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Chapter

SENSORY MODALITIES PROCESSING IN SENSORIMOTOR TASKS DEPENDS ON STATE AND TRAIT ANXIETY

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ABSTRACT

In the daily life activities, the ability to divide attention between different sensory modalities is essential since we have to cope with tasks that require multisensory integration. An individual has to select the relevant information, and sometimes shifts their attention from one sensory modality to another when one sensory modality is inadequate, absent, or salient. These sensory reweighting mechanisms are needed to maintain an efficient performance. Previous works have suggested that the highly complex attentional system that is needed in such situations could be influenced by affective states, such as anxiety. Indeed, it has been shown that an anxious state influences the efficient functioning of the attentional system. This can result in differences in the processing of sensory modalities. Moreover, recent works have highlighted that the allocation

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of attentional resources towards sensory modalities can be modulated by personality traits, such as trait-anxiety. This review focuses on the interdependence between anxiety state, anxiety trait and sensory modalities processing during tasks that require multisensory integration (*e.g.* sensorimotor tasks, balance control, posture...)

INTRODUCTION

In everyday life, most of our activities require us to simultaneously integrate and process various sensory inputs. This mechanism of multisensory integration is essential, since it allows us to perceive a world of coherent perceptual entities [56]. In order to achieve our behavioural goals, we must appropriately select and integrate the sensory inputs that are the most relevant to successful behaviours. In this context, the interactions between multisensory processing and attentional selection systems are fundamental for an effective functioning [96]. Since the 1960s, selective attention research was largely concerned in studying each sensory modality in strict isolation. The recent decade has seen an important increase of research activity in crossmodal attention and multisensory processing (*e.g.*, [3, 15, 51, 74, 96]).

In normal conditions, the various sensory systems provide complementary and redundant information about the environment. Individual has to select relevant information, and sometimes shifts his attention from one sensory modality to another [21, 90]. Among attentional mechanisms that lead individual to shift his attention, it is conventional to distinguish between exogenous mechanisms of attention (driven by salient stimuli), versus endogenous mechanisms [81], that allow to select continuously from among incoming sensory stimuli, the relevant stimuli that will benefit from faster and heightened processing [3]. These sensory reweighting mechanisms are needed to maintain an efficient functioning.

These attentional mechanisms are central in many sensorimotor tasks. For example, numerous studies have investigated the weight of sensory inputs involved in balance control [20, 23-25, 44, 45, 70, 77, 78]. Because information from the various sensory inputs involved in balance control is not always available or accurate, the weight assigned to each modality may need to be adjusted -or reweighted-, in order to maintain stance in a wide variety of environmental conditions [77, 78]. This perceptual inhibition (*i.e.* the ability to centrally suppress the inaccurate sensory input) is highly linked to the ability to shift attention between sensory modalities [84, 85].

As well as other cognitive mechanisms, these multisensory mechanisms could depend on psychological states [6, 10, 43, 71, 101, 107]. Among the psychological states, anxiety is a complex phenomenon that influences various aspects of cognition including the attentional systems. Indeed, numerous studies have highlighted relationships between anxiety and attention (for a review, see [29]), especially for the inhibition and the shifting functions [62]. Since these two functions are central in multisensory integration, we hypothesized that anxiety could greatly influence the allocation of attentional resources toward one or other sensory modality.

Anxiety, which could be considered with low moods in a single construct [8], is a multidimensional phenomenon that can be divided into state and trait dimensions. As stated by Spielberger [91], while state anxiety is transitory, trait anxiety may be conceived as latent dispositions to perceive and to behave in a specific manner. According to Spielberger, personality traits will be manifested in behaviour particularly if they are triggered by appropriate stimulus [91]. In line with previous studies that have demonstrated that groups of different trait anxiety level will adopt different behaviours when exposed to a stressor [68, 105], we conducted some experiments with subjects possessing different trait anxiety level, in order to determine the effect of state anxiety on multisensory integration underlying various sensorimotor tasks.

The behavioural consequences and mechanisms underlying the effects of trait and state anxiety on multisensory integration provide the focus of this article. The relationship between anxiety and sensorimotor performances involving different sensory modalities is discussed.

