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Balance dysfunction in childhood anxiety: findings and theoretical approach

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Abstract

A recent special issue of the *Journal of Anxiety Disorders*, reviewed the experimental and clinical findings related to comorbidity of balance disorders and anxiety [J. Anxiety Disord. 15 (2001) 1.]. The studies mentioned in that issue were based mostly on adult subjects but prevalence of balance disorders in childhood anxiety is yet to be established. We have tested a small sample of children diagnosed for general or separation anxiety disorder and a control group of normal children. Extensive neurological examination revealed no clinically relevant vestibular impairment. Nevertheless, detailed questionnaires and balance tests confirmed an excessive sensitivity of anxiety disordered children to balance-challenging situations. Moreover, balance-challenging tasks triggered more balance mistakes and slower performance in anxiety versus control children. These findings support the notion of subclinical balance disorder in childhood anxiety. Results are discussed in terms of the two-stage theory of learning, which predicts that anxiety disorder may be an offshoot of lasting balance dysfunction.

Keywords: Childhood anxiety; Vestibular impairment; Balance disorder; Balance tasks; Two-stage theory of learning; Classical conditioning; Emotional conditioning; Motor conditioning

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1. Introduction

Decades of research has established the essential involvement of the brain limbic system in emotional behavior. The amygdala is a very well attended component of the limbic system. Divergent outputs to other limbic and extra-limbic systems make the amygdala a key component in the initiation of coherent emotional responses (Davis, 1992; Davis & Whalen, 2001). Afferents from the thalamus enable the amygdala to evaluate the emotional valence of aversive cues, while considering only the crude features of these cues and thus bypassing the processing of high cognitive structures (LeDoux, 1993). Involvement of the amygdala in anxiety disorders has long been suspected. Both under and over-expression of fear and anxiety were, respectively reported after induction of lesion or the stimulation of the amygdala (Aggleton, 1993; Chapman et al., 1954; Gloor, 1992). Combined with recent neuroimaging findings (Birbaumer et al., 1998; Rauch et al., 2000), there is sufficient evidence that limbic/amygdaloid pathology is causally involved in anxiety disorders.

An alternative view holds that limbic malfunction is not a necessary pre-requisite for anxiety disorders. Rather, anxiety may reflect an excessive response of the normal limbic system interacting with abnormally functioning extra-limbic structures. This view is consistent with frequently reported comorbidity of anxiety with neurological disorders, such as dizziness, vertigo, imbalance, and vestibular dysfunction (Sklare, Konrad, Maser, & Jacob, 2001). To mention a few examples from recent extensive review, fear and emotional displeasure are frequently associated with incidents of acute vertigo and motion sickness (see review by Balaban & Thayer, 2001). Patients with even mild vertiginous symptoms score high on the State-Trait Anxiety Scale (Alvord, 1991). Dizziness and vestibular dysfunction prevail in panic disorder patients during and between panic attacks (Jacob, Furman, & Balaban, 1996a; Jacob, Furman, Durrant, & Turner, 1996c; Sklare, Stein, Pikus, & Uhde, 1990). Balance dysfunction is related to agoraphobic avoidance in panic disorder patients (Jacob et al., 1996c), while vestibular dysfunction is related to height phobia (in Jacob, Redfern, & Furman, 1995). These observations are not only confined to clinical samples, as correlation between dizziness and anxiety was also confirmed in community surveys (see Yardley et al., 2001). A possible interpretation of these frequent associations is that anxiety is a byproduct of an interaction between a normal limbic system and malfunctioning balance systems.

Interaction with a malfunctioning balance system may bear particularly harsh consequences during childhood. Balance-challenging situations trigger fear responses, which are constructive in future avoidance of similarly dangerous situations (Balaban & Jacob, 2001; Yardley, Todd, Lacoudraye-Harter, & Ingham, 1992). Avoidance of balance threats may be an effective strategy for adults, as it often requires only a minor modification of their life style. An avoidance strategy seems to be less effective in children, whose environment features frequent and varied balance threats, ranging from mildly challenging situations, such as balancing on an uneven surface, to highly challenging situations, such as balancing on unstable surface. Given their frequent encounter with balance threats, children with balance disorder will experience repeated fear responses that may eventually precipitate a development of a chronic anxiety disorder. It is possible, therefore, that balance dysfunction is an important trigger for childhood anxiety.

