The Effect of Anxiety on Postural and Voluntary Motor Control.

Mina Gerges

35428119

Master of Kinesiology, Kin 595

Supervisor: Mark Carpenter

Second Reader: Romeo Chua

Introduction

Anxiety is a negative emotion that is distinguished by a tense anticipation of a vague and harmful event (Rachman, 2004). Despite experiencing increased vigilance, anxious individuals may be unable to identify the cause (Rachman, 2004). Anxiety can also persist for long periods of time especially if it is trait anxiety which is usually part of the individual’s personality and not an incident driven emotion (Gidron, 1989). Fear is also a negative emotion that is identified by an anticipation of a harmful event; however, it is the result of a clear and direct danger that the individual perceives. The cause of fear is an obvious threat that can be considered an emergency and is accompanied by a sympathetic response (Rachman, 2004). Since it is controlled by specific stimuli, fear is temporary and usually ceases when the threat is removed. Both fear and anxiety cause an elevation in physiological arousal with symptoms like increased heart rate (HR) and perspiration. The literature discussed below have adopted measures of arousal and/or anxiety, however it is important to highlight the difference between the two. Arousal is a state of heightened physiological activity that is characterized by an increase in wakefulness and consequent alertness and attention. Arousal is not an anxiety or fear specific symptom, it can occur with any emotional presence like joy, anger, excitement, frustration or hate. Therefore, experiments that use physiological measures like heart rate or perspiration can confirm the presence of arousal but not necessarily anxiety. Subjective measures like questionnaires and surveys are usually used to detect change in anxiety and fear.

The influence of anxiety on human movements has been shown in previous literature. For instance, anxiety has biomechanical effects on gait characterized by slower velocity, shorter stride length, broad-based gait, longer times in the double limb support phase (both feet touching the ground simultaneously), significantly smaller range of motion in the ankle, knee, and hip, and a smaller angular velocity in ankle joint (Brown, Gage, Polych, Sleik, & Winder, 2002; Jahn, Zwergal, & Schniepp, 2010). In addition, anxiety can influence the physiological economy of gait and running. Nibbeling, Daanen, Gerritsma, Hofland, & Oudejans (2012) showed higher oxygen uptake in gait patterns under anxiety despite its conservative characteristics. The influence of anxiety can also be seen in competitive settings. Nibbeling et al. (2012) showed a reduction in performance and efficiency of dart throwing with anxiety. Similarly, social-induced anxiety has been shown to increase arousal in pianist performers causing elevations in HR, perspiration, Electromyography (EMG), and co-contractions of muscles the shoulders, and most importantly a reduction in performance (Yoshi, Kudo, Murakoshi, & Ohtsuki, 2009). There is similar evidence showing the same effects in professional and amateur sports (Englert & Bertrams, 2012; Judge et al., 2016).

The purpose of this thesis is to investigate how anxiety influences human movement. I will be comparing and contrasting the effects of anxiety on upper body movements versus postural control. This comparison will focus on the physiological dimensions of anxiety and how it influences kinematics and muscular behavior. The upper body literature discussed below will involve some isometric contractions, corrective responses, and anticipatory responses. It is acknowledged that the level of voluntary involvements in all three types will differ depending on the task and the reader’s perspective. For the sake of simplicity, they will all be categorized as “voluntary upper body movements”.

The Psychological Influence of Anxiety on Motor Control.

Anxiety has a psychological component that is important to address in order to understand its overall influence on motion. A feeling of anxiety is the result of an excitation in the amygdala of the limbic system which reduces the contributions of prefrontal control mechanisms over behavior (Bishop, Duncan, & Lawrence, 2004a, b; Kim et al., 2004; Somerville, Kim, Johnstone, Alexander, & Whalen, 2004). Thus, anxious individuals find it difficult to concentrate on a task and efficiently process the relevant information, which often leads to a decrease in cognitive performance and motor control (Beilock & Gray, 2007; Eysenck & Calvo, 1992; Eysenck, Derakshan, Santos, & Calvo, 2007). The psychological effects of anxiety have been explained by two models: "the distraction model" from attention control theory and "the execution focus model". The first model proposes that if more attention becomes focused on the threat, there are less resources available to dedicate to the task and therefore a decrease in quality or success rate is observed (Nieuwenhuys & Oudejans, 2012). For example, when a soccer player is required to take a penalty kick, under anxiety he/she may focus his/her attention on the goal keeper (source of threat) rather than the target resulting in missing the shot. On the other hand, the execution model proposes that the amount of attention given to a specific task does not change, especially when that task becomes automated (like in professional musicians). Instead, anxiety leads to attention being drawn inwards, causing a desire to consciously control every movement. For experts, this disrupts their automated ability and overall quality (Nieuwenhuys & Oudejans, 2012). Although both models propose different mechanisms, they lead to the same outcome, that is a drop in performance. Beyond attention, anxiety can also influence the interpretation of external information. One may pay sufficient attention to task-relevant information; however his/her interpretation of such information can be biased towards threat. For instance, at a given height, individuals who suffer from fear of heights tend to perceive being higher than individuals who are not afraid of heights (Teachman, Stefanucci, Clerkin, Cody, & Proffitt, 2008). Similarly, police officers who are afraid of being hurt on duty are more likely to recognize a suspect's weapon even when there isn't one, making them more susceptible to wrongful shootings (Correll, Park, Judd, & Wittenbrink, 2002; Nieuwenhuys, Savelsbergh, & Oudejans, 2012; Payne, 2001). In addition, anxiety has a known effect on behavior, both emotionally and physically. It can halt action readiness and cause a tendency towards emotional responses. It also increases heart rate (HR), breathing rate, muscle activity and energy expenditure all which can cause inefficiency in motion (Nibbeling et al., 2012; Pijpers, Oudejans, Bakker, Beek, 2006).