In a first section, we examine the effects of anxiety on attentional mechanisms involved in response time performances of different sensory modalities. In a second section, we focus on the role of trait anxiety on balance control in control and anxiogenic condition.

STATE ANXIETY, TRAIT ANXIETY AND ATTENTIONAL MECHANISMS UNDERLYING RESPONSE TIME PERFORMANCE IN DIFFERENT SENSORY MODALITIES

Anxiety and Response Time Performances

The relationship between anxiety and sensorimotor performances has been widely investigated and a complex and contrasted relationship has been

highlighted [7, 10, 11, 28, 47, 71, 101]. On the basis of the inverted-U theory [109] suggesting that sensorimotor performance is maximized at intermediate levels of anxiety [59, 82], Oxendine [73] has suggested that simple motor task requiring rapidity or strength would be maximized at high level of state-anxiety, whereas complex motor skills would be altered.

As far as response time tasks are concerned, it has been suggested that in tasks with high information content such as complex auditory and visual choice response time tasks, the state anxiety may produce a slowing down of the information processing and motor strategies [31, 47]. These deficits in performance of complex tasks may be due to alterations in higher brain function [1]. Alternatively, state anxiety would lead to better performances in visual stimulus-response tasks such as two-choice response tasks, which depend greatly on automatic abilities, by recruiting motivational capacities [7]. In fact, high state anxiety provokes attentional selectivity [4, 76], which in turn would favor the information processing in binary visual choice reaction time task [7]. Besides, previous data have provided insight into the interactions between trait anxiety and response time performances [9]. Trait anxiety favours the processing of information of stimulus-response tasks, but not that of controlled tasks that required strategic processes [9]. According to Spielberger, personality traits, that may be conceived as latent dispositions to perceive and to behave in a specific manner, will be manifested in behaviour particularly if they are triggered by appropriate stimulus [91]. In this way, a study comparing groups of different trait anxiety levels during normal and anxiogenic conditions has indicated that arousal and the impairment of the accuracy in performing a motor task increase with trait anxiety, particularly when the intensity of the stressor elevates [68]. Nevertheless, to the best of our knowledge, there is only very limited research that have investigated and discussed the interrelation between state anxiety, trait anxiety and response time tasks.

Thus, we have conducted two studies in order to assess in subjects possessing contrasted levels of trait anxiety whether moderate state anxiety influences reaction or movement time in response time tasks of different sensory modalities. While the first study concentrated on simple response time tasks in visual and auditory modalities (each assessed separately) [35], the second study used a bimodal choice response time task (visual or auditory) [36] that could be closer to daily life situations in which attention must be coordinated between auditory and visual modalities.

The induction of moderate state anxiety was made by the Stroop Color-Word Test with interferences, combined with video recording. This

association has been shown to induce transitory psychological and physiological modifications [34, 88, 97, 98, 104], whatever the subjects' trait-anxiety [55, 105]. The Stroop Color-Word Test with interferences was performed before the response time tasks. Indeed previous studies have shown a persistence of the physiological arousal after that the stressful Stroop task has been completed [104, 105].

In these two studies, the subjects whose trait anxiety scores (STAI [92]) were at the extremes of the distribution were assigned in two separate groups. According to the Spielberger's classification [92], individuals were shifted as subjects with a very low trait anxiety (VLTA) level or an intermediate trait anxiety (ITA) level. Response time tasks were performed in control and anxiogenic conditions. Response times were distinguished for two components: (i) reaction time, *i.e.* the time required to evaluate the stimulus, and to select and trigger the response, and (ii) movement time, *i.e.* the time required to execute the motor response [46].

Unimodal Sensory Processing: Simple Response Time Tasks in Visual and Auditory Modalities

The main finding of this study focusing on simple reaction time in visual and auditory modalities each assessed separately, is that moderate state-anxiety differently improves performance in individuals possessing intermediate trait anxiety or very low trait anxiety level. While VLTA subjects improved performance in auditory response time, ITA subjects improved performance in visual response time (see figure 1). In both groups, improvement of performance in response time occurred at the reaction time and movement time level.