This hypothesis is in line with findings of a high correlation between abnormal balance/vestibular symptoms and indices of anxiety in large samples of children (Levinson, 1989a, 1989b, 1989c). Our samples included children who were referred to the clinic for learning disability and therefore it would be highly relevant to demonstrate comorbidity of anxiety and balance disorder in children referred to the clinic for anxiety disorder. Therefore, the present study tests the hypothesis that childhood anxiety disorders may be associated with balance deficiency.

2. Methods

2.1. Subjects

Children with anxiety disorders were recruited from consecutive admittance of children to the ambulatory clinics of Geha Psychiatric Hospital ($n = 20$). The control children were recruited from regular public school and were free from psychiatric and neurological symptoms ($n = 20$). They were matched to the anxiety sample with respect to age, gender, weight, height and handedness (see Table 1). DSM-IV criteria was used by a psychiatrist (Jonathan Sever) to confirm separation anxiety ($n = 11$), generalized anxiety disorder ($n = 7$), PTSD ($n = 1$), and a variety of anxiety symptoms, which did not meet specific DSM criteria ($n = 1$). In addition, Tourette syndrome, PTSD (ICD-10), conduct disorder dysthymia, and simple phobia, were each diagnosed in one child. ADHD was encountered in 11 children and ADD in 2 additional children. Epilepsy was diagnosed in two children. Children's fears and anxieties were confirmed also by the well-established Fear Survey Schedule for Children (FSSC). The Israeli version is based on the original (Scherer & Nakamura, 1968) and an updated version (Ollendick, 1983), and has been validated in a dissertation study (Pichman, 1996).

Table 1
Personal details of the anxiety and control groups (mean ± S.E.M. and range)

Group	Age (years)	Weight (kg)	Height (m)	Gender (F/M)	Handedness (R/L)	Familial handedness (R/L)
Anxiety ($n = 20$)	10.2 ± 0.38 (7–14)	34.2 ± 2.6 (18–65)	1.4 ± 0.02 (1.1–1.6)	8/12	15/5	7/13
Control ($n = 20$)	10.6 ± 0.36 (7–13)	35.7 ± 2.1 (24–54)	1.4 ± 0.02 (1.2–1.65)	8/12	17/3	10/10
t-test	ns	ns	ns			

The questionnaire yields seven separate scales for specific fears and anxieties related to death, criticism, staying alone, animals, medication, strangers, and current violent situation in Israel. Scores on the seven subscales of the FSSC survey were analyzed by MANOVA with Group and Gender as independent variables and Age as a covariate. General main effects were found for Group [$F(7, 29) = 3.0$, $P < .05$] and Gender [$F(7, 29) = 2.4$, $P < .05$] with anxiety reactions higher in anxiety versus control group and in female versus male subjects. In separate MANOVAs for each subscale, significant Group differences were found on fear scales of being alone [$F(1, 35) = 10.2$, $P < .01$], strangers [$F(1, 35) = 7.7$, $P < .01$], and Israeli condition [$F(1, 35) = 5.3$, $P < .05$]. A single significant gender effect was found on the animals' fear scale [$F(1, 35) = 11.5$, $P < .01$] with females showing higher anxiety score versus males.

None of the subjects had any past history of acute vestibular disorder or chronic ear disease. All children volunteered to participate in the study, and written consent was obtained from their parents. Subjects of both groups participated in all tests except for the neurological examination, which included 17 anxiety and 11 control children.

