction.[12] Additionally, we followed the sensor placement procedure for surface EMG when conducting the experiment. The steps consisted of the selection of the EMG sensor, preparation of the skin by avoiding contact with external objects, positioning of the patient in the starting experiment posture, determination of the sensor location, placement and fixation of the sensor, and testing of the connection.[11] Two channels were recorded using Biopac Systems MP160. Electrode placement can be seen in Figure 2.

Channel 1 primarily recorded the electrical activation of the deltoid muscle, with the red (+) and white (-) electrodes placed over the middle deltoid muscle on the right arm and the ground electrode placed at the base of the neck. In channel 2, the (+) and (-) recording electrodes were placed on the right shoulder above the spine of the scapula, with the ground electrode placed near the base of the right neck. This electrode placement was optimal for recording the activity of the supraspinatus muscles but is in a position to also pick up signals from the trapezius. Ground electrodes were placed at locations in which the risk for a large common mode disturbance signal was minimal.

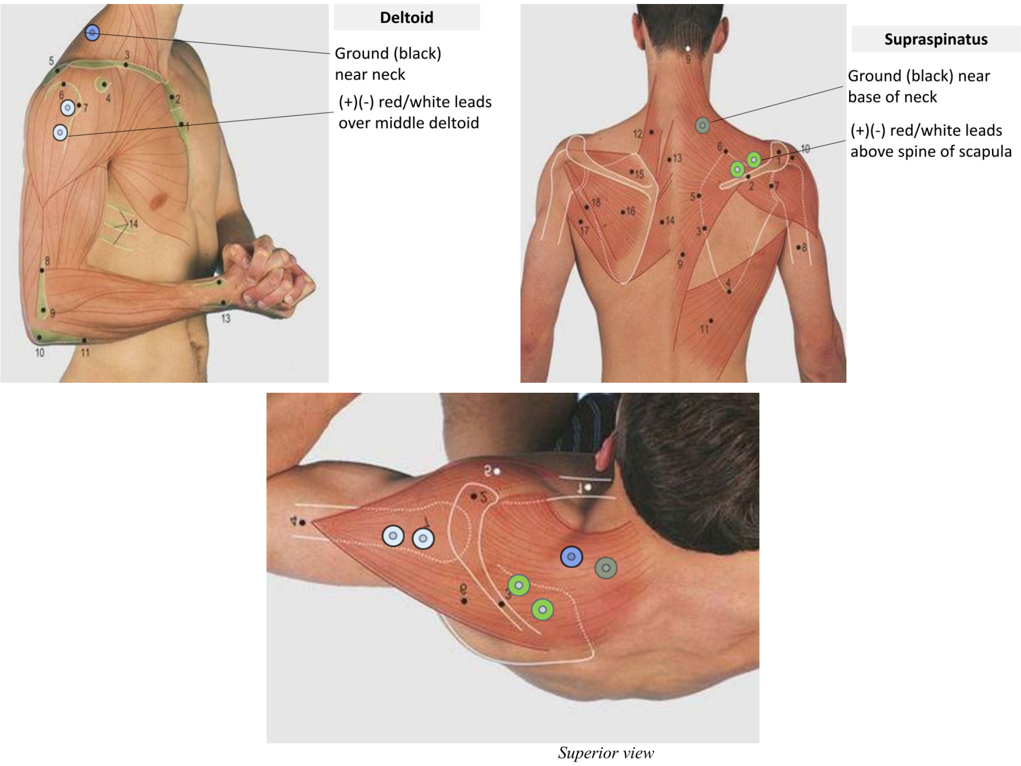

Figure 3. Placement of electrodes to record the primary abductors of the shoulder (deltoid and supraspinatus).

EMG analysis was performed using Biopac Student Lab 4.1 software. To eliminate artifacts in the data due to movement and electrical fluctuations, the original EMG data were transformed using the IIR (infinite impulse response) digital filter function available in the software package. Analysis was conducted using the transformed values. EMG readings were recorded for 5 different time periods during the experiment: Pre (prior to pushing against the frame), Early (at the beginning of 30-second hold), Late (towards the end of 30-second hold), Post 1 (immediately after stopping contraction), and Post 2 (a few seconds after Post1) [see Figure 3].