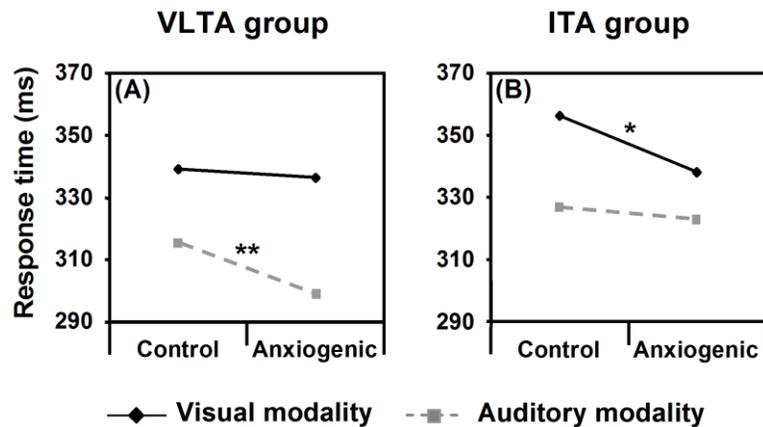
Reaction time, movement time and state anxiety

As far as reaction time is concerned, attentional mechanisms, that can strongly modulate sensory processing [22], could play a central role in the improvement of performances during the anxiogenic condition. Indeed, several studies have shown the relationship between anxiety and attention [4, 7, 28, 29, 60, 76, 87]. Anxiogenic condition may increase arousal [40, 69, 105], which could improve attention and lead subjects to attend actively to any incoming signal [19]. In line with a previous study [7], the present results suggest that state anxiety could have improved reaction time performances by modulating attentional mechanisms involved in sensory processing [22]. As

far as movement time is concerned, our results suggest that the anxiogenic condition has a positive effect on the movement time as well as the reaction time. In addition to the effects on reaction time, attention could contribute to improve the movement time performances. It has been demonstrated that the increases in attention and arousal could lead to an elevated muscular tension [93, 102, 103]. Moreover state anxiety is also associated with increase in muscular tension [38, 39, 57] even when a moderate state anxiety is induced by the Stroop Color-Word Test with interferences [97, 104, 105]. In line with studies showing that an optimal muscular tension tends to shorten response time [27, 49, 93], our results suggest that a high arousal level due to the anxiogenic condition could have improved the muscular tension [39, 105] leading to better movement time performances. Overall, our results in anxiogenic condition suggest that the improvement in response time performance could have a central origin (modulation of the sensory processing), and a peripheral origin (increase in muscular tension). However, in the relationship between response time and state anxiety, our results have also indicated some differences in visual and auditory tasks according to the level of trait anxiety.

State anxiety, trait anxiety and unimodal sensory processing

As stated above, ITA, but not VLTA, subjects improved performance in visual response time. This agrees with previous data [99] that have demonstrated in a non-anxiogenic condition that subjects with intermediate level of trait anxiety show a greater visual dependence than subjects with a very low trait anxiety level while performing a perceptual-motor task. In addition, given that behaviours associated with trait anxiety are manifest during anxiogenic conditions [91], it is likely that improved performance in visual response time produced by moderate state anxiety in ITA subjects may have resulted from a greater arousal [69] and attention for visual stimuli. Alternatively, VLTA, but not ITA, subjects improved performance in auditory response time. This suggests that VLTA subjects exposed to anxiogenic conditions may focus on auditory stimuli rather than on visual stimuli. It should be noted that in normal condition, auditory stimuli, that have an automatic alerting effect, are processed less actively than visual stimuli [18, 50, 80]. Conversely, in anxiogenic condition, the general arousal induced by the state anxiety could have led VLTA subjects to develop more attentional resources and to process consciously auditory stimuli as well as visual stimuli. In this context, the improvement of auditory response time task in VLTA group could reflect some changes in attentional processing of this modality.



* $p < 0.05$, ** $p < 0.01$ Significant differences between the control condition and the anxiogenic condition.

Figure 1. Response time performances (mean in ms), *i.e.* the sum of the reaction time and the movement time, in the control condition and the anxiogenic condition for the very low trait anxiety subjects (VLTA; A) and the intermediate trait anxiety subjects (ITA; B).