Static balance/quiet stance

Static balance is the ability of an individual to hold an upright posture by maintaining the centre of mass (COM) within the base of support (BOS) during quiet stance (Bannister, 1969; O'Sullivan, Schmitz, Fulk, 2014). In the inverted pendulum model, the body is controlled as a rigid segment that rotates around a single point at the ankle joint. The centre of pressure (COP) is the average point of all forces applied by the body on the ground. The COP is seen to control the movement of the COM; the amplitude of movement of the COP must be greater than that of the COM in order to accelerate the COM in the opposite direction (Carpenter, Frank, & Silcher, 1999). In the lower limb, the COP is manipulated using postural muscles. Anteriorly, ankle muscles like tibialis anterior (TA) contract to dorsiflex the foot and cause the COP to move backwards and the individual to tilt forward at the ankle joint. On the posterior side, muscles such as the medial and lateral gastrocnemius and the soleus (SOL) contract to counterbalance the activity of the anterior muscles; they cause the COP to shift forward and the individual to tilt backwards at the ankle joint (Moore, Agur, & Dalley, 2011). The nervous system is responsible for maintaining a delicate balance between the anterior and posterior muscles for the body to stay upright and not tilt too far in either way. As this is achieved, the COM is successfully contained within the BOS outlined by the individual's feet. The movement of the COM within the BOS during quiet stance is known as "Postural Sway" (Carpenter, Frank, Silcher, & Peysar, 2001).

There is a significant body of literature examining the effect of anxiety on static balance. In a study by Carpenter et al. (2001), 3 conditions were created using height to compare anxious and non-anxious conditions for subjects. At low threat, the subject stood at low height away from the edge; at medium threat, the subject stood at high height and away from the edge, at high threat, the subject stood at high height at the edge. The results indicated that the COM and COP movements inside the base of support were significantly influenced by postural threat. The mean power frequency (MPF) of the COP increased while the displacement amplitude of the COP and COM decreased resulting in a reduction in sway. There was also an observed stiffness at the ankle in high threat conditions compared to medium and low. This stiffness, along with the decrease in postural sway, are achieved through an increase in co-contraction at the agonist and antagonist muscles of the ankle joint (Carpenter et al., 1999). These results were replicated in multiple other experiments with additional patterns being shown. Work by Adkin, Frank, Carpenter & Peysar (2000) relied on a similar methodology; however they used double the height used in the previous experiment with 1.6 m compared to only 0.8 m. The results were similar to those explained above: an increase in COP frequency and a decrease in its displacement with postural threat. Another study by Cleworth, Horslen & Carpenter (2012) compared the effects of real height-induced anxiety to virtual height induced anxiety. Electrodermal Activity (EDA) was recorded in both modalities. With real and virtual height, there was an increase in EDA indicating an increase in arousal. The COP behaved similarly in real and virtual height as described above. This experiment demonstrated the benefits of virtual reality as it can simulate threatening situations without compromising the safety of the subject.

Looking at a different demographics, work by Brown, Polych & Doan (2006) compared the effects of postural threat on older versus younger individuals. They implemented edge/no edge conditions at each height to have different levels of threat and examine the effect of injurious consequences of falling (when standing at edge). The findings were consistent with prior work: smaller COP displacements and an increase in frequency. In addition, there was no difference in the effect of anxiety on older versus younger adults. Regardless of age, there was a more conservative approach to postural control with the addition threat. No comparisons were made in terms of the magnitude of reduction in sway between older and younger participants.

Emotional differences between individuals may play a significant role in how they respond to threat. A study by Davis, Campbell, Adkin, & Carpenter (2009) was designed to obtain a deeper understanding of the influence of emotional state and fear of falling on postural control. Healthy young adults were recruited to perform a quiet standing task at low and high heights. Some of these subjects reported an increase in anxiety and a robust fear response at height while the remaining subjects reported an increase in anxiety and a minimal fear response. Both groups showed an increase in COP frequency with height. Interestingly however, only the non-fearful group showed a reduction in COP displacement while the fearful group showed an increase in COP displacement. A similar study by Sturnieks, Delbaere, Brodie & Lord (2016) examined how trait anxiety can affect the response to postural threat. Trait anxiety reflects the level of consistent predisposed anxiety that an individual may express in his/her behavior. Prior to standing at height, subjects were categorized into "fall concerned" and "not fall concerned" based on the falls efficacy scale-international and "anxious" and "not anxious" based on the Goldberg anxiety scale. Compared to those with low trait anxiety, individuals with higher trait anxiety usually have an elevated and more permanent sense of tension and they experience higher levels of physiological and cognitive arousal and motor impairment under threat (DeMoja & DeMoja, 1986; Grillon, Ameli, Foot, & Davis, 1993; Noteboom, Barnholt, & Enoka, 2001; Sade, Bar-Eli, Bresler, & Tenenbaum, 1990; Weinberg & Hunt, 1976; Weinberg & Ragan, 1978). Findings indicated that fall concern did not affect the postural control observations expected at height. However, “anxious” individuals did not decrease their postural sway while the non-anxious individuals swayed less at height. All groups showed an increase in COP frequency.

In the real world, there are multiple stimuli that can elevate anxiety and arousal other than height. In a study by Horslen and Carpenter (2011), pictures were used to stimulate emotions while subjects carried out quiet stance trials for 90 seconds each. The pictures were categorized by normative ratings of arousal (high and low) and valence (pleasant and unpleasant). EDA and the Self-Assessment Manikin (SAM) for arousal and valence scales were used to confirm the presence of arousal and valence. The results showed an increase in COP frequency and a decrease in displacement with arousal but not with high valence pictures. Another study by Tanaka, Shimo and Nosaka (2016) who asked their subjects to maintain standing posture on a balance board. They used a cash reward-punishment protocol that was dependent on the subject’s performance. They also used HR to confirm an increase in arousal under the anxious trials. The area in which the COP moved was significantly smaller in pressure trials compared to the non-pressure trials confirming an anxiety related effect on postural control. In contrast, in work by Hainaut, Caillet, Lestienne and Bolmont (2011) anxiety was induced using a Stroop color word test with interference which relies on color words printed in incongruent colors. The subject was asked to say the colour of the ink used in each word rather than the word itself, as quickly as possible. To simulate public performance anxiety, the subject was filmed with a video camera and shown his/her own trial live as they performed it. The results showed that under anxious conditions there was an increase in COP displacements, contradicting height studies and the two studies mentioned above. One limitation to this study is that anxiety was confirmed using the STAI Y1 and Y2 forms which are questionnaires that rely on subjective reporting.