Figure 4. Representatives transformed EMG recordings for channels 1 and 2, with the 5 different time periods that were analyzed indicated.

Effect of external loading. Another subset of subjects (n=20) were asked to attempt the original trial (described above) at the narrow frame width, and then repeat the experiment while holding a 2.5-pound weight in their right hand. Subjects were asked to compare the sensations they felt compared to the original (no-weight) effect and also to compare the effects of their weight-bearing (right) to their other arm.

Electrical interference. Lastly, a subset of volunteers (n=12) repeated the experiment (at the narrow frame width) while being stimulated by a TENS unit attached to their right deltoid muscle. We utilized the TENS 3000 equipment set to 220 µS for pulse width and about 50 Hz for pulse rate. The intensity of the electrical stimulation was determined by applying an amount of electric current at a voltage that the participant could report feeling, but that was not strong enough to cause visible muscle contraction. The current was applied throughout the whole experiment, which included the 30-second voluntary contraction followed by the relaxation of the arms.

Results

Overall 33 of 39 total participants (84.6%) in this study experienced the Kohnstamm effect in standard position, pushing against the frame with the back (dorsal side) of the hand. Within the 33 subjects who experienced the phenomenon, 26 of them reported a greater effect when pressing against the narrow width; 4 subjects reported a greater effect when pressing against the wide width, while 3 subjects reported an equal effect when pressing against the two different door frame widths (Figure 4).

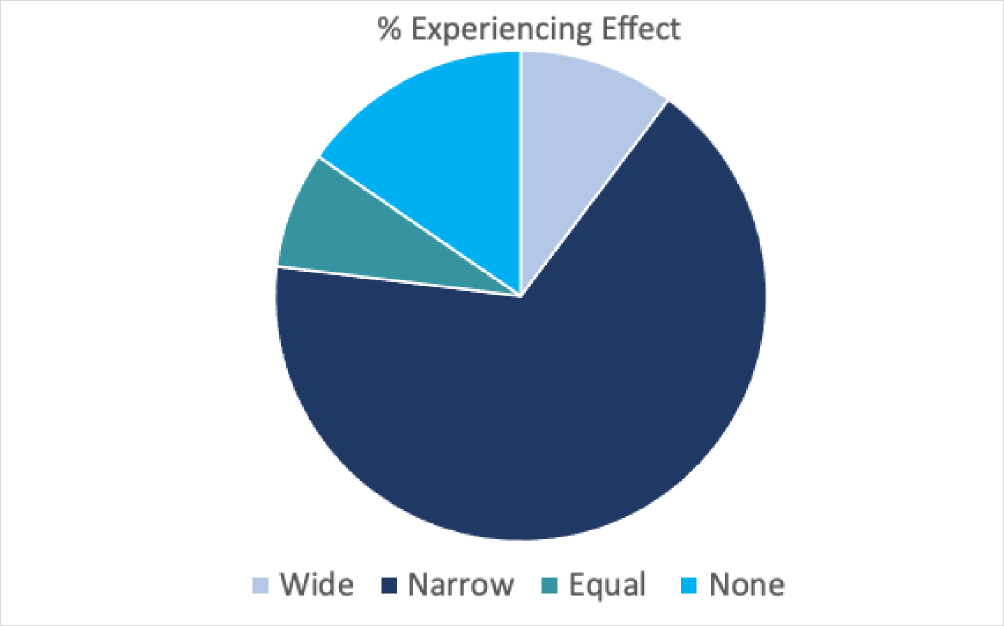

Figure 5. Percentage of participants who experienced no effect, greater effect at narrow width, greater effect at wide width, and equal effect at both widths.