Multisensory Processing: Bimodal Choice Response Time Tasks in Visual or Auditory Modalities

Although each sensory modality can be considered in strict isolation, in many situations people have to process simultaneously information from various modalities. Therefore, our second study [36] aimed to determine thoroughly by which anxiety may influence reaction time and/or movement time in a crossmodal task. The subjects' performances in response time were assessed using a bimodal choice task providing either visual or auditory modality. The subjects were required to press as quickly as possible the response button corresponding to the stimulus.

Relevant modality according to trait anxiety

Contrary to our first study, statistical analysis did not show any main effect of condition on both reaction and movement times. Although no significant effect was detected on reaction time, we found that moderate state anxiety improves movement time performances in visual modality in ITA subjects, as well as movement time performances in auditory modality in

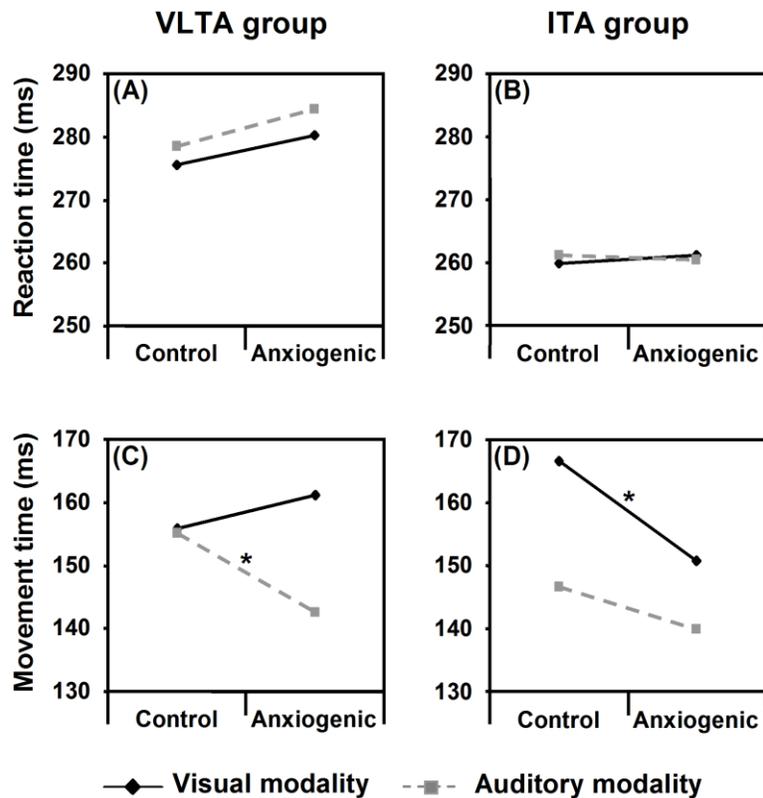
VLTA subjects (see figure 2). This confirms the results of our precedent study cited above [35], on the relationships between state anxiety, trait anxiety and response time to visual and auditory stimuli given separately [5]. Taken together, these two studies suggest that, whether or not a decision-making is required, individuals exposed to anxiogenic conditions could favour the information processing of a specific “relevant” modality, either visual or auditory, depending on their trait anxiety level. As such, ITA subjects would focus their attention towards visual stimuli, and VLTA subjects towards auditory stimuli. It should be noted that in similar tasks where attention is divided between visual and auditory modalities, Driver has shown that subjects mainly attend to one modality versus another [21]. Given our findings, we suggest that this may be related to the subjects’ trait anxiety level. In addition according to the work of Spielberger [91] who has suggested that a specific behaviour would be amplified if it is triggered by an appropriate stimulus, we hypothesise that these effects could be intensified in anxiogenic conditions.

Paradoxically, in anxiogenic condition, improvement of performance in both groups occurred at movement time, but not at reaction time in the preferential modality (See Figure 2). According to Driver [21], some crossmodal selection could apparently arise before diffusion of the stimulus. In this way, we suggest that subjects would prepare themselves to react to the expected modality, and thereby could start early motor program for this modality. Thus, this could contribute to facilitate movement execution when the expected modality corresponds to the presented modality, but not when the presented modality differs from the expected modality. However, despite the subjects’ oriented attention towards a specific modality, we found no improvement in reaction time. We suggest that this could be due to a stage of verification that the presented modality really corresponds to the expected modality.