Table 1 summarizes the literature discussed in this section. Height induced anxiety leads to an increase in COP frequency, joint stiffness, and co-contractions in postural muscles. It also leads to a decrease in postural sway. These observations are also individual dependent where predisposed anxiety and fear of falling can increase postural sway at height. Non-height induced studies show mixed results when it comes to postural control.

Height Studies	Subject	Stimulus	COP Frequency	COP displacement	COM displacement	Co-contraction	Arousal measurement
Carpenter et al. (2001)	Young adults	Height (0.8 m)	↑	↓	↓	↑	
Adkin et al (2000)	Young adults	Height (1.6 m)	↑	↓	↓		
Cleworth et al. (2012)	Young adults	Real and virtual height	↑ in both conditions	↓ in both conditions	↓ in both conditions		EDA & questionnaires
Brown et al. (2006)	Young vs. old	Height + Edge/no edge	↑ in both groups	↓ in both groups			Galvanic skin conductance
Davis et al 2009	Young adults. Fear grouping	Height	↑ in both groups	↓ in non-fearful. ↑ in fearful			EDA & questionnaires
Sturnieks et al (2016)	Older adults. Trait anxiety grouping	Height	↑ in both groups		↓ in non-anxious. ↑ in anxious.		EDA, Blood pressure

Non - Height							
Horslen and Carpenter (2011)	Young Adults	Pictures	↑ in arousal not valence	↓ in arousal not valence			EDA & questionnaires
Tanaka et al. (2016)	Young adults	Cash reward/punishment		↓		↑	HR
Hainaut et al (2011)	Young adults	Stroop color word test + Social anxiety		↑			STAI Y1 and Y2 forms

Table 1: summary of Static balance literature.

Isometric Upper Body Motor Control.

Quiet stance involves joints that employ agonist and antagonist muscles to hold a static position against a constant force (Gravity). Therefore, the motor tasks chosen for comparison will be isometric in nature and involve agonist and antagonist counterparts. For example, the ankle joint in static balance studies can be compared with the elbow joint in an isometric hold at 90 degrees or the metacarpo-phalangeal/interphalangeal joints in a pinch hold task. This should provide a similar enough comparison between upper body motor control and postural control under anxiety.

In a study by Noteboom, Fleshner and Enoka (2001), they investigated the effect of adding a stressor to an isometric task. The subjects were asked perform a pinch hold between the thumb and the index finger on a force transducer and apply a continuous 4 N force for 10 seconds. Steadiness during the task was quantified as the coefficient of variation for force; an increase in the coefficient means a reduction in steadiness. Some trials were performed without any stressors as a baseline while others were performed with an electric shock delivered to the back of the left hand (the non-performing hand). The shocks were delivered randomly without prior knowledge from the subjects. Physiological parameters such as continuous HR, blood pressure (BP), and EDA were used to measure arousal. The results showed that under the stress of electric shock, subjects' steadiness declined and higher standard deviation around the target force was observed. These effects were present in both men and women. Similarly, work by Christou, Jakobi, Critchlow, Fleshner, & Enoka (2004) examined stress effects on young, middle and older adults. A series of noxious electrical stimuli were delivered randomly to the back of the non-performing hand. Subjects were asked to perform a pinch grip hold at 2% of their maximum voluntary force. Anxiety was assessed using the STAI-state index and the visual analog scale (VAS). Stress hormones like epinephrine, norepinephrine, cortisol and adrenocorticotropic hormone in venous blood were also monitored. During high stress periods, force standard deviation increased. This was most notable in older compared to middle and young adults. EMG amplitudes changes were insignificant under anxious conditions. The findings above were again replicated by Christou (2005) where all ages experienced a significant increase in force fluctuations; however older adults showed higher variance in force production with stress than young and middle-aged adults.

Another study was performed by Noteboom, Barnholt and Enoka (2001) to investigate whether similar results would be observed in individuals with different trait anxiety levels. Subjects were grouped into low or moderate trait anxiety. Electric shocks were delivered to the non-performing hand and their intensity was progressively increased with time. HR, systolic and diastolic blood pressure, and EDA were measured. The results showed that electric shock increased the variance in force in both low and moderate trait anxiety groups. The reduction in steadiness was greater and only statistically significant in the moderate anxiety group. This suggests that general arousal increases force variance in general; however the effect is exaggerated in individuals with moderate trait anxiety. EMG had no significant difference across conditions or groups.

The studies described above all used electric shock as a method to induce stress and relied on an isometric pinch task. There are other methods to induce anxiety and other tasks that were used in the literature. A study by Marmon and Enoka (2010) compared the effect of electric shock and cold pressor as a source of arousal. There is previous evidence that cold pressor, like electric shock, can increase sympathetic activity (Yamamoto, Iwase & Mano, 1992). The task was an isometric hold at 5% of maximal voluntary contraction of the index finger's abductor muscles. In contrast to studies described above, the addition of both stressors did not decrease the steadiness of the subject despite objective and subjective anxiety measures showing an increase in physiological arousal. In the study by Notebloom et al. (2001) mentioned previously where electric shock was used to stimulate anxiety, mental math was also used as a stressor. Subjects performed serial subtraction of a four-digit number. First, they counted backward by 13, starting from 1,022 and were instructed to count as fast and as accurately as possible. When a mistake was made, the investigator would say, "Stop. Begin again. 1,022,". In addition, subjects were asked to keep pace with a metronome that produced an auditory signal once every 3s. This went on for 5 minutes then the subjects performed the pinch task and completed the VAS assessment. Subsequently, the math task was continued for another 5 min. Then, the investigator told the subjects "This task is obviously too difficult for you. Instead, please count backward by 7, again starting from 1,022. Begin.". Immediately after the second math stressor, the pinch task was repeated, and the VAS was assessed again. Although there was a significant increase in EDA with this protocol, it was still smaller than the increase seen with electric shock. The mental math condition in this experiment was more taxing than other studies and there was added pressure from the investigator. Despite that, there was no increase in force fluctuations with the mental math condition. Finally, a study by Coombes, Gamble, Cauraugh, and Janelle (2008) looked at the effect of showing pleasant, unpleasant or neutral pictures on force production in a pinch grip task. There were no physiological or psychological measures for arousal and anxiety. There were no changes in force fluctuations.