Table 1. Force and fatigue of right and left arms for all (n=39) participants on the narrow (1.00 m) and wide (1.25 m) frame. Cells indicate mean ± standard deviation [minimum – maximum]

	WIDE	NARROW
FORCE (n)	Right: 56.6 ± 50.21 [6.2 – 280.4] Left: 54.0 ± 44.43 [4.3– 253.3]	Right: 59.4 ± 43.16 [8.5 – 232.3] Left: 49.7 ± 40.74 [6.54 – 220.5]
FATIGUE (%)	Right: 93.2 ± 14.47 [59.1 – 118.3] Left: 93.0 ± 13.57 [64.6 – 120.2]	Right: 103.1 ± 18.46 [49.7 – 146.1] Left: 96.4 ± 16.69 [43.1 – 134.7]

Summary statistics for force and fatigue during the 30-second hold are in Table 1 and figure 5.

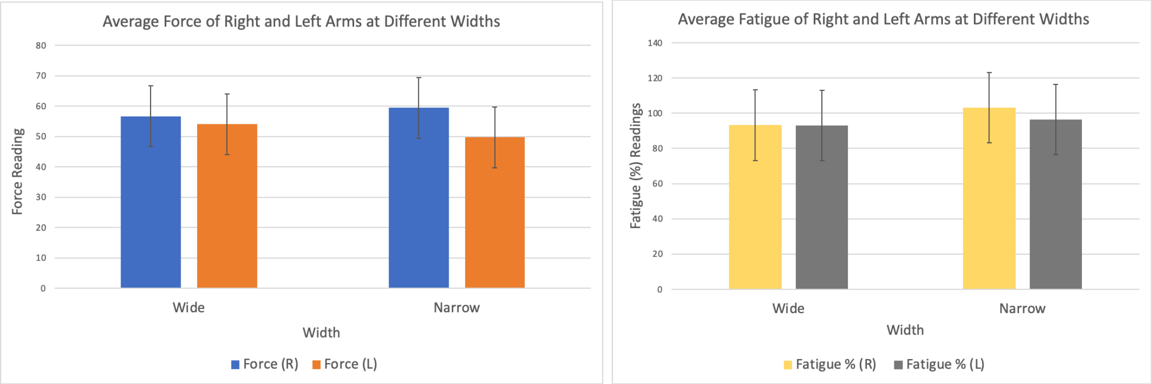

Figure 6. (A) Average force of right and left limbs at narrow and wide widths. (B) Average fatigue of right and left limbs at narrow and wide widths.

2-way repeated measures ANOVA showed no significant differences between the force generated by the left and right limbs (F(1,1) = 0.11, p = 0.74) nor was there a significant difference in the amount of force at the wide and narrow frames (F(1,1) = 0.05, p = 0.82)). No significant interaction between the two variables was detected (F(1,1) = 0.001, p = 0.97). Similarly, a 2-way repeated measures ANOVA of fatigue (%) detected no significant differences between the left and right limbs (F(1,1) = 0.74, p = 0.39) or the wide and narrow frames (F(1,1) = 3.62, p = 0.06), and no significant interaction between the 2 factors (F(1,1) = 0.66, p = 0.42)

Given the absence of significant differences between the left and right limbs, the analysis focused solely on data from the right limb when comparing individuals who experienced the effect with those who did not. At the narrow frame width, there was no significant difference between the amount of force exerted by participants who experienced the effect, compared to those who did not experience the effect (t(6) = 0.99, p = 0.36). Similarly, there were no significant differences in fatigue (the percentage change in force) in the participants who experienced the effect and those who did not experience the effect (t(4) = -0.43, p = 0.69). Similar results occurred at the wide frame width, with no significant difference in the amount of force exerted (t(4) = 1.32, p = 0.26) or fatigue experienced (t(9) = -0.93, p = 0.38) by subjects who did and did not experience the effect.