Conclusion

In conclusion, our results show that subjects exposed to an anxiogenic condition would allocate attentional resources towards a specific relevant modality, either visual or auditory, depending on their trait anxiety level. In simple reaction time tasks, when modalities are assessed separately, both reaction and movement time performances could be improved in an anxiogenic condition by more active stimulus processing and enhanced

muscular tension [35]. In bimodal choice response time task, such attentional resources would influence movement time, but not reaction time [36]. Further experiments are needed to determine whether our findings may occur in subjects with higher state anxiety levels. However, according to the inverted-U hypothesis [59, 109] and given the human limits of adaptation, it is possible to hypothesize that in contrast with our findings, performance may decline in conditions eliciting high levels of state anxiety. Overall, these results highlight personality and individual differences as regards to the human/environment interaction.



* $p < 0.05$, significant difference between the control condition and the anxiogenic condition.

Figure 2. Differences of reaction time and movement time performances (mean in ms) between the control condition and the anxiogenic condition for the very low trait anxiety group (VLTA; A, C) and the intermediate trait anxiety group (ITA; B, D).

STATE ANXIETY, TRAIT ANXIETY AND MULTISENSORY INTEGRATION IN BALANCE CONTROL

Balance Control and Multisensory Integration

Although response time tasks are very interesting models to understand the attentional mechanisms when subjects have to direct attention toward one or other sensory modality, we devised another experiment [37] in order to study relative weighting of different sensory information directly related to balance control, *i.e.*, when subjects have to perform balance tasks.

The human balance control system, that depends on the quality and the integrity of the motor effectors, results from the integration at the central nervous system level of vestibular, somatosensory, and visual inputs [75]. Each sensory system plays a major role in the control of posture. This has been well established through the clinical observation of individuals deprived of sensory inputs from one or more of the three systems. A lack of input, or a lack of accurate input, generally decreases postural control performance [106]. All these sensorial afferences allow organisation of motor reflex responses, such as the vestibulo-ocular and the vestibulo-spinal reflexes, and the occurrence of adaptive and compensatory ocular and body movements [67]. Among these sensory systems, the importance of vision is well known in postural stabilization, especially for maintaining the balance precision as measured by the Sway Area (SA). Although the SA parameter with eyes open depends on distance to target fixation (SA decreased when the distance shortened [48, 54]), classically, the SA parameter is larger with eyes closed (EC) than eyes open (EO). Indeed, the lack of visual input decreases postural performances. When their eyes are closed, subjects would compensate the lack of visual input by an ankle stiffness strategy, in order to enhance the somatosensory perception [30]. This sensory reweighting strategy could help subjects to maintain precision of balance when vision is absent.

Balance Control and Anxiety

Moreover, studies have shown that balance performance could depend on psychological states such as state anxiety [2, 10, 17, 71, 101]. The fact that

patients suffering from different pathological anxiety disorders are frequently confronted with postural instability has been highlighted [33, 89]. This association between anxiety and balance disorders is not restricted to clinical samples and even occurs in healthy subjects [52, 108]. State anxiety in healthy subjects could be considered to be a transitory state of either apprehension or arousal, resulting from the anticipation of an actual or non-actual threatening event respectively. It has been shown that state anxiety caused by actual threat of a fall could lead a healthy subject to develop a postural stiffness strategy in order to avoid this fall; this strategy is characterized by a smaller amplitude and higher frequency in CFP displacements [2, 14, 16, 17]. In contrast, few studies have investigated the effect of state anxiety not directed toward potential postural threat [10, 71, 101] on static balance performance. When vision is available, state anxiety could influence interactions of visual input with vestibular and somatosensory inputs [71, 101]. Another study on this issue, one which used a computer-controlled movable platform, has also shown that state anxiety and adverse mood changes could affect the subjects' ability to use inputs from the vestibular system in order to maintain balance [10]. These studies suggest that state anxiety could influence one or more sensory inputs underlying static balance control. In line with our precedent studies cited above [35, 36] suggesting that individuals possessing different trait anxiety levels preferentially process some sensory modalities in an anxiogenic condition, it could be helpful to take into account the state anxiety and the trait anxiety, in assessing the individual sensory strategies used to maintain static balance. Thus, in agreement with these previous results and with Spielberger's concept [91], we hypothesized that the weight of sensory inputs involved in balance control could be differently affected by state anxiety, depending on trait anxiety level.

