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Anxiety–performance relationships in climbing: a process-oriented approach

J.R. (Rob) Pijpers *, Raôul R.D. Oudejans, Floris Holsheimer, Frank C. Bakker

Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands

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Abstract

Objectives: Two experiments were conducted to investigate manifestations of anxiety at the subjective, physiological, and behavioural level of analysis.

Design: In Experiment 1 we investigated the manifestations of state anxiety at the first two levels by comparing low- and high-anxiety conditions during climbing. In Experiment 2 we explored behavioural differences under these conditions.

Methods: We manipulated anxiety by using a climbing wall with routes defined at different heights (low and high). Participants were 13 and 17 novice climbers in Experiments 1 and 2, respectively (ages 19–30 years). We measured self-reported state anxiety, heart rate (Experiments 1 and 2), blood lactate concentration and muscle fatigue (Experiment 1), and climbing time and fluency of movements (Experiment 2).

Results: At the level of subjective experience we found that when novices climbed a route high on a climbing wall they reported significantly more anxiety than when they traversed an identical route low on the climbing wall. At the physiological level, they exhibited significantly higher heart rates, more muscle fatigue, and higher blood lactate concentrations. The results of Experiment 2 showed that state anxiety also affected participants' movement behaviour, which was evidenced by an increased geometric index of entropy and by longer climbing times.

Conclusions: Results indicated that anxiety indeed manifested itself at three levels. A possible explanation for the effects of anxiety that is also found in the literature is that a temporary regress may occur to a movement execution that is associated with earlier stages of motor learning.

Keywords: Anxiety; Sport climbing; Heart rate; Muscle tension; Blood lactate concentration; Entropy

* Corresponding author. Tel.: +31-20-4448453; fax: +31-20-4448529.
E-mail address: j_r_pijpers@fbw.vu.nl (J.R. Pijpers).

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In the eyes of coaches, trainers, sport psychologists, and athletes it is important to control anxiety in sport situations in order to optimise performance. Too much anxiety, fear, or stress may impair sport performance. Not surprisingly, many people within the world of sport are intrigued by competitive anxiety and how it can be controlled either by reducing it or by learning to cope with it when facing competition.

Although the relationship between anxiety and performance in sport has received considerable research attention (for overviews see for example Gill, 1994; Gould & Krane, 1992, Hackfort & Schwenkmezger, 1993; Jones, 1995a; Landers & Boutcher, 1998; Raglin, 1992; Raglin & Hanin, 2000; Smith, Smoll, & Wiechman, 1998; Weinberg, 1989, 1990), "research findings have proved equivocal, with little evidence of the predicted relationships" (Jones, 1995b, p. 461). The frequent use of global performance measures (e.g., win or lose; hit or miss) is proposed as one of the possible reasons for the disappointing results to find support for the theoretical predictions. These outcome scores—denoting a product-oriented approach—may be too insensitive to detect significant anxiety effects (e.g., Parfitt, Jones, & Hardy, 1990; Weinberg, 1990). So far only few studies directly examined the *processes* by which performance mediation may take place (Collins, Jones, Fairweather, Doolan, & Priestley, 2001; Collins, Priestley, & Jones, 1996; Jones, Collins, & Doolan, 1998; Mullen & Hardy, 2000).

A process-oriented approach of the study of the relationship between anxiety and performance would not only consider changes in outcome but also changes in the execution of movements that might or might not lead to changes in outcome (Gould & Krane, 1992; Weinberg, 1989). In the present study we take such a process-oriented approach and investigate movement behaviour of participants placed in a threatening situation. We follow the general idea that an emotion, and hence anxiety, may manifest itself at three levels, namely, the level of subjective experience, the physiological level, and the behavioural level (e.g., Eysenck, 1975; Frijda, 1986; Hackfort & Schwenkmezger, 1993; Hanin, 2000; Lazarus, 2000; Vallerand & Blanchard, 2000).[1] For a full understanding of the effects of anxiety on performance it is important to gain insight at these three levels. However, there has been hardly any research taking all three levels into account. Especially the (movement) behavioural aspects remain under-exposed (see also Hanin, 2000). In the current study we examined the manifestations of anxiety at the three levels. In Experiment 1 we focussed on the subjective experience of anxiety and on concomitant physiological changes, both in autonomic variable heart rate and in muscle fatigue. In Experiment 2 we took a first step in investigating whether and how these covert manifestations of anxiety are accompanied by changes in participants' overt movement behaviour.