Table 2 summarizes the literature concerning the effect of anxiety on upper body motor control. Despite one exception in the work by Marmon and Enoka (2010), electric-shock induced anxiety seems to increase force variance in isometric tasks. Other methods to induce anxiety such as mental math, emotional images or cold pressor seem to have no influence on force fluctuations. Important to note that most of the studies used here relied on an pinch hold task.

	Subjects	Stimulus	Force Variance	EMG	Measurement of arousal/anxiety
Notebloom et al (2001)	Young adults	Electric shock vs. mental math	Electric shock: ↑. Mental math: no change.		HR, BP, EDA, VAS
Christou et al (2004)	Young, middle & older adults	Electric shock	↑ More in older adults.	No changes.	STAI-state index, VAS, Stress hormones
Christou (2005)	Young, middle & older adults	Electric shock	↑ , more for all older adults		
Notebloom et al. (2001)	Moderate vs. low trait anxiety	Electric shock	↑, more for moderate trait anxiety	No changes	HR, systolic & diastolic BP, & EDA
Marmon and Enoka (2010)	Young adults, finger abduction task	Electric shock vs. cold pressor	No change for both stimuli		HR & questionnaires

Coombes et al (2008)	Young adults	Pleasant, unpleasant & neutral pictures	No changes		

Table 2: summary of Isometric literature.

Discussion

Anxiety has a stiffening effect on postural control in quiet stance where there is an increase in COP frequency, and a decrease in COP and COM displacement. Carpenter et al. (2001) proposed that the rigidity observed with height is due to the CNS implementing tighter control over the COM within a smaller area in the base of support. This is achieved through an increase in co-contractions and background muscle activity in agonist and antagonist muscles in the ankle joint. The overall result is a reduction in standing sway.

In the work by Davis et al. (2009) and Sturnieks et al. (2016), individuals with trait anxiety or experienced a robust fear response at height showed an increase in COP frequency but not in COP displacement or overall sway. These findings were explained by Sturnieks et al. (2016) using the distraction and the execution focus models. The increase in COP frequency in all groups signify the attempt of the CNS in all subjects to have tighter control over the COM; however only those with low trait anxiety are able to do so. In predisposed trait anxiety, individuals may adopt an internal focus over balance and attempt to control it consciously (McNevin & Wulf, 2002). This leads to loss of automaticity and consequently, an increase in sway. Alternatively, fearful or anxious individuals may have a poorer ability to prioritise attention and filter sensori-motor noise resulting in fewer resources being allocated toward postural control (Loram et al., 2001). Nevertheless, it seems that predisposed anxiety and fear of falling have a significant effect on standing balance where postural sway increases in threatening conditions.

In experiments that did not use height to induce anxiety, the results have been mixed. The work by Horslen & Carpenter (2011), Cleworth et al. (2012) and Tanaka et al. (2016) showed an increase in COP frequency and a reduction in COP displacement with arousal and/or anxiety. In contrast, the work by Hainaut et al. (2011) which used the Stroop color test showed in increase in COP displacement. The differences in results can be attributed to the methodology used. Although the Stroop color test in Hainaut et al. (2011) requires mental effort, it may not be the correct stimulus to induce anxiety or arousal. The study by Horslen and Carpenter (2011) used EDA and SAM scales to measure arousal and valence while the study by Hainaut et al. (2011) only used questionnaires (STAI Y1 and Y2). These mixed results highlight the importance of using both physiological and psychological measures of arousal and anxiety. Simply being emotionally affected or mentally occupied does not necessarily cause an anxiety related effect on postural control.

Upper Body Motor control

Anxiety seems to increase force fluctuations in isometric upper body motor control. It also seems to have no effect on background EMG in the muscles involved. This is based on work that used electric shock to induce anxiety. The effects were magnified in individuals with trait anxiety (Nootebloom et al., 2001) which can be explained by the distraction and execution focus models similar to the work by Davis et al. (2009) and Sturnieks et al. (2016) in postural control. On the other hand, the study by Marmon and Enoka (2010) showed no increase in force fluctuations with electric shock in an isometric finger abduction task. Differences in results can be explained by the parameters of the electric shocks delivered (voltage, duration and frequency). It could also be due to the task employed where finger abduction does not allow for delicate motor control and therefore no significant changes in variance were seen. In the upper body literature, methods other than electric shock were used to induce anxiety like cold pressor, mental math and pleasant/unpleasant images. The results from these studies showed no increase in force variance. This could be due to the type of stimulus used not being strong enough to induce anxiety. For example, in the study by Notebloom et al. (2001), mental math was compared to electric shock. Although there was an increase in EDA with mental math, it was not to the same magnitude as electric shock. This highlights that not all stimuli are equal in their ability to induce an anxiety-related effect; this should be considered in future studies.