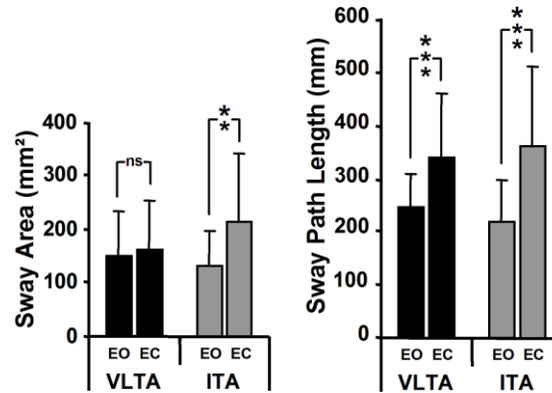
Consequently, we have conducted a study in order to determine the influence of state anxiety on static balance performance with EO and EC in two groups of healthy human subjects with contrasted trait anxiety levels (named VLTA and ITA groups, according to the Spielberger's classification [92]). As well as in our previous studies, subjects performed the tasks in control condition and in anxiogenic condition induced by the Stroop Color-Word Test with interference. We used posturographic parameters, such as Sway Area (SA) and Sway Path Length (SPL), as revealed by Centre of Foot Pressure (CFP) displacements in order to investigate balance control [100]. As far as static posturography is concerned, low values for both SPL (distance in

mm covered by the CFP displacement) and SA parameters (surface in mm² covered by the CFP displacement) reflect efficient balance control. While the SPL parameter is closely linked to sway velocity, the SA parameter is considered to be the most representative parameter regarding precision in balance [26].

Trait Anxiety and Visual Dependence

Our results have demonstrated that a moderate state anxiety increases the SA and SPL balance parameters (i.e., larger and faster body sways) for both VLTA and ITA groups when visual input is available. In contrast, with EC, the anxiogenic condition affects balance performance differently according to the level of trait anxiety.

These results should be analysed considering the specificities according to the level of trait anxiety to maintain balance in the control condition. Indeed, our results in the control condition (see figure 3) highlight some specificities in the way balance is regulated when vision is absent. Comparisons between eyes-open and eyes-closed performances have shown that SPL increases in both groups, while SA increases in the ITA group only. In agreement with previous studies, VLTA subjects tended to compensate the lack of visual input with an ankle stiffness strategy [30]. This somatosensory regulation of balance, which increases the SPL parameter, allows the SA parameter to be maintained when the eyes are closed [54, 72]. In contrast, in this condition, the ITA subjects do not seem to use a strategy like this to compensate for the absence of visual input. These discrepancies could be explained by a visual dependence phenomenon. Studies have shown that anxious patients were visually dependent in balance performance [43, 107]. Moreover, it has been also suggested that ITA subjects have a greater visual dependence than VLTA subjects while performing a perceptual-motor task [99]. In agreement with this concept of visual dependence and our own results in the control condition showing a significant SA increase in eyes-closed compared to eyes-open performances, we suggest that the lack of visual input could disrupt the precision of static balance control in ITA subjects more than in VLTA subjects. Given this potential visual dependence, we have hypothesized that the ITA subjects could be perturbed by the EC test even in the control condition.



** $p < 0.01$, *** $p < 0.001$, significant difference between EO and EC tests.

Figure 3. Control condition: differences of balance performances (sway area and sway path length) between eyes-open (EO) and eyes-closed (EC) tests.