2.2. Neurological and neuro-otological examination

A neurologist (CRG) performed formal neurological examination and a detailed bedside neuro-otological examination (Baloh, 1995; Zee & Fletcher, 1996). This included: evaluation of spontaneous nystagmus with and without visual fixation using Frenzel lenses and ophthalmoscopy with the other eye occluded to prevent fixation; evaluation of dynamic Vestibulo-Ocular Reflex (VOR) under conditions of dynamic visual acuity; head thrust or rapid Doll's eye test; ophthalmoscopy during head shaking and head shaking nystagmus test; positional and positioning tests (Dix-Hallpike); vestibulo-spinal testing using past pointing; Romberg test, Fukuda stepping test and tandem gait; eye movement tests consisting of alignment, range of motion, vergence, saccades, smooth pursuit, optokinetic nystagmus and visual cancellation of the VOR.

At the end of the neuro-otological examination, motion sickness susceptibility was evaluated according to procedures described for the Brief Vestibular Disorientation Test (Ambler & Guedry, 1971, 1978; Reason & Brand, 1975). This test is based on cross-coupled (Coriolis) vestibular reactions elicited by tilting the head 45° during whole-body passive rotation. The subject was seated with eyes closed and head upright in a rotary chair, which was rotated at a constant velocity of 15 rpm. After 30 s, the subject was asked to assume and to maintain for 30 s each of the following head positions: right tilt, upright, left tilt, upright, right tilt, upright, left tilt, upright, forward tilt and upright. After completion of this sequence (330 s), chair rotation was stopped and the subject was asked to open his/her eyes after the illusory sensation of motion had ceased. At the end of the rotation period the neurologist estimated the overall subject's condition on a scale of 1 (good) to 20 (extremely bad), according to three criteria: pallor, cold sweating and anxiety (each evaluated on a scale of 1–5; see Gordon, Ben-Aryeh, Szargel, Attias, & Rolnick, 1988). In case of severe nausea or malaise during rotation or if the subject requested, the chair rotation was stopped, time of rotation was recorded and the test ended.

2.3. Balance tests

Static and dynamic balance was assessed by six thematically diverse tests. Each of the tests consisted of two to eight tasks, applied in an order of an increased challenge for either static or dynamic balance. To evaluate tasks reliability, children were subjected to the tests on two sessions with a 5- to 50-day interval between the sessions (mean = 15 days). The children were videotaped and their performance was assessed off-line for rate of balance mistakes, scored as leg deviation or use of hands for a support in an attempt to regain balance, and for time to task completion. The correlation between performance scores achieved in the two sessions was used to assess the test–retest reliability of each task. Difficult tasks resulted in high rate of balance mistakes and the scores were positively correlated across the sessions ($P < .05$, one tailed). Nonsignificant test–retest reliability was usually observed on relatively easy tasks that resulted in a low rate and a low variability of balance mistakes. Results of the first session were further analyzed for group differences. Rate of mistakes on each of the six tests was subjected to a separate analysis of variance (six MANOVA's). All tasks with nonsignificant test–retest reliability on the measure of balance mistakes were excluded from the analysis of balance mistakes except for four tasks, each originating from a different test, that were included in order to prevent missing cells in the MANOVA's. Measure of the time to task completion was relevant only for three tests (Tests 4, 5 and 6) and significant test–retest reliability was achieved for all tasks consisting these tests ($P < .05$, one tailed). Thus, all tasks in these three tests were included in the MANOVA's testing the time to task completion. Following is the description of the six tests.

The first test included eight tasks that assessed the two-leg standing balance for 15 s, on two surfaces (floor vs. bench), with two levels of foot base width (joined vs. heel-to-toe), and two eye states (open vs. closed-covered). Only the four tasks assessing heel-to-toe standing balance were included in the final analysis of balance mistakes with test–retest reliability confirmed in three of the tasks (the condition of standing heel-to-toe on a bench with eyes-open did not attain significant reliability). Time to task completion was not a relevant measure in this task.

The second test included six tasks that assessed one-leg standing balance for 15 s, on three surfaces (floor vs. bench vs. unsteady trampoline), and two eye states (open vs. closed). All six tasks were included in the analysis of balance mistakes with five of them showing significant reliability (condition of standing on trampoline with eyes-open did not attain significant reliability). Time to task completion was not a relevant measure in this task.

The third test included two tasks that assessed two-leg standing balance for 20 s, on an unsteady cylinder with two head positions (held still vs. nodding). The cylinder was 20 cm in diameter and was positioned on a soft mattress. Both tasks showed significant reliability for the balance mistakes and for time to task completion and therefore, both were included in the analysis. Time to task completion was not a relevant measure in this task.