In the literature there has been little attention for the consequences of state anxiety on movement execution, pre-eminently the level of interest for athletes, coaches, physical educators, sport psychologists, and others. Notable exceptions in this regard are the studies by Weinberg (1978), Weinberg and Hunt (1976), Allmer (1983), Beuter and Duda (1985), Beuter, Duda, and Widule

[1] Other categorisations are possible, for instance, the well-known division of anxiety in cognitive and somatic anxiety and self-confidence (Martens, Vealey, & Burton, 1990), or Hanin's (2000) classification into seven components (cognitive, affective, motivational, bodily-somatic, motor-behavioural, performance, and communicative). We consider the division in the subjective, physiological, and behavioural level most appropriate for the purposes of the current study. The distinction between cognitive anxiety, somatic anxiety, and self-confidence does not capture the behavioural level, and most of Hanin's rather detailed seven components are captured by the three more general levels used in this study.

(1989), and the more recent studies by Collins et al. (1996, 2001), Jones et al. (1998), and Mullen and Hardy (2000). These studies were aimed at investigating the processes that underlie performance affected by anxiety either by measuring the electromyographic (EMG) activity of the muscles (Weinberg, 1978; Weinberg & Hunt, 1976), by studying movement characteristics such as the angle between upper leg and upper body (Allmer, 1983), by examining kinematic characteristics of a particular movement (Beuter & Duda, 1985; Collins et al., 1996, 2001; Jones et al., 1998; Mullen & Hardy, 2000), or by making kinetic analyses of movements (Beuter et al. 1989).

The results of the studies just cited support the contention that changing an individual's state (i.e., making him or her more anxious) can alter the characteristics of movement. For instance, anxiety is accompanied by movements that are less smooth, less efficient in terms of time and energy, and less variable (e.g., Beuter & Duda, 1985; Weinberg & Hunt, 1976). As indicated by Gould and Krane (1992), specifying the changes occurring in the execution of movements under high-anxiety conditions may provide insight into the question when performance may be impaired under the influence of anxiety and when no effects on performance may be expected. Therefore, one of the aims of the present study was to address anxiety-related changes in movement behaviour.

Thus far, the anxiety and motor performance research has specifically centred around the paradoxical performance effect or "choking under pressure", that is, "…the occurrence of inferior performance despite individual striving and situational demands for superior performance" (Baumeister, 1984, p. 610). Several attentional models have been put forward to explain debilitating effects of anxiety on performance such as the "distraction" model (Wine, 1971) and the "self-focus" model (Baumeister, 1984). Especially the self-focus model has recently received empirical support (e.g., Beilock & Carr, 2001; Lewis & Linder, 1997). It states that pressure raises self-consciousness about performing correctly, and that the increased attention to skill execution together with the subsequent step-by-step control is thought to disrupt the normal processing of the task (see also Jones, 1990; Lewis & Linder, 1997; Mullen & Hardy, 2000). Masters (1992, 2000) explicated the role of explicit and implicit knowledge in the disruption of the automaticity of a skill under pressure. According to Masters (1992, 2000), increased state anxiety *and* explicit knowledge about task performance may induce conscious control that disrupts the normal, automatic processing of the task at hand. The studies of Hardy, Mullen, and Jones (1996) and Mullen and Hardy (2000) produced evidence supporting Masters' (1992) "conscious processing hypothesis".

In these studies the renewed conscious control under pressure is seen as a temporary regress to a lower skill level, that is, to an earlier stage of learning, an idea that links back to stages of perceptual-motor learning introduced by Fitts and Posner (1967). After the cognitive and associative phases of learning, movement execution in the final autonomous phase is nearly fully automated (Fitts & Posner, 1967). Cognitive control of movements is no longer necessary. In fact, it is widely accepted that such cognitive control may be detrimental to skilled performance as it interferes with the well-learned automatisms of the skill. Thus, in going through these stages of learning the cognitive involvement in perceptual-motor control slowly diminishes. Following these ideas, a temporary regress to an earlier stage of motor learning would have to incorporate a reinvestment of cognition in perceptual-motor control, similar to the arousal-induced conscious control in Masters' (1992, 2000) conscious processing hypothesis.