Comparison

One major difference between the experiments looking at postural control and those looking at upper body control is the context of the threat applied. Most balance studies rely on height where there is a risk of falling; the potential of harm is dependent on the performance of the task, that is if the subject loses balance, they will fall. The threat is task-dependent and therefore it is logical that improvements to the task are usually observed in order to minimize the risk. On the other hand, anxiety in the upper body studies was mostly induced using electric shock. The individual's performance in a pinch task did not determine the frequency or the intensity of the shocks delivered. This also applies even when other stimuli were used like cold pressor or emotional images. Therefore, the risk of harm is not related to the task and therefore it is logical to expect a distraction from the task and a shift of attention towards the anticipation of the next electric shock. The context of the threat is an essential variable that needs to be controlled to be able to make appropriate comparisons. One exception to this pattern was the study by Horslen and Carpenter (2011) where arousal and valence images were shown to the subject. In this case, the stimulus is not related to the task, yet the anxiety-related effects on postural control were observed. More experiments similar to the last study are needed in order to confirm this effect.

Future studies should involve a task and a threat that are connected in upper body experiments, like implementing a frequency of shocks this is dependent on the performance of a pinch task.

Older adults

In older adults, the upper body literature showed an exaggerated effect of anxiety on force variability. Although older adults showed an increase in force fluctuations in all anticipatory, stressor, and recovery phases of Christou's protocol (2005), the effect was still magnified in the stressor period. On the other hand, static balance studies showed similar patterns in young and older adults when it comes to postural control under anxiety. This could be explained by tasks involved in these experiments. The pinch hold task requires fine motor control in the hands which tends to disappear with age while the standing balance relies on large leg muscles with gross motor control (Seidler et al., 2010). Nevertheless, there was a magnified effect with anxiety in the upper body that was not seen in postural control. This could be explained by the consequences of the tasks involved in each category where a fall from height is much more detrimental than being electrically shocked.

Conclusion

In quiet stance or isometric tasks, the effect of anxiety on posture is different from that on upper body motor control. However, this could be simply due to the context of threat used in each experiment. Future studies should implement threat related tasks and psychological and psychological measures of anxiety and arousal.

Dynamic Balance

While quiet stance requires the individual to control the COM in a static position, dynamic balance requires the control of the COM during motion or in response to perturbations

(Bannister, 1969). The CNS can displace the COM without losing stability by keeping its motion within the BOS (O'Sullivan et al., 2014). The literature discussed here will address dynamic balance during perturbations, more specifically the corrective responses employed to regain stability. One relatable example is being onboard a bus which suddenly accelerates; the standing passengers feel an external force making them lean backwards and they must respond with a postural correction to prevent a fall from occurring.

There are some common corrective patterns observed in the case of a perturbation to quiet stance. Losing balance can occur from multiple sources, a translational force in any direction, a rotational force of the ground or acceleration/deceleration of a moving vehicle. In any perturbation, there is a muscular stretch in one or more joints like the ankle and the hip. For example, if an individual is pushed from the back, their COM is displaced in the forward direction and there is a stretch in ankle planter flexor muscles. Just like a stretch reflex, postural corrections have involuntary short latency M1 (40–100 ms), medium latency M2 (80–120 ms) and long latency M3 responses (120–220 ms). Following these 3 phases, other voluntary responses may take place like secondary balance-correcting responses (240–340 ms), and stabilizing reactions (350–700 ms) (Carpenter, Frank, Adkin, Paton, & Allum, 2004; Jacobs & Horak, 2007). The main balance correcting responses are thought to be the long latency M3 responses.

Anxiety has a significant effect on dynamic balance. A study by Cleworth, Chua, Inglis, and Carpenter (2016) examined the effect of postural threat and anxiety on dynamic balance and corrective responses. In this experiment, virtual reality (VR) was used to simulate being at low or high height. VR has been previously used to induce fear and anxiety with postural effects similar to those observed in a real setting. (Cleworth et al., 2012; Hsiao, Simeonov, Dotson, Ammons, Kau, & Chiou, 2005). Subjects were shown a low virtual height at 0.4 m and a high virtual height at 3.2 m. During each height, the subject experienced 8 forward and 8 backward surface perturbations that were delivered randomly. The subjects were asked to remain upright and not step; however when they did the trial was removed. Anxiety was assessed using a questionnaire after every block of trials. The forward perturbations data were removed due to high stepping rate. As expected, there was an initial forward displacement of the COM in response to backward perturbations followed by a correction to the original position. There was no difference in COM movement between low and high conditions. In addition, there was no difference in leg and trunk displacements between the two heights. Arm flexion and abduction however increased significantly in the high compared to low condition. Unlike the COM, the virtual height had a significant effect on COP. There was an initial forward displacement in COP in response to the backward perturbation in order to follow and control the COM displacement. In addition, the peak displacement and the time to peak COP displacement were significantly larger and faster at the high condition, respectively. The heightened COP responses can be attributed to an increase in background activity observed in the TA and an increase in co-contraction in the ankle plantar and dorsi-flexors. In addition, the high condition led to earlier onsets in the medial gastrocnemius, the deltoids and the external obliques and significantly larger EMG amplitudes in deltoids and medial gastrocnemius.

Another study by Brown and Frank (1997) looked at dynamic corrective balance using real height to induce anxiety. The purpose of this study was to focus on the COM and how its control changes with anxiety. Unlike the previous study where the standing surface translated forward and back, here the perturbations were delivered to the upper back causing a forward force. Trials took place at a low height at ground level and a high height which was determined individually using a psychometric test designed to determine the maximum perceived and the maximum real height from which individuals could descend using a typical `step down' response. The platform exceeded the maximum perceived height. Following the nudge, subjects were instructed to maintain their balance, stepping was permitted but step trials were removed from data analysis. At height, there was a reduction in the COM forward displacement and a shorter latency to the first peak of COM velocity. The time to the first velocity peak represents the time the CNS needs to initiate corrective strategies and impose control over the COM. There were no measures of fear or anxiety in this study.