The fourth test included two tasks that assessed walking balance on six cubicles with two eye states (open vs. closed). The cubicles sizes were 30 cm × 40 cm × 30 cm, and they were spread with intervals corresponding to the length of the subject's foot. The two tasks were included in the final analysis of balance mistakes with one of the tasks showing significant reliability (condition of walking with eyes-open did not attain significant reliability). Time to task completion was scored as the time required to walk over all cubicles. The two tasks showed significant test–retest reliability on this measure and therefore all were included in the analysis of time to task completion.

The fifth test included eight tasks that assessed walking balance on two surfaces (bench vs. rope stretched on the floor), with two levels of foot base width (normal vs. heel-to-toe), and two eye states (open vs. closed). Only the four tasks assessing walking on the rope were included in the final analysis of balance mistakes, three of them showing significant reliability (condition of normal walking on a rope with eyes-open did not attain significant reliability). Time to task completion was scored as time required to walk the whole length of the bench or the rope. All eight tasks showed significant test–retest reliability on this measure and therefore all were included in the final analysis of time to task completion.

The sixth test included two tasks that assessed walking balance on a rope stretched on the floor after axial self-spinning in two positions (spinning in either straight vs. bent posture). Both tasks showed significant reliability for the balance mistakes and therefore both were included in the final analysis of balance mistakes. Time to task completion was scored as time required to walk the whole length of the rope. The two tasks showed significant test–retest reliability on this measure and therefore both were included in the final analysis of time to task completion.

2.4. Dizziness questionnaire

The questionnaire was composed of three subscales. The first subscale was composed of 15 questions directed at verifying whether the subject experienced the sensation of vertigo or associated nonvestibular, autonomic-visceral, sensations of dizziness (e.g., Do you feel that objects around you turn around? Have you felt sudden paleness?). The second subscale was composed of six questions directed at characterization of situations, which predispose to episodes of dizziness (e.g., Is the feeling of dizziness related to change of posture or movement? Do you have problems in moving in darkness?). The third subscale was composed of 10 questions directed at correlating the dizziness episodes with ear problems (e.g., Have you suffered from ear diseases? Have you suffered from ear pain?).

2.5. Motion sickness questionnaire

Subjects were asked to fill out a biographic questionnaire concerning sensations triggered by car/bus riding, flight, sailing, elevator, amusement park rides and wide screen movies. They were also asked to grade their sensitivity to each of these situations and the recurrence of vomiting, nausea, dizziness, drowsiness, and headache, on a four grade scales.

3. Results

3.1. Neurological and neuro-otological examination

None of the children with anxiety disorders (17 tested) had spontaneous nystagmus and all had normal dynamic VOR evaluation. Tandem gait with eyes closed was mildly abnormal in six children. Four of these children and additional two children had soft neurological signs: five had restlessness, three had minimal involuntary movements and two had minimal muscle hypotonia. One child had a congenital VI nerve palsy with an otherwise normal neuro-otological examination. All control subjects (11 tested) had a completely normal neurological and neuro-otological examination.

Children with anxiety disorders asked to stop the rotary experience on BVDT sooner than the control children [196 s vs. 283 s; $t(26) = 2.7, P < .02$]. Scores of pallor, cold sweating and anxiety after the end of rotation test were analyzed by multivariate test of variance with no significant group effects.

3.2. Balance tests

Rate of balance mistakes on the first session was analyzed by separate MANOVAs for each of the six balance tests. Similarly, time to task completion on the first session was analyzed by separate MANOVAs for three balance tests. Each MANOVA included the between subjects Group factor (anxiety vs. control), and one to three within subjects factors, which were the manipulations applied in the particular test. The manipulation factors applied in different tests consisted of the Surface (floor vs. bench; floor vs. bench vs. trampoline; bench vs. rope lined on a floor), Eyes (open vs. closed), Walking (normal vs. heel-to-toe), Head (still vs. nodding), and Posture during axial spinning (straight vs. bent).