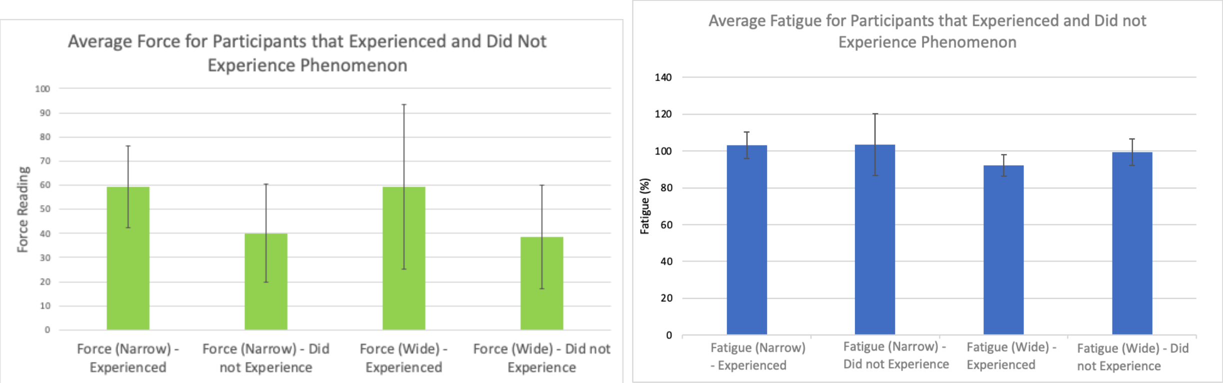

Figure 7. (A) Force readings for participants that experienced and did not experience the effect at narrow and wide width. (B) Fatigue for participants that experienced and did not experience the effect at narrow and wide width.

A summary of the findings of the EMG analysis can be found in Figure 6. Our results showed greater activity of channel 2 (supraspinatus) compared to channel 1 (deltoid) at post 1 (t(25) = -4.23, p = 0.0003). No significant differences between channel 1 and channel 2 were detected at any of the remaining 4 time periods ($p > 0.05$). EMG activity during the segment immediately following contraction (Post 1) was not significantly different than the period before contraction (Pre) for both muscle groups (channel 1: t(13) = 1.18, p = 0.26; channel 2: t(15) = 0, p = 1.00), indicating that the muscles are "turned off" before the phenomenon starts. However, both channels showed a significant increase in EMG activity in the later period after contraction, from Post 1 to Post 2 (channel 1: t(27) = -3.02, p = 0.005; channel 2: t(27) = -2.22, p = 0.03)

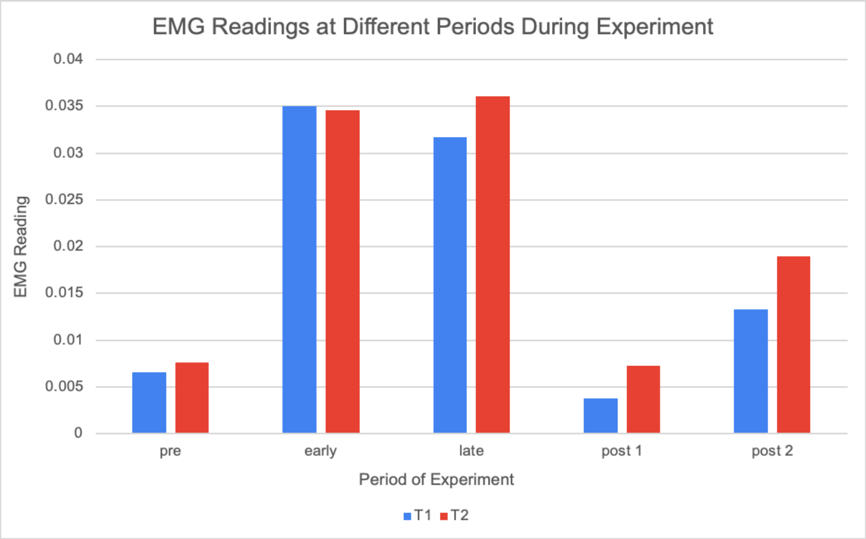

Figure 8. EMG readings at different periods during pre, early, late, post 1, and post 2 periods of the experiment.