Finally, work by Carpenter et al. (2004) examined the effect of height-induced anxiety on corrective responses to standing surface rotations. Participants stood at heights of 60 or 160 cm above the ground and were subjected to random surface rotations in multiple directions. Kinematics and EMG activity were recorded. With height, there was a reduction in COM displacement, and reduced displacements of the leg, pelvis and the trunk. This was accompanied by an increase in EMG amplitude of balance-correcting responses at 120-220 ms in leg, trunk and arm muscles; however height had no effect on muscle background activity except for the bicep femoris.

Table 3 contains the results of the three experiments discussed above. The effect of anxiety on dynamic postural corrections can be seen in larger and faster COP displacements, shortened response times from the CNS, increase in muscle background activity especially in the lower leg, increase in amplitude of balance-correcting responses, and finally an increase in antagonist muscle co-contractions. Such changes result in more conservative COM displacements after perturbations, keeping it within the base of support and limiting the risk of a fall.

	Cleworth et al. (2016)	Brown & Frank (1997)	Carpenter et al. 2004
Stimulus	Virtual height	Height	Height
Perturbation	Backward translations	A forward push to the back	random surface rotations
Anxiety measure	Anxiety, stability & confidence questionnaires		Balance, confidence questionnaire
COM	No change	↓ in forward displacement	↓
COM Latency to peak Velocity		↓	
COP displacement	↑		
COP time to peak displacement	↓		
EMG @ corrections	↑ in MGAS & deltoids		↑ @ 120-220
EMG onset time	↓ in MGAS, deltoids, & external oblique		
Background muscle activity	↑ in TA		↑ only at bicep femoris
Co-contraction	↑ in lower leg		

Table 3: summary of Dynamic balance literature.

Corrective responses in upper body motor control

In the upper body, corrective movements can be observed in response to limb perturbations, similar to postural control. Unfortunately, to my knowledge there is a lack of literature that looked at perturbed upper body movements under anxiety. In a study by Van Loon, Masters, Ring, and McIntyre (2001), upper body stiffness and corrective responses under anxiety were examined. Subjects were asked to hold a supported tray with supinated hands. The tray was then dropped and the subject's task was to bring it back to its original horizontal position as quickly as possible. The task was performed under 4 conditions: a hard-mental arithmetic, easy-mental arithmetic, number repetition condition, and control. In the first condition, subjects were presented with numbers from 1-9 every 2 seconds in an auditory signal, they were required to add them up and say the sum at the end of the trial. The second condition is the same as the first except the participants are given 4 seconds between each number. In the number repetition condition, subjects repeated the number they heard out loud, the numbers were heard every 4 seconds. In the control condition, there was no secondary task. EMG activity was recorded from the biceps and triceps, and the HR was monitored to confirm an increase in arousal. The secondary tasks were successful in raising arousal with an increase in HR and self-reported arousal in the hard-arithmetic condition, followed by the easy arithmetic condition and finally the number repetition and control conditions. In the hardest condition, tray displacement was the smallest after the perturbation, the elbow angle changed significantly less compared to the easy arithmetic condition, indicating higher joint stiffness at the elbow. In the biceps and triceps' EMG, there were larger short latency responses (M1) in the hard-arithmetic condition compared to the other conditions. Interestingly, there was no significant difference in background activity before the drop of the tray in both muscles, and no difference in biceps-triceps co-contractions. There was also no difference in medium/long latency stretch responses between 50 and 150 ms (M2 and M3).

To summarize (table 4), in corrective responses, the effect of anxiety on dynamic motor control in the upper body has some similarities and some differences with that in postural control. In the perturbation experiment by Van loon et al. (2001), the increase in EMG amplitude occurred in an early involuntary phase (M1) which is different form postural control where it occurs at the M3 phase.

	Van Loon et al (2001)
Task	Elbow angle perturbation
Stimulus	Mental math
EMG	↑ in M1 only
Anxiety measure	HR
displacement	↓ with arousal
Background EMG	no change
Co-contraction	No change

Table 4: effect of anxiety on corrective responses in the upper body.

Discussion

In postural control under anxiety, there is an increase in ankle stiffness, co-contraction and EMG amplitude of balance correcting responses in the lower leg muscles. In addition, anxiety seems to enhance the overall reactivity of the CNS. This can be observed in the work by Frank and Brown (1997) where COM time to peak velocity was reduced and in the work by Cleworth et al. (2016) where the COP time to peak displacement was reduced as well. This can be attributed to the increase in stiffness in lower leg muscles which has been shown to increase the speed and amplitude of short, medium and long latency responses (Allum and Mauritz 1984; Bedingham & Tatton 1984; Bloem et al. 1993; Sinha & Maki, 1993;). The COM displacement in the work by cleworth et al. (2016) did not change with anxiety, contradicting the work by Brown & frank (1997) and Carpenter et al. (2004). This could be due to using virtual reality instead of real height. In addition, the increase in background activity was present in the work by Cleworth et al. (2016) and Carpenter et al. (2004) but in different muscles. This could due to the different perturbations used in the two studies, forward translations versus surface rotations. Despite these differences, the postural control mechanisms in all 3 studies seem to overlap with the goal of limiting COM displacements.

In the upper body, only one study was found to address the effect of anxiety on corrective responses. The work by Van loon et al. (2001) used mental math to induce arousal and using HR as a physiological measure increased the validity of the study. In this case, mental math was sufficient to raise arousal; however in the previous section, it was shown to be not as effective as direct threat like electric shock. Future studies should continue to employ physiological and psychological measures of anxiety and use more direct threat like height or electric shock.

There are some similarities in the effect of anxiety on postural and upper body motor control. In both domains, there was a reduction in displacements following a perturbation. This was seen in the work by Brown & frank (1997) and cleworth et al. (2016) in terms of COM displacements and in the work by Van Loon et al. (2001) in terms of elbow joint angular displacement. The reduction in response latencies seen in postural control was not reported by Van Loon et al. (2001). Interestingly however, a study by Langlet, Hainaut, & Bolmont (2017) showed a reduction in response times in a reaction time task with anxiety. Nevertheless, anxiety may enhance overall CNS reactivity.