Statistical results of balance mistakes are summarized in Table 2. It shows that all manipulations, except the standing on a bench versus floor, significantly modulated the rate of balance mistakes. Test 1 required a simple heel-to-toe standing balance, which triggered only infrequent mistakes and consequently no

Table 2
Statistical results of the rate of balance mistakes

Test[a]	Manipulation	Manipulation effect[b]	Interaction Group by manipulation[b]	Group effect[b]
1: standing heel-to-toe	Surface (floor vs. bench)	ns	ns	ns
	Eyes (open vs. closed)	**	ns	
2: standing on one-foot	Surface (floor vs. bench vs. trampoline)	***	*	ns
	Eyes (open vs. closed)	***	ns	
3: standing with two-foot on cylinder	Head (still vs. nodding)	*	ns	*
4: walking on cubicles	Eyes (open vs. closed)	***	ns	ns
5: walking on rope	Walking (normal vs. heel-to-toe)	***	ns	
	Eyes (open vs. closed)	***	*	*
6: walking on rope	Spinning (straight vs. bent)	***	ns	ns

[a] Rate of balance mistakes on each of the six balance tests was analyzed by separate MANOVA.

[b] Significance of the manipulation effects, Group effects and interactions of Group with manipulation is marked by: (*) $P < .05$; (**) $P < .01$; (***) $P < .001$. See text for explanation of the significant results.

significant difference between groups was observed. Test 2 required a one-leg standing balance and revealed significant Group by Surface interaction indicating that balancing on a trampoline, but not on a floor or bench, caused more mistakes in the anxiety versus control group. Test 3 required two-legs standing balance on a cylinder and resulted in a significant Group effect with balance mistakes prevailing in the anxiety versus control group. Test 4 required walking balance on cubicles which triggered very low rate of mistakes with no significant difference between the groups. Test 5 required walking on a rope stretched on the floor, and resulted in a significant Group effect and a significant Group by Eyes interaction. These results reflect a higher rate of mistakes in the anxiety versus control group, particularly in the eye-closed state. Finally, Test 6 required walking on a rope stretched on the floor after axial spinning and showed no significant effects.

Time to complete the task could be assessed in Tests 4–6. Statistical results are summarized in Table 3 and confirm that the tasks were generally more difficult for the anxiety group. Thus, all manipulations, except for the posture during spinning in Task 6, significantly modulated the time to task completion. Test 4 was the easy task requiring walking on cubicles and showed similar performance in the two groups. Test 5 required walking on a rope versus bench and resulted in a significant Group effect reflecting longer time to completion in the anxiety group. In addition, Test 5 resulted in a significant Group by Surface by Walking interaction, indicating that shifting from bench to rope surface slowed down the performance of the anxiety group irrespectively of whether it required normal or

Table 3
Statistical results of the time to task completion

Test[a]	Manipulation	Manipulation effect[b]	Interaction Group by manipulation[b]	Group effect[b]
4: walking on cubicles	Eyes (open vs. closed)	***	ns	ns
5: walking on rope	Surface (bench vs. rope)	**	ns	*
	Walking (normal vs. heel-to-toe)	***	ns	
	Eyes (open vs. closed)	***	ns	
	Surface by Walking		*	
6: walking on rope	Spinning (straight vs. bent)	ns	ns	**

[a] Time to task completion on balance Tests 3–6 was analyzed by separate MANOVAs.

[b] Significance of the manipulation effects, Group effects and interactions of Group with manipulations is marked by: (*) $P < .05$; (**) $P < .01$; (***) $P < .001$.

heel-to-toe walking, while the performance of the controls was slowed down only due to heel-to-toe walking. Finally, Test 6 which required walking on a rope after axial spinning, confirmed a significant Group effect, indicating that the anxiety group was delayed in completion of the tasks in comparison to the control group.

3.3. Dizziness questionnaire

Dizziness episodes were reported by 16 children (80%) of the anxiety group and by 8 children (40%) of the control group. Rate of "Yes" answers was higher in the anxiety group for all three dizziness subscales. Significant group differences were observed for the second scale dealing with the scope of situations which predispose to dizziness [$t(38) = 2.7, P < .01$), and for the third scale relating the dizziness to ear complications [$t(38) = 2.2, P < .03$].