To not only investigate a rather dramatic end product of the inability to cope with anxiety—

choking—we follow Masters' (1992) suggestion to also examine the processes underlying anxiety-related performance decrements and to search for behavioural concomitants of anxiety. In this search we set out from the hypothesis that anxiety results in a movement execution that is also associated with movements found at a lower skill level.

What can we expect to find at the behavioural level? Early in the process of mastering a perceptual-motor skill, performance is slow, irregular, and requires much effort. A common experience when starting to learn a new skill is that parts of the body, or sometimes even the whole body, are held rigid (think of your first dancing lessons). Bernstein (1967) called this the freezing of excessive biomechanical degrees of freedom necessary to turn the motor apparatus into a controllable, yet inefficient, system. It results in errors and inconsistent performance (Magill, 1998) with jerky, clumsy, and erratic movements (Den Brinker & Van Hekken, 1982; Vincken & Denier van der Gon, 1985; Whiting, Bijlard, & Den Brinker, 1987). Learning a task may be characterised by a gradual release of the rigid couplings between parts of the body, that is, by a release of the degrees of freedom. This "freeing" of degrees of freedom turns the motor apparatus into a controllable and efficient system, which would result in smoother and more fluent movements (Vereijken, Van Emmerik, Whiting, & Newell, 1992).

Recently, the evolution from irregular, jerky movements to regular, smooth movements has also been studied from the perspective of dynamical systems theory, a branch of mathematics concerned with the analysis and formal modelling of complex time series. A key notion in this theory is that of dimensionality, that is, the number of active dynamical (i.e., as opposed to biomechanical) degrees of freedom[2] that are required to portray or model a system's trajectory or succession of states. For instance, to identify the state and future trajectory of an ordinary second-order mass–spring system two active degrees of freedom are required: position and velocity; if these are known, the acceleration of the system follows uniquely from the laws of motion. For more complex trajectories, such as a movement trajectory, the number of active degrees of freedom is unknown a priori, but may be estimated using a variety of analytical tools. Mitra, Amazeen, and Turvey (1998) applied one of these techniques (Abarbanel's phase-space reconstruction method) to movement trajectories obtained during intermediate learning of a bimanual rhythmic coordination task. They found that intermediate learning gradually and monotonically reduces the number of active degrees of freedom of the learned coordination dynamics, implying a reduction in dimensionality.

There are parallels between the movement characteristics of early learning and those of performance under pressure. Just as in the beginning of the learning process, under the influence of anxiety performance is also characterised by rigid and jerky movements, and a stiffening of the body that resembles the freezing of biomechanical degrees of freedom as described by Bernstein

[2] Newell and Vaillancourt (2001) described the distinction between biomechanical degrees of freedom and active dynamical degrees of freedom as follows:

> In the tradition of mechanics and physics we use the term degrees of freedom as the number of independent coordinates required to uniquely describe the configuration of the system. Therefore, the term degrees of freedom is reserved for the potential configurations of the many physical components at each level of analysis of the system. In contrast, dimension is used to capture what has been called the number of active or dynamical degrees of freedom that are required to model the attractor dynamics of the movement system. There is often no obvious correspondence between the physical degrees of freedom of a system and the dimension of an attractor (…) (p. 696).

(1967) in early learning. This is probably accompanied by an increase in the number of active degrees of freedom in the sense of dynamical systems theory. Movement behaviour accompanying anxiety is tense resulting from "generalized muscular tension, wholly or partly independent of overt movement" (Frijda, 1986, p. 40). A rigid posture and jerky movements are discernible characteristics of this tenseness, just as early in learning.

In the present study we will focus on effects of anxiety using psychological, physiological (Experiment 1), and behavioural measures (Experiment 2). Because we expect performance under anxiety to be tense, in Experiment 1, apart from changes in heart rate, we also investigated whether there is a difference in muscle tension in anxious and non-anxious movement execution. To obtain an indication of muscle tension, we used muscle fatigue (blood lactate concentration and EMG) because a higher muscle tension would have to result in more muscle fatigue (Vincken & Denier van der Gon, 1985). In Experiment 2 we ask whether the expected muscle tension at the physiological level has repercussions for the smoothness of movement execution at the behavioural level as measured with the "geometric index of entropy" (Cordier, Mendès France, Bolon, & Pailhous, 1993; Cordier, Mendès France, Pailhous, & Bolon, 1994), a variable we will explain in the introduction to Experiment 2 and that may be connected conceptually to the notion of active dynamical degrees of freedom introduced before. As a result of the higher muscle tension we expected jerkier, more rigid movements in anxiety-provoking than in anxiety-neutral situations, and, therefore, a higher geometric index of entropy.