Comparing the beginning and end periods of the 30-second hold (Early, Late), there was a significant decrease in channel 1 (deltoid) activity at the wide frame width (t(12) =

3.40, p = 0.005), but not at the narrow frame width (t(12) = 0.076, p = 0.94). In contrast, channel 2 (supraspinatus) showed a significant increase (t(12) = -2.50 , p = 0.02) in activation at the narrow frame width, but no significant changes at the wide frame width (t(12) = 0.04, p = 0.97)

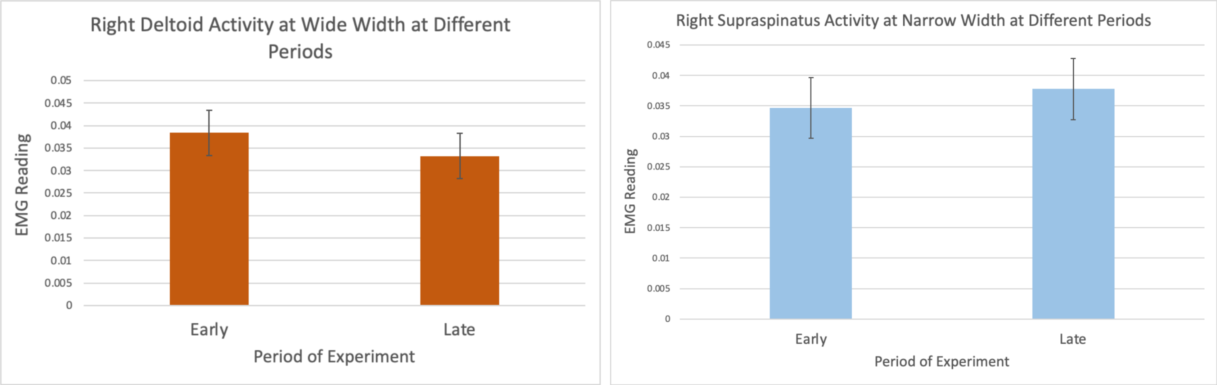

Figure 9. (A) EMG readings of right deltoid muscle at wide frame during early and late periods of the voluntary hold. (B) EMG readings of right supraspinatus muscle at narrow frame during early and late periods of the voluntary hold.

Of the 20 subjects who held a 2.5-pound weight while performing the experiment on the narrow-width door frame, 14 subjects (70%) reported that the phenomenon persisted, and 6 subjects (30%) reported that the phenomenon did not happen. For the subjects that reported the presence of the Kohnstamm phenomenon with the light weight in their right hand, 11 subjects (55%) stated that they felt a decrease in effect on their right arm, but felt no change in effect on the left arm compared to the original experiment, 2 subjects stated they felt no change in intensity of the effect, and 1 subject stated they felt a greater effect in the arm holding the weight.

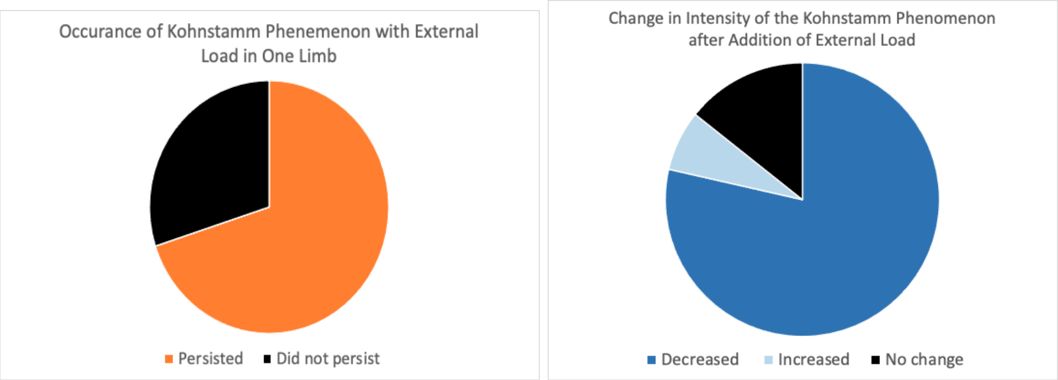

Figure 10. (A) Occurrence of Kohnstamm phenomenon with 2.5-pound weight in the right limb. (B) Change in intensity of the Kohnstamm phenomenon after addition of 2.5-pound weight in the right hand.