There are some differences in the EMG responses in both categories. In postural control, the M3 corrective responses that occur in the 120-220 ms range increased with anxiety (Carpenter et al., 2004). The work by Van Loon et al. (2001) showed no difference between conditions in the M2 or M3 responses. This indicates that anxiety had no effect on long latency corrective responses in non-postural tasks, highlighting a major difference between upper body motor control and postural control. This could be due to the inconsistency of long latency responses in upper body stretch reflexes (Corden, Lippold, Buchanan, & Norrington, 2000). On the other hand, the increase in short latency responses (M1) with anxiety shown by Van Loon et al. (2001) has been previously reported in postural (Horslen, Murnaghan, Inglis, Chua, & Carpenter, 2013) and non-postural settings (Bonnet, Bradley, Lang, & Requin, 1995; Both, Boxtel, Stekelenburg, Everaerd, & Laan, 2005; Hjortskov, Skotte, Hye-Knudsen, & Fallentin, 2005).

Conclusion

There is a lack of literature looking at corrective responses in the upper body with more research is needed in the future. Based on the work discussed here, anxiety has mixed effects on postural and upper body motor control. Enhanced reactivity and smaller displacements are observed in both categories; however, there are differences in the long latency corrective responses.

Anticipatory postural Adjustments

Anticipatory postural adjustments (APAs) are modifications in postural control that occur prior to a movement in order to counteract any destabilizing forces or act as destabilising movements themselves in order to assist with the main movement's initiation or efficiency. They also occur in anticipation of an upcoming perturbation if the direction is known (Adkin, Frank, Carpenter & Peysar, 2002).

The work by Carpenter et al. (2001) showed that in static balance at height, the COM and COPs average locations were moved backwards away from the edge of the standing surface, compared to the medium and low conditions. By that, the system can create a greater buffer between the COM and the edge in case of an unexpected perturbation to the body (Brown &

Frank, 1997; Carpenter et al., 1999). The effect of anxiety on APAs is similar to that of static balance and dynamic balance. The goal is to minimize the likelihood of falling by moving away from the threat. A study by Adkin et al. (2002) examined the effect of height on APAs. The task required subjects to perform a toe rise which has a specific sequence of APAs. First, the dorsi-flexors like TA must be activated and the plantar flexors like SOL and Gastrocnemius (GA) become inactive. This brings the COM forward over the toes and may cause an elevation in the heel. Then the doriflexors become inactive and the plantar flexors become activated to raise the body up and maintain an upright elevated stance. Subjects performed this task at a ground level of 0.4 m and at a high level of 1.6 m to induce anxiety. Step restriction was also altered where subjects either stood with toes facing the edge or away from the edge. Condition LOWAWAY was the least threatening and condition HIGHEDGE was the most threatening. EDA and questionnaires were used to measure arousal. In the HIGHEDGE condition, the COM and COP were initially moved backwards to increase the margin of safety. In the APA, there was a significant reduction in the magnitude and speed at which the COM shifted forward prior to the toe elevation. In addition, the background activity in SOL, TA and GA were reduced at HIGHEDGE. The results in this experiment are supported by other literature that used height to induce anxiety. Yiou, Deroche, Do, & Woodman (2011) examined APAs in the medio-lateral plane using a hip flexion task where subjects shifted their weight to one leg while raising the knee rapidly. Trials were performed at ground level and 60 cm above the ground on a confined surface. With the increase in anxiety, there was a reduction in medio-lateral APA forces required to shift the weight towards the standing leg. Similarly, a study by Gendre, Yiou, Gelat, Honeine, & Deroche (2016) asked subjects to perform lateral leg raises from the hip joint at ground level and 1 m above the ground. 2 conditions were created: an “avoidance condition” where subjects stand laterally at the edge and raise the outward leg so they lean inwards and an “approach condition” where they stand laterally at the edge and raise the inward leg so they lean towards the edge. The amplitude of APA forces was lower in the approach condition compared to the avoidance condition, that is, subjects were looking to minimize their outward lean. In the last two studies, the reduction in pre-motion forces was compensated for with an increase in APAs’ duration so that postural stability, peak leg velocity, movement duration and final limb position remain unchanged.

Another study by Phanthanourak, Cleworth, Adkin, Carpenter and Tokuno (2016) examined the influence of anxiety on APAs as well; however, they used a different stimulus. An “easy” condition required a heel rise once the participant heard a warning then go signal. In a “hard” condition, after the warning signal, they either heard a go signal to perform the heel rise or a random medio-lateral perturbation was applied. According to the previous studies that used height, it was expected to see smaller and slower APA responses. Instead, at the high threat condition, subjects showed a larger and faster COP displacements and a larger activation in SOL EMG.

To summarize (Table 5), Anxiety reduces the magnitude of APA forces, the speed of COM movements, and muscle background activity.

	Adkin et al. (2002)	Yiou et al. (2011)	Gendre et al. (2016)	Phanthanourak et al. (2016)
Stimulus	Height	Height	Edge/noedge	perturbation
Task	Toe rise	Knee raise	Lateral leg raise	Heel rise
Anxiety measure	EDA & Questionnaires			EDA
COP displacement	↓	↓	↓	↑
COM displacement	↓			

COM speed	↓	↓	↓	↑
Background activity	↓			↑

Table 5: summary of APA literature.

To my knowledge, only the work by Van Loon et al. (2001) from the previous section addressed the influence of anxiety on anticipatory adjustments in upper body movements. In this experiment, subjects lightly held an externally supported tray at an elbow angle of 90° until it was dropped and the subject was required to bring it back to a horizontal position. With anxiety, subjects initially positioned the tray higher and applied more force in anticipation of the drop.