A crucial aspect of studying the effects of anxiety on movement behaviour is the way in which anxiety is manipulated. The common approach to manipulate anxiety is to use the "cognitive ego stressor method": via several steps of giving negative feedback on performance anxiety is provoked (e.g., Beuter & Duda, 1985; Beuter et al., 1989; Bootsma, Bakker, Van Snippenberg, & Tdlohreg, 1992; Mullen & Hardy, 2000; Weinberg, 1978; Weinberg & Hunt, 1976; Weinberg & Ragan, 1978). There are, however, some disadvantages to this method. First, negative feedback may compel participants to change their movement behaviour in a way they did not prefer initially. The change in movement behaviour may lead to a decrease in performance and to the wrong conclusion that anxiety impaired performance (Bakker, 1981). Second, most studies using the ego-stressor method managed to provoke only mild forms of anxiety that are below those typically found during competition (Williams & Elliott, 1999). Third, the ego-stressor method can cause an inward focus of attention that may in itself result in disruption of the automatism of the skill (Masters, 1992, 2000).

In the present study, we manipulated anxiety in a natural way by using a climbing wall where different heights provided different anxiety conditions. Some authors would rather speak of fear in this case, because of the presence of real physical danger (Morris, 1997; Spielberger, 1966). Apart from the presence or absence of physical danger, fear and anxiety have similar characteristics. Therefore, in this study we considered fear and anxiety as synonyms, which fits with the broad definition of anxiety given by Schwenkmezger and Steffgen (1989):

> *Anxiety* can be regarded as a broad concept for a number of very complex emotional and motivational states and processes that occur as a result of threat. This threat is related to the subjective evaluation of a situation, and concerns jeopardy to one's self-esteem during performance or social situations, physical danger, or insecurity and uncertainty (pp. 78–79).

Thus, the climbing wall provides an ecologically valid environment for the execution of climbing movements, and hence, an attractive location for studying the relationships between anxiety and performance (Jones & Hardy, 1990). Participants were asked to perform a climbing task in a threatening condition, that is, high on the climbing wall, and in a non-threatening condition, low on the wall.[3]

Although the climbing task was new to the participants when they entered the experiments, the climbing route was very easy and readily learned before actual testing started. In this regard, Fitts (1964) remarked that for simple skills the earliest learning phase may be of very short duration "covering only the time required to understand instructions, to complete a few preliminary trials, and to establish the proper cognitive set for the task" (p. 262). Therefore, and because performance decrements under pressure may occur irrespective of skill level and ability (Baumeister, 1984), we considered this task (the execution of which may not have been fully automated) suitable for testing our hypotheses.

Experiment 1

Method

Participants

Thirteen participants, five male and eight female, aged 20 to 30 years, volunteered to participate in the experiment. The participants, mainly college students, had no experience in climbing, and were naive to the purposes of the experiment. They were paid a small fee for their participation.

As a standard check, the Dutch version of the A-Trait scale of the State-Trait Anxiety Inventory (STAI)[4] was used to measure trait anxiety (Spielberger, Gorsuch, & Lushene, 1970; Van der Ploeg et al., 1979). The mean trait anxiety score for the male participants was 36.4 (SD = 10.62), and for female participants 31.8 (SD = 4.94). The mean score of male participants was comparable with the mean score for Dutch male college students reported by Van der Ploeg, Defares, and Spielberger (1980) [mean (M) = 36.1, $t = -0.06$, not significant (*ns*), *t*-test between a sample and a population mean; Thomas & Nelson, 1996]. The female participants were significantly less trait anxious compared to Dutch female college students [M = 37.7, Van der Ploeg et al., 1980, $t(7) = 3.38$, $P < 0.05$, *t*-test between a sample and a population mean]. The results indicate that the participants had no extraordinary tendency to respond to situations perceived as threatening with an elevation in state anxiety (e.g., Smith et al., 1998).