3.4. Motion sickness questionnaire

Anxiety children reported enhanced sensitivity to motion sickness provoking situations [$t(38) = 2.2, P < .04$]. The rate of excessive reactions to provoking situations was always higher in the anxiety group, however significant differences were observed only for the rate of nausea episodes [$t(38) = 2.1, P < .04$].

4. Discussion

The anxiety group was composed of children who reported high levels of anxiety on the FSSC survey subscales, in comparison to the control group, and particularly on the subscales measuring their reactions to being alone, with strangers and to risks associated with the national conflict of Israel with its Palestinian neighbors. In terms of psychiatric diagnosis this was a heterogeneous sample with a primary diagnosis of generalized or separation anxiety disorders or PTSD. In addition, a significant proportion of children were diagnosed as ADHD or ADD.

Neurological and neuro-otological examination revealed that children in the anxiety group were free from clinically significant vestibular dysfunction and had normal VOR examination under both static and dynamic conditions. Minor motor and balance abnormalities were observed only in about 50% of the anxiety group. These included soft signs in the form of restlessness and involuntary movements and mildly abnormal gait in darkness. All control subjects had completely normal neurological and neuro-otological examination.

Further examinations demonstrated enhanced susceptibility to motion and balance-challenging conditions in anxiety children. The BVDT showed that children with anxiety disorders could sustain the rotary chair for significantly shorter periods of time in comparison to controls. Their early withdrawal from the challenging situation might have played a self-protective role, as indeed, the postrotatory condition of children with anxiety disorders, including pallor, cold sweat and anxiety, was comparable to that of controls. Questionnaires demonstrated that anxiety versus control children seem to be sensitive to a wider scope of situations predisposing them to dizziness, such as a change in posture or head position, movement and darkness. Such enhanced sensitivity may explain the finding that nearly all children with anxiety disorders (80%) versus less then half of the control children (40%) reported recurrent episodes of dizziness. Similarly, children with anxiety disorders reported an enhanced sensitivity to situations that provoke motion sickness with significant increase in episodes of nausea. Cumulatively, these findings point to a subclinical dysfunction characterized by an increased susceptibility to balance-challenging conditions.

Poor motor balance also seems to be an important consequence of enhanced susceptibility to balance-challenging conditions. Poor motor balance may be particularly taxing for children who frequently encounter balance-challenging situations. In the present study children were subjected to some nonstandardized balance tasks that simulate some of their daily life situations. Tasks were gradually made more balance challenging by manipulations that constrained subjects' behavior. Scores of balance mistakes and time to task completion confirmed that manipulations, such as eye closing, head nodding, axial spinning, heel-to-toe walking, and unsteady surface, all had balance-challenging properties for both anxiety and control children. Nevertheless, some of the tasks appeared to be easy and induced low level of balance mistakes in both groups. Thus, children with anxiety disorders balanced well while standing with one or two legs on a floor or on a narrow bench. They also balanced well when stepping on cubicles closely spaced over the floor. Maintaining balance during these tasks was more difficult in the eye closed state, but decline in performance was similar in both groups. It seems therefore that children with anxiety disorders can balance quite normally on steady surfaces, which were the common denominator in the above tasks.

Children with anxiety disorders performed worse than the control children on more challenging tasks, as confirmed by the higher rate of balance mistakes and/or slower completion of the task. The two-leg balancing on an unsteady cylinder was more difficult for children with anxiety disorders, irrespective of whether simultaneous head nodding was required or not. Similarly, one-leg balancing on an unsteady trampoline was more arduous for children with anxiety disorders, irrespective of the open or closed eye state. A common denominator in these tasks is the unsteady surface, which seems to be particularly challenging for the anxiety children. Another set of tasks, which differentiated between the groups consisted of stepping on a rope stretched on the floor. Children with anxiety disorders had more difficulty to balance while walking on the rope normally or heel-to-toe, in the eye open or closed state, and with or without self-induced fast axial spinning before the walking test. The common denominator in these tasks is the narrow lateral foot base, which seems to be particularly challenging for the children with anxiety disorders. In summary, of all balance tasks, it seems that anxiety and control children balance equally well on steady surfaces. However, both static and dynamic balance of children with anxiety disorders is preferentially compromised by unsteady surfaces and by a narrow lateral foot base. Following the notion that vestibular dysfunction drives more reliance on visual channel we expected that eye closing will be a particularly taxing manipulation for children with anxiety disorders, (Bles, de Jong, & de Wil, 1983; Jacob et al., 1995). However, the overall effect of eye closing on balance was quite similar in anxiety and control children.