Role of Trait Anxiety in Anxiogenic Condition

When visual input is available, our results show that whatever the subjects' trait anxiety level, SA and the SPL parameters increase in the anxiogenic condition (see figure 4). Studies have shown that state anxiety could modify multisensory integration by modulating the processing of visual input [71, 101] and/or by exerting direct effects on vestibular functioning [5, 6, 42], provoking larger and faster body sways, which increase the SA and SPL parameters. In the present study, similar effects may have occurred. In addition, the somatosensory system could also be influenced by state anxiety. Previous studies showed that fear of falling induces anxiety and leads subjects to adopt a postural stiffness strategy (increased co-contraction of ankle joint agonist/antagonist muscle pairs) characterized by smaller amplitude and higher frequency in CFP displacements [2, 14, 16, 17]. In contrast, in the present study, state anxiety that is not related to a potential postural threat may have led subjects to adopt different behaviour without muscular co-contraction to fix posture. However, muscular tension associated with state anxiety [39, 97, 105] may have increased motor activity, which in turn increased both SA and SPL parameters. Finally, when all sensory inputs are available, state anxiety may modify the processing or integration of visual, vestibular and/or

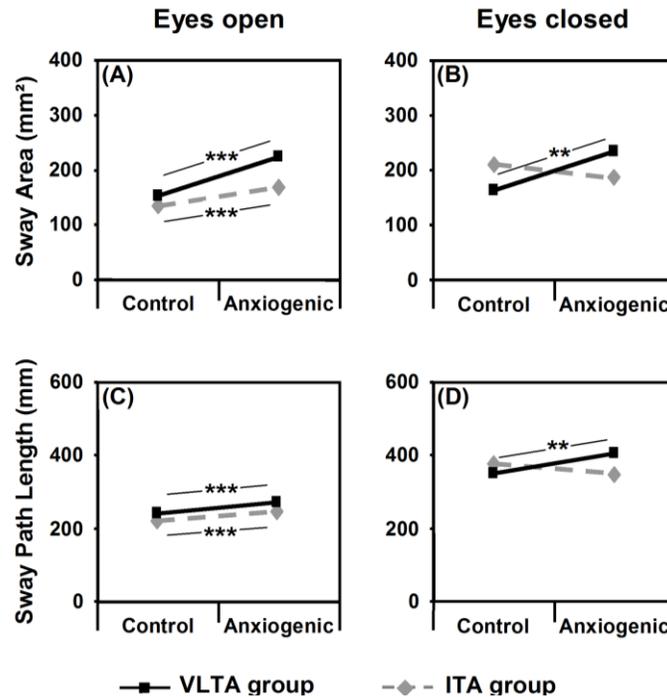
somatosensory inputs, whatever the trait anxiety level. In the present study, this led subjects to perform larger and faster body sways.

When vision is not available, results have shown a different effect of the anxiogenic condition on static balance performance according to the level of trait anxiety (see figure 4). Previous studies on this issue did not show any influence of state anxiety in the EC condition [71, 101], but none of them took the level of trait anxiety into account. In the present study, the VLTA group but not the ITA group increased the SA parameter and the SPL parameter in the anxiogenic condition. These results may provide initial insight into inter-individual trait anxiety differences in managing static balance without visual input. Similarly to the test performed with visual input, VLTA subjects have larger and faster body sways in the anxiogenic condition when vision is absent. In agreement with studies that proposed a relationship between sensory inputs and psychological states [5, 10, 42, 71, 101], we suggest that in this condition, state anxiety may influence vestibular input and/or somatosensory input. Moreover, the effects of state anxiety on static balance control do not seem to be dependent on whether visual input is present for VLTA subjects. In contrast, static balance control of ITA subjects may not be influenced by the anxiogenic condition when vision is absent. The lack of increase in SA and SPL parameters between control and anxiogenic conditions in the eyes-closed test in ITA subjects could suggest that moderate state-anxiety would not disturb the ability to use vestibular input and/or somatosensory input. Given the potential visual dependence of the ITA subjects that occur in the control condition, we hypothesized that the state anxiety induced -that remains moderate- could not be sufficient to cause additional perturbation. The main discrepancy between VLTA and ITA groups is that VLTA subjects are less visually dependent than ITA subjects, and so, more sensitive to the effects of moderate state anxiety in the EC test. These results are in concordance with those of previous studies that have demonstrated that phobic postural vertigo patients [41] or elderly adults with postural trait anxiety, characterized by high visual field dependence [23, 24] show poor balance performances in normal conditions compared to healthy subjects and young subjects respectively, but are less vulnerable to anxiogenic conditions.