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[3] Jones (1995a) and Swain and Jones (1996) claims that direction of anxiety—whether anxiety is perceived as debilitative or facilitative—should also be taken into account when studying the effects of anxiety. However, Jerome and Williams (2000) argue that the results concerning this issue are equivocal. In addition, in the current study the focus is on *changes* as a result of anxiety either for better or worse. Therefore, in this study we did not consider direction of anxiety.

[4] The STAI A-Trait scale is a self-report questionnaire that measures anxiety proneness, that is, the tendency to respond to situations perceived as thrilling with an elevation in state anxiety intensity. Scores range from a low of 20 to a high of 60. Normative data for the STAI A-Trait scale depict a mean score of 36.1 [standard deviation (SD) = 8.4] for male college students, and of 37.7 (SD = 8.4) for female college students (Van der Ploeg, Defares, & Spielberger, 1979).

Experimental set-up

Participants climbed on a 10° inclined artificial wall (width: 3.5 m; height: 7.0 m; see Fig. 1), which was placed in a large experimentation room. The wall consisted of nine laminate panels with a grey grainy texture for friction. Holds of varying shape and size could be bolted almost anywhere on the wall.

On the wall, two identical, horizontal routes (so-called "traverses", built by a professional route designer) were mounted (see Fig. 1). Each traverse consisted of five foot and six hand holds of varying size and shape, all suitable for novice climbers. The traverses could be easily mastered within minutes of practice. The mean height of the five foot holds of the low traverse was 0.3 m (*low* condition); the mean height of the five foot holds of the high traverse was 5.1 m (*high* condition). To be able to start with the high traverse in the same physical condition as in the low traverse, a movable platform, 5.0 m above the floor, was placed 1.2 m in front of the climbing wall.

All participants wore well-fitting climbing shoes (Enduro 954, La Sportiva). In the high condition, participants wore an integral harness (Edelrid), connected to a climbing rope. A standard protection technique was used to ensure the safety of the participants. One of the experimenters served as belayer. The use of chalk was permitted.

To determine the manifestations of anxiety at the level of subjective experience we used the " anxiety thermometer" validated by Houtman and Bakker (1989). The anxiety thermometer is a 10 cm continuous scale on which participants were asked to rate their anxiety feelings at a particular moment, ranging from 0 (*not anxious at all*, the left end) to 10 (*extremely anxious*, the right end). Individuals had to place a cross on the 10 cm scale to indicate how they felt at a particular moment. The distance between the left end and cross (in cm) was used as a measure of the reported anxiety. Consequently, it is a quick way to measure state anxiety, in contrast to the often-

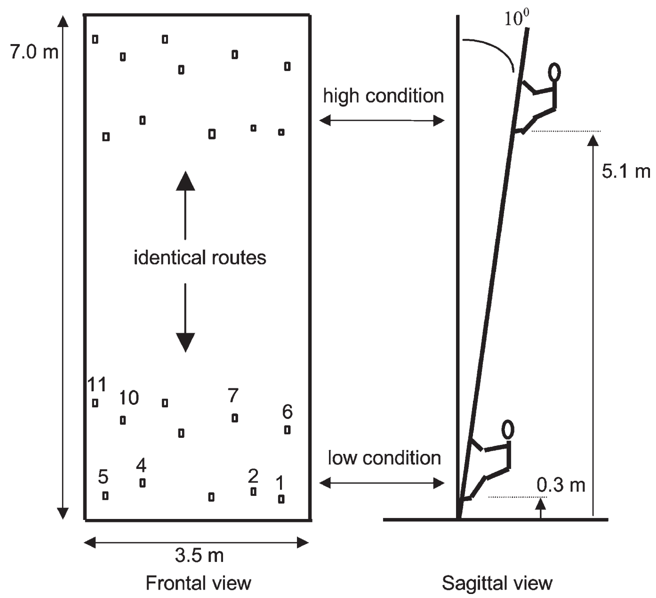

Fig. 1. Front view and side view of the climbing wall used in Experiments 1 and 2. In Experiment 2 the climbing wall was placed perpendicular.

used Competitive State Anxiety Inventory-2 (CSAI-2, Martens et al., 1990), which would be unsuitable for our purposes. In this regard it should be noted that the anxiety thermometer does not take into account the distinction between cognitive and somatic anxiety as measured with the CSAI-2. Anxiety thermometer scores appear to correlate equally with cognitive anxiety scores and somatic anxiety scores on the CSAI-2, on average $r = 0.59$ and $r = 0.62$, respectively (Bakker, Vanden Auweele, & Van Mele, 1996). For each measurement, a separate anxiety thermometer was used.