These findings support the notion that children with anxiety disorders are sensitive to balance-challenging conditions and have balance difficulties under these conditions. Comorbidity of anxiety and balance disorders was already noted in adults centuries ago (Balaban & Jacob, 2001). Although the two disorders are believed to be interrelated, the chicken versus egg question has not yet been resolved. In some cases, balance may be altered by excessive vigilance (Schuerger & Balaban, 1999), or anxiety (Jacob, Furman, & Perel, 1996b), and therefore can be considered as psychosomatic manifestation of anxiety (Yardley & Redfern, 2001). This reasoning may explain for example why anxiety children have abandoned the passive experience on rotary chair earlier than the control children. Also, anxiety might have increased body sway and “cause subjects to abandon attempts to maintain balance in difficult situations (such as standing on one leg) before balance is actually lost” (Beidel & Horak, 2001). In contrast to this prediction, however, children with anxiety disorders showed no attempt to abandon active balance tests and, in fact, had sustained the active attempts to balance for longer periods than the control children. Indeed, a reversed relation was suggested whereby balance dysfunction may trigger an anxiety response. In this context, anxiety may be seen as a precursor of learning, driving either operant avoidance of balance-challenging situations (Balaban & Jacob, 2001) or Pavlovian acquisition of better balance skills. The latter hypothesis (i.e., anxiety as a drive for balance improvement), may be evaluated in context of neurobehavioral studies of motor–emotion interaction attempted under the umbrella of the ''two-factor theory of learning'' (Lennartz & Weinberger, 1992).

The ''two-factor theory of learning'' predicts that confrontation with aversive unconditioned stimulus (US) invokes two successive stages of learning (Lennartz & Weinberger, 1992; Thompson et al., 1987). In terms of classical conditioning theory, the two stages of learning stand for successive acquisition of conditioned emotional responses (emotional CRs) and conditioned motor responses (motor CRs), respectively. Acquisition of fear CR is fast, typically requiring exposure to just a few paired CS-US trials. The autonomic, hormonal, and behavioral components of the fear CR are considered as ''nonspecific'' in the sense that they energize the organism and redirect its attention to the relevant CS stimulus but do not help to alleviate the impact of the impending aversive US. In contrast, acquisition of motor CR is typically slow, but its skeletal components are considered ''specific'' in the sense that they provide effective protection against the noxious US (Lavond, Lincoln, McCormick, & Thompson, 1984; Lennartz & Weinberger, 1992; Weisz, Harden, & Xiang, 1992).

At first account, the emotional and motor learning stages seem to be independent of each other as indeed they are processed with different time constants at different brain sites. The amygdala has a significant role in the acquisition and expression of the fear CRs during the first stage of learning (Davis, 1992; LeDoux, 1993). The cerebellum is essential for acquisition and expression of discrete motor CRs, such as the defensive eyeblink, in the second stage of learning (Lavond, Kim, & Thompson, 1993; Mintz, Lavond, Zhang, Yun, & Thompson, 1994; Thompson, 1986). In spite of such apparent modularity, the two learning stages proved to be highly interrelated. Lesions of the amygdala hindered acquisition of the cerebellum-based eyeblink CRs (Neufeld & Mintz, 2001; Weisz et al., 1992). The implication for the intact brain is that acquisition of amygdala-based fear responses promotes subsequent acquisition of the cerebellum-based protective motor responses. Testing the reversed relation showed that cerebellar lesions that were sufficient to abolish motor conditioning had absolutely no effect on the acquisition of fear CRs (Lavond et al., 1984). This is, however, of little surprise given that acquisition of fear is accomplished long before motor conditioning takes any significant shape. In fact, further experiments showed that cerebellar-based motor learning promotes extinction, rather than acquisition, of fear CRs (Mintz & Wang, 2001). Thus, intact rats showed the expected fast acquisition of the fear CRs, but these emotional responses were extinguished after acquisition of motor-CRs. Rats with cerebellar lesions showed similar fast acquisition of the fear CRs, but subsequent massive training failed to induce motor conditioning and failed to extinguish the fear CRs. Clearly, motor disability precipitated by cerebellar lesions, prevented extinction of the fear CRs. Normal extinction indicates, therefore, that fear CRs are redundant when the organism has to its disposal the highly specific and protective motor CRs (Powell, Lipkin, & Milligan, 1974).