The effect of TENS stimulation on the subjective strength of the Kohnstamm effect was minimal. In a subset of participants (n=12 who had a TENS unit attached, 8 (66%)

self-reported a slightly decreased perception of the effect, and 4 (34%) reported no noticeable change.

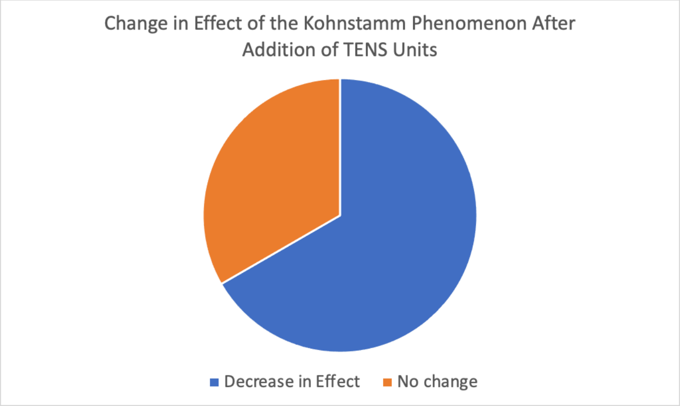

Figure 11. Change in effect of the Kohnstamm phenomenon after addition of TENS unit on subject's right deltoid muscle.

Discussion

The aim of this study was to investigate the Kohnstamm phenomenon, specifically honing in on the standpoint of the muscles involved in this movement in the peripheral nervous system. More specifically, we aimed to examine the effect of shoulder position, muscle activation, external loading, and external electrical stimulation changes during the Kohnstamm phenomenon. To test these parameters, we set out a plethora of working hypotheses, in which their efficacy is recorded in the following paragraphs.

Before conducting the experiment, we hypothesized that the Kohnstamm phenomenon might not occur, as we expected a lack of force or effort exerted by the participants during the activity. We found no evidence to support this hypothesis. In both the narrow and wide testing conditions, our analysis did not yield substantial evidence to indicate that those who did not manifest the Kohnstamm phenomenon did so because of insufficient exertion during the exercise or excessive fatigue. The presence or absence of the phenomenon appears to be a trait that varies naturally among individuals.

Our study was further guided by the hypothesis that the intensity of the effect might vary with the distance the arms are abducted (frame width), which would help identify the muscle group that is primarily responsible for the effect. The supraspinatus is generally considered to be more active during the first several degrees of abduction, while the deltoid becomes more involved with greater degrees of abduction.[15] Of the 33 participants that experienced the phenomenon, the majority (n=26; 78.8%) of subjects reported a greater effect when pressing against the narrow width. This evidence suggests that the supraspinatus may be the greater contributor to the Kohnstamm phenomenon, contrary to most authors that attribute the effect to the deltoid. [4,16,3]

EMG analysis further elucidates the roles of the different muscle groups. We hypothesized that at the narrower frame, the supraspinatus muscle would be recruited deliberately, leading to a stronger EMG activity recorded. This effect was seen as the EMG from the supraspinatus increased throughout the hold at the narrow frame only, indicating a pattern of greater motor unit recruitment and possibly fatigue of that muscle.

A further hypothesis proposed that the wider frame will involve more deltoid muscle activity in comparison to the supraspinatus. We found a significant decrease in activation of the deltoid during the hold at the wide frame width, which did not occur at the narrow frame. This may indicate that the subject is experiencing more pain or fatigue at the wider frame width.

For the subjects who held a 2.5-pound weight in their right hand while participating in the experiment, we anticipated that there would be a greater abduction of the left arm in comparison to the right arm holding the weight, due to an external force negating the effect. When holding the weight, about 70% reported that the phenomena still occurred and about 30% did not experience the effect, which is similar to the percentage of participants in the control condition who experienced the effect versus those who didn’t. Over half of those who experienced the effect stated that they felt a decrease in the effect in their right arm, but no change in the left arm compared to the control condition. This suggests that holding the weight may dampen the effect for some people, but it does not increase or change the effect in the other limb.