During climbing we recorded heart rate values every 5 seconds using a Sporttester (Polar Electro-3000). Afterwards, for every climb the mean heart rate was calculated. The blood lactate concentration of capillary blood samples (10 μl) was determined using photospectrometry (Dr. Lange, Mini 8).

To measure muscular fatigue we followed the guidelines of Petrofsky, Glaser, Phillips, Lind, and Williams (1982) using the decrease of the median frequency of the power spectrum of the EMG signal of the "hand-grip muscles" (see also Gamet & Maton, 1989). Participants performed an isometric contraction on a hand-grip dynamometer (Lafayette Instrument Co., ranging from 0 to 100 kg with the distance between the palm of the hand and the phalanxes being adjustable to hand size). During this contraction the electrical activity of the flexor muscles in the forearm was measured (surface EMG). The placement of the two bipolar silver–silver chloride surface electrodes (Medi-trace, ECE 1801) was on the diagonal line from the medial epicondyle of the humerus to the styloid of the ulna, at one-third proximal. The interstice of the electrodes measured 2.5 cm. A reference electrode was placed on the lateral condyle of the humerus. The EMG was measured by a differential amplifier (DISA, type 15C01, Skovlunde, Denmark) using a bandwidth of 10–200 Hz. The signal was sampled by a 12 bits A/D convertor at 1000 Hz, and stored in a computer. The median frequency of the power spectrum of the EMG signal was calculated by using a fast Fourier transformation.

The size of the grip of the dynamometer was adjusted for each participant (second joint of the middle finger of the hand holding the dynamometer was bent at a 90° angle). The participants sat at a table with their arm laying on the table; the arm was bent at about 90° angle and supinated. Maximal grip strength was determined beforehand (see Procedure) by having the participants squeeze the dynamometer with their preferred hand with maximal force. This was done three times. The best score was taken as the final result. During the experiment participants were asked to squeeze the dynamometer with 50% of their maximal force for at least 3 s. This was done twice in each condition, namely, before and after climbing. We took 50% of the maximal voluntary contraction (MVC) to ensure that for all squeezes the same force was generated. This guaranteed honest comparisons of muscle activity between the low and high conditions. During the isometric contractions the EMG activity was recorded. The median frequency before climbing and the median frequency after climbing were calculated and the difference in both median frequencies was used as index of muscle fatigue. Petrofsky et al.'s (1982) investigation showed that this is "…a good non-invasive index of muscle fatigue" (p. 221). As mentioned in the Introduction, together with blood lactate concentration we used this index of muscle fatigue as indirect measure of muscle tension.

Procedure

For each participant (tested individually) the experiment was spread over three days. *Day 1* was intended to familiarise participants with the procedure of the experiment and to learn the task they had to perform. Participants were first informed in general terms about the aims and procedure of the experiment. Next they signed a statement of informed consent and completed the Dutch version of the STAI A-Trait scale (Van der Ploeg et al., 1979). Then the maximal voluntary grip strength was determined (left or right hand by choice). Three minutes later participants practised the traverse five times back and forth in the low condition, ensuring that they could easily execute the task (at least in the low condition).

On *Day 2* (three to 10 days after Day 1) participants received a more detailed explanation of the procedure. Subsequently, the electrodes to measure EMG activity and the Sporttester were placed, and participants put on their climbing shoes and harness.

Seven minutes before climbing participants performed an isometric contraction with their preference hand on a hand-grip dynamometer, during which the EMG activity was recorded. Six minutes before climbing participants took a seat either on the floor or on the platform. One minute before climbing participants filled out the anxiety thermometer (Houtman & Bakker, 1989). Then, starting at the right side of the wall, participants climbed the traverse 6.5 times in the high or in the low condition (counterbalanced) with a set traverse time of 20 seconds. Hence, the total climbing time was 2 minutes 10 seconds. In the high condition the belayer lowered the participant using a standard technique to safely bring back participants to the floor. After climbing, participants immediately took a seat. They were asked to recall how anxious they had felt during climbing and to record this on the anxiety thermometer scale. The mean of the two anxiety scores in each condition was used as an anxiety score for that condition. After 1.5 minutes participants again performed an isometric contraction on the hand-grip dynamometer during which the EMG was recorded. Three minutes after climbing a blood sample was obtained from the participants' thumb and the blood lactate concentration was measured.