Discussion

Anxiety has a significant effect on APAs in postural control. In quiet stance or in anticipated postural perturbations, individuals tend to shift their COM away from the source of threat. In postural tasks, anxiety reduces the magnitude of APA forces and the speed at which the COM moves. In addition, the background activity of the muscles involved is usually attenuated. In the study by Adkin et al. (2002), a reduction in APAs is expected as a toe rise requires an initial forward shift towards the edge of the platform. A rapid movement can cause the COM to move outside the base of support which would result in a fall. The CNS looks to minimize the risk by applying tighter and slower control on the forward shift to ensure a safer completion of the task. The same concept can be applied to the medio-lateral studies where side leaning is reduced. In contrast, the different findings by Phanthanourak et al. (2016) can be attributed to the context of the threat. In the previous studies the subject was usually required to move towards the threat in their APAs. However in this case, the perturbation is perpendicular to the movement required in the task, making the threat of falling a constant and not dependent on the individual's movement.

The findings in the work by Van Loon et al. (2001) can be compared to the findings in static balance and anticipated perturbation studies. Participants tend to lean back in order to reduce the risk of falling. Similarly, subjects raised the tray higher to minimize the displacement after perturbation. It is clear that more research is needed in this domain in order to be able to compare APAs in postural control to anticipatory responses in the upper body under anxiety.

General Discussion

Anxiety has a significant effect on motor control, whether in balance or in upper body movements. This is partially or fully attributed to the psychological effect of anxiety explained by the distraction or the execution focus models. In static balance, the general findings showed a tightening effect of anxiety on postural control. Individuals who stood at height experienced less sway and more reactive COP movements. In contrast, in isometric upper body tasks like the pinch hold, anxiety seemed to increase variability in force production. In dynamic balance, the effect of anxiety is similar to that in static balance. A reduction in post-perturbation displacement is seen under anxious conditions. Also, the reactivity of the CNS is enhanced, showing shorter responses latencies. Likewise, in APAs anxiety has a restricting effect with reductions in COM and COP speed and displacements. Unfortunately, there is a lack of research in the upper body's corrective and anticipatory responses.

In all the literature described above, there were drawbacks in that may have contributed to inconsistent findings. First, in upper body motor control, electric shock seems to be the most effective method in raising anxiety and arousal. Other methods like mental math or cold pressor showed mixed results. Regardless of the stimuli, physiological and psychological measures of arousal and anxiety should be implemented in every experiment to confirm the ability of the stimuli to induce the required emotions. Physiological measures like EDA and HR, and psychological measures like the STAI Y1 and Y2 have been used in the past with reliable results. Also, in all the electric shock studies mentioned, the shock was delivered to the non-performing hand. This can shift the attention away from the task and may explain the reduction in performance with anxiety in upper body tasks. Future work should apply the stressor to the performing limb to increase the relation between stressor and task.

Overall, anxiety has a tightening effect on postural control. Although there isn't enough literature in upper body anticipatory and corrective responses, from the static literature alone, it seems that anxiety has a loosening effect on upper body motor control. One possible explanation is the automaticity of postural control. Humans perform postural activities every day like quiet stance, gait, corrective responses and others. This makes standing balance a simple activity that is carried out by healthy individuals without any considerable struggle. On the other hand, upper body tasks like submaximal pinch holds are usually not perfected previously by the subject. Therefore, when anxiety is induced, performance declines in isometric upper body tasks but not in postural ones. The results could also be attributed to the stimuli being used in the upper body versus postural control. In electric shock, there is fear of pain while at height there is fear of falling. Work by Martin, Hadjistavropoulos, & McCreary (2005) highlighted that fear of falling is different but related to fear of pain. Fear of falling includes fear of pain upon impact in addition to fear of injury, especially in individuals who experienced injuries falls before. Since humans can experience pain from many different stimuli, it is a broader concept than fear of falling and may lead to different patterns in motor control. In the work by Gendre et al. (2016), a side lean towards the edge of an elevated platform involves a risk of injury. In contrast, there is no risk of physical injuries in upper body tasks, making performance improvements unnecessary.

Finally, the effects of anxiety on balance can be attributed to the greater involvement of subcortical regions of the brain in posture, compared to voluntary motor control. For example, the vestibular system is known to have a significant contribution to postural control and there is anatomical evidence showing neural connections between emotional regions in the brain and vestibular nuclei in the brain stem (Balaban, 2002; Balaban and Thayer, 2001; Naranjo, Allum, Inglis, & Carpenter, 2015; Staab, Balaban, & Furmanal, 2013). The higher involvement of cortical regions in voluntary motor control may contribute to the increase in variance with anxiety.

The testing conditions in height studies should be replicated in upper body experiments in order to be able to make more valid comparisons. In static balance studies, participants can sway in any direction within an allowed range highlighted by the base of support with no performance feedback given during the trial. Similarly, upper body isometric tasks should allow for multi-directional movements rather than a simple pinch hold. For example, a finger can be placed in a ring that has a safe zone to move within. If the subject gets too close to the edges, they feel an electric shock. No additional movement parameters to be shown to the subject during the trial. This will give the participant a compelling reason to improve their performance under anxious conditions.

As shown above, anxiety tends to increase performance variability in upper body tasks. This can have significant effects on some jobs in today’s society. For example, medical surgeons under stress and anxiety show higher levels of hand tremor which impairs their performance and puts patients at risk (Fargen, Turner, & Spiotta, 2016). Similar results are found in police force literature. Anxiety was shown to reduce shooting accuracy which can be detrimental to innocent bystanders and the officer’s own safety (Nibbeling, Oudejans, Ubink, & Daanen, 2014;

Nieuwenhuys & Oudejans, 2010). This effect can be seen in any task that requires steadiness; understanding the mechanisms behind anxiety and motor control is essential in order to be able to minimize it's influence.

Conclusion

Anxiety has a restrictive effect on postural control and a loosening effect on isometric upper body motor control. Possible explanations include the automaticity of postural control, the consequences of falling or the subcortical involvement in balance. More research is needed in upper body corrective and anticipatory responses in order to have a viable comparison with dynamic balance and APAs, respectively.

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