Conclusion

Our results provide further evidence that state and trait anxiety could affect sensory inputs involved in balance performance. When vision is

available, whatever the trait anxiety level, state anxiety could modify the processing or integration of visual, vestibular and/or somatosensory inputs. When vision is absent, the precision of static balance control in individuals with an intermediate level of trait anxiety, characterized by a higher visual dependence, is altered. Furthermore, moderate state anxiety would disturb the ability of individuals with a lower trait anxiety, but not that of individuals with intermediate trait anxiety, to use vestibular and/or somatosensory inputs. These results confirm the interdependence of trait anxiety, state anxiety and static balance control. It should be interesting that future research concerning multisensory integration in balance control incorporates psychological states including intrinsic predispositions in order to obtain a comprehensive assessment of balance control.



Legend: —■— VLTA group -◆- ITA group
 ** $p < 0.01$, *** $p < 0.001$, significant difference between the control condition and the anxiogenic condition.

Figure 4. Differences in balance performances with eyes open (A, C) and eyes closed (B, D) for the sway area (mean in mm²; A, B) and the sway path length (mean in mm; C, D) between the control condition and the anxiogenic condition for the very low trait anxiety group and the intermediate trait anxiety group.

GENERAL CONCLUSION

Our work attempts to explore the influence of state and trait anxiety on multisensory integration involved in various sensorimotor tasks. The results of these studies have mainly evidenced that according to the trait anxiety level, state anxiety may have distinct influences on attentional processes underlying multisensory integration. We have suggested that the allocation of attentional resources toward sensory modalities could depend on the personal relevance of stimuli, which appears different between groups of low and intermediate trait anxiety level. Indeed, contrary to individuals with low level of trait anxiety, individuals with higher level of trait anxiety appear to have a greater visual dependence when performing sensorimotor tasks.

These results should be considered on the basis of previous studies in this research area. Most of the studies considering the relationships between emotions and crossmodal attention have used emotional stimuli (*e.g.*, [12, 13, 53, 58, 79]), and have highlighted some attentional biases that are specific to emotional processing. As far as anxious personality is concerned, previous studies have suggested that attentional biases could result from a disruption in the balance between the endogenous and the exogenous attention. Indeed, it has been shown that anxious subjects are automatically induced to direct their attention toward threatening stimuli [63], and have difficulties in voluntarily disengaging attention from them [32, 110]. The few studies that have used nonemotional stimuli in investigating the competition between endogenous and exogenous attention have also suggested that anxious individuals have an enhanced exogenous attentional system and that they are attracted to salient stimuli regardless of emotionality [64, 65].

It should be noted that in our studies, the experimental design is quite different. Indeed, subjects were asked to perform experimental tasks that require the processing of various modalities. There were neither task-irrelevant stimuli (*e.g.* distractor), nor salient stimuli (*e.g.* abrupt or high-contrast stimulations), nor emotional stimuli (*e.g.* threatening stimuli). Moreover, given our experimental design, we can not assert that subjects have voluntarily or consciously directed their attention toward a specific modality. Our results rather suggest that the allocation of attentional resources was involuntarily and unconsciously conducted, depending on the subject's trait anxiety level. This mechanism, linked to the personality, could be considered as a filter on our sensory processing.

Such results seem to highlight that certain modalities could be specifically relevant according to the individual's personality. It should be noted that

previous study has suggested a specific involvement of the amygdala, which is particularly associated with anxious temperament [83], in the appraisal of relevant stimuli [86]. Besides, it has been shown that the thalamus, highly linked to the amygdala, could direct attention to one sensory modality rather than another [61, 94, 95]. By directing attentional resources toward the personally relevant modality, these two structures, which are involved in the emotional system, might therefore play a role in the behavioural differences in sensory modality processing between individuals with contrasted trait anxiety. The assumption that the individual may have personal priorities in the attentional processing of sensory inputs is consistent with a recent study that has revealed a neural mechanism for the construction of a priority map involved in the selection of the important stimuli for attention [66].

The interest of this emerging research is to understand the role of personality in the influence of affective states on multisensory processing underlying action, in order to allow better adaptation processes of man that interact with environment. However, the dynamic relationship between personality traits, affective states and the weight of each sensory modality involved in sensorimotor tasks remains complex and ambiguous. Therefore, further data are needed to determine thoroughly the mechanisms by which the allocation of attentional resources may be inhibited, shifted or directed toward specific modalities.

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