Based on these results we proposed that the two-stage theory of learning should be supplemented with a third stage and that the stages should be described in terms of interactions between emotional and motor learning, when appropriate (Mintz & Wang, 2001). Thus, fear CRs are acquired in the first stage. Fear CRs prevail in the second stage and promote the acquisition of the adaptive motor CRs. In the third stage, motor CRs provide a reliable protection against the noxious US and promote extinction of fear CRs. Conversely, fear CRs may prevail if motor performance is compromised due to a deficiency in the motor learning system.

The ‘‘three-stage’’ theory of learning provides useful theoretical background for the hypothesis that a balance disorder may lead to anxiety. Balance-challenging events, such as an unsteady surface, may be considered as US and may invoke the sequential acquisition of fear- and motor-balance-CRs. Motor CRs must be of a form that helps to keep or regain the balance, such as limb movements, reaching movements, saccades, vestibulo-spinal reflexes, and VOR. Balance components of these motor CRs are acquired in the cerebellum, which is considered an important station for all sensorimotor integration processes. Their acquisition involves a process that is distinctly similar to that involved in acquisition of the eyeblink CRs. Indeed, the connectivity, microanatomy, and physiology of the cerebellum are remarkably regular over its different areas and may therefore support site invariant neuro-computation process. For example, similarities were noted in the organization of the floccular circuitry involved in the motor learning of the VOR, and the anterior lobe circuitry essential for the eyeblink conditioning (Raymond, Lisberg, & Mauk, 1996). Such similarities imply that reliable acquisition of cerebellar-based balance movements may also promote extinction of fear CRs in a process akin to the extinction of fear CRs after acquisition of the protective eyeblink CRs. Execution of the entire learning sequence may be impaired by peripheral, brain stem or cerebellar dysfunction, which hinders the acquisition of balance movements and consequently prevents the extinction of fear responses. Thus, exposed to frequent balance threatening situations and equipped with poor balance restoring movements, the child experiences frequent fear CRs that are not extinguished with repeated exposures to challenging situation. These repeated experiences may generalize eventually to a state of anxiety.

The brainstem is a likely place for the interaction between the amygdala-based emotional conditioning and the cerebellum-based motor conditioning. The neuronal model of the eyeblink CR’s emerges in the deep nuclei of the cerebellum. From there it descends to the trigeminal complex (Clark & Lavond, 1996), where it may inhibit cells conveying the US-related signal to the amygdala, thus, providing conditions sufficient for extinction of emotional-CRs (Mintz & Wang, 2001). Interaction between balance and anxiety systems may take place in the parabrachial nucleus (Balaban & Thayer, 2001). In spite of the anatomical disparity, similar functions were delegated to the two sites of interaction. Most importantly, both sites were proposed to mediate the inhibitory effects of the cerebellum on emotional output. It, therefore, follows that deficient cerebellar output, in terms of intensity or timing mismatch, may fail to inhibit the emotional output and therefore lead to an anxiety disorder. This scenario is compatible with the hypothesis that friction at the cerebellar-limbic junction may trigger anxiety. The asset of the present theoretical scheme is that it details the functional relations between the cerebellar and limbic systems that result in either normal fear or enduring anxiety responses.

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