The final discovery that we were hoping to make with this research was whether or not the primary source of the phenomenon is ascribed to the sensory nervous system or as a result of the ongoing stimulation of the muscles by the motor nervous system. We tested this by applying transcutaneous electrical nerve stimulation (TENS) units to stimulate the insertion area of the right shoulder. Of the 12 subjects in this research group, 8 (66%) self-reported a somewhat decrease in perception of the effect, while 4 (34%) reported no noticeable change in the effect. The level and type of stimulation that we applied were not sufficient to negate the effect, so a greater stimulus might be required to offset internal proprioceptive input. Given these findings, we can not make a strong statement about the role of the sensory nervous system in the Kohnstamm effect.

This study revealed significant differences in muscle activation between the supraspinatus and deltoid muscles at Post 1, with greater activity in the supraspinatus. This can be interpreted as a greater recruitment of the supraspinatus muscle over the deltoid immediately following contraction, meaning that the beginning of the involuntary muscle contraction stems from the rotator cuff muscles, which then goes to recruit the deltoid muscles; creating the effect. However, this discrepancy vanished in subsequent time periods. Despite this fact, both muscle groups exhibited increased activation from early to late post-contraction, indicating an increase in motor unit recruitment, even though this is the time period of involuntary movement. This means that there is further muscle activation even when there is an unintentional muscle contraction. It is intriguing that no statistically significant differences were observed between the time immediately after the voluntary muscle contraction (Post 1), and the muscle activity in early involuntary contraction (Pre), highlighting the latent period between when the muscles are turned off and then activated again during the involuntary muscle contraction of the phenomenon. These findings deepen the perspective of sustained muscle contractions and the related muscle activity.

The limitations of this research include inevitable inconsistencies in the placement of electromyography (EMG) electrodes on participants due to user error. Additionally, early studies have shown variation in EMG signals recorded by a single electrode during repeated identical actions[13], which may contribute to discrepancies between subjects' EMG readings. Furthermore, the movement of participants during the recording phase of the experiment posed challenges to the accuracy of the EMG readings, which could cause an unwanted confound in this experiment. Other limitations may include user error using the force plates, as these need to be zeroed out before each use. In addition, the participant pool was created from a population of college students, so this sample has a lack of generalizability among the general population. It should be noted that there is a lack of significant findings, which may be due to a variety of factors including a small sample size.

The subjective nature of measuring the phenomenon through participant self-reports of arm raising or light sensation of the limbs introduces potential biases and inaccuracies in the data. It is also important to acknowledge that some individuals may actively resist or inhibit the observed effect of the phenomenon, which could impact the reliability of the findings. These limitations accentuate the importance of interpreting the results with caution and indicate potential directions for future research aimed at mitigating procedural challenges.

People are plagued with conditions and illnesses that cause involuntary muscle contractions such as Parkinson's Disease, Tourette Syndrome, or Huntington's Disease. Further exploring the mechanisms of these awry muscle contractions and the physiology that may cause them is key to understanding the methods by which we try to treat this particular symptom of these diseases. There are also situations in athletics, both in the performance and recovery realms, that may benefit from training each muscle group in this way.[17] Moreover, understanding the Kohnstamm phenomenon may help to treat athletic injuries that cause involuntary muscle contractions. Exercise-associated muscle cramps (EAMC), for example, are the most common heat-related illness in athletes but their cause and mechanism of action are unclear. Recent studies suggest that EAMC is caused by a convergence of an individual's intrinsic and extrinsic risk factors, which can change the central and peripheral nervous system excitability.[14]

Future research on the Kohnstamm phenomenon would include similar tests with different peripheral muscle groups, such as the calves, hamstrings, quads, etc. It could also be done on more central muscle groups such as the latissimus dorsi, or abdominal muscles. Additionally, there is a necessity for research in this area including large and representative samples of participants to generalize the findings better to the greater population.

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