On *Day 3* (three to 10 days after Day 2) the procedure of Day 2 was repeated. The order of the conditions, however, was reversed.

Statistical analysis

The effects of Height (low condition, high condition) and Day (Day 2, Day 3) were tested with four two-factor within-subject analyses of variance (ANOVAs) with repeated measures on either anxiety thermometer scores, muscle activity indices, blood lactate concentrations or heart rates. Eta squared (η^2) assessed the explained variance in the ANOVA models. Pair-wise comparisons were made to identify specific mean differences when appropriate. In these cases the Bonferroni method (Kinnear & Gray, 2000) was used, requiring the alpha level to be adjusted to 0.008.

Results

The mean maximal voluntary grip strength of the participants was 43.4 kg ($SD = 11.67$), which is a normal grip strength for non-climbers (cf. Grant, Hasler, Davies, Aitchison Wilson, & Whittaker, 2001; Grant, Hynes, Whittaker, & Aitchison, 1996).

Subjective experience of state anxiety

The ANOVA performed on the anxiety thermometer data revealed that participants reported significantly more anxiety in the high condition ($M = 4.3$, $SD = 2.39$) than in the low condition ($M = 1.5$, $SD = 1.28$), $F(1,12) = 28.03$, $P < 0.001$, $\eta^2 = 0.70$. Scores did not differ significantly between Day 2 and Day 3. Also the interaction was not significant.

State anxiety at a physiological level

Heart rate The mean heart rate was significantly higher in the high condition ($M =$ 164.8 bpm, $SD = 14.06$) than in the low condition ($M = 146.1$ bpm, $SD = 18.07$), $F(1,12) = 101.69$, $P < 0.001$, $\eta^2 = 0.89$. There was also a significant interaction between Height and Day, $F(1,12) = 6.26$, $P < 0.05$, $\eta^2 = 0.34$. In the low condition on Day 2 ($M = 143.9$ bpm, $SD =$ 17.76), the mean heart rate was significantly lower than in the low condition on Day 3 [$M =$ 148.4 bpm, $SD = 19.17$, $t(12) = -2.08$, $P < 0.006$]. In the high condition the mean heart rate on Day 2 was 165.8 bpm ($SD = 13.06$) and on Day 3, 163.8 bpm ($SD = 15.36$). This difference was not significant ($P > 0.008$). The significant difference between Day 2 and Day 3 in the low condition was probably due to day-to-day heart rate fluctuations (see Table 1). Of particular relevance here is that the mean heart rate in the high condition was significantly higher than in the low condition.

Muscle tension Visual inspection during the experiment made clear that participants were able to accurately squeeze the hand-grip dynamometer at 50% of their MVC with minimal variations only. No further records of the squeeze accuracies were made.

The index of muscle fatigue and the blood lactate concentration were influenced by the height of climbing. The index of muscle fatigue was significantly higher in the high condition ($M =$ 8.2, $SD = 5.76$) than in the low condition ($M = 4.8$, $SD = 6.74$), $F(1,12) = 6.64$, $P <$ 0.05, $\eta^2 = 0.36$, as was the blood lactate concentration (high condition: $M =$ 7.2 mmol/l, $SD = 1.91$; low condition: $M = 6.0$ mmol/l, $SD = 1.26$), $F(1,12) = 6.42$, $P <$ 0.05, $\eta^2 = 0.35$. No other significant effects were found.

Table 1
Heart rate (bpm) for the low and high condition (mean and standard deviation) in Day 2 and Day 3 (Experiment 1)

	Day 2		Day 3	
	Low condition	High condition	Low condition	High condition
Starting in low condition	133.9	158.3	160.9	174.5
	(15.45)	(11.80)	(12.19)	(11.62)
	($n = 7$)	($n = 7$)	($n = 6$)	($n = 6$)
Starting in high condition	155.5	174.6	137.6	154.7
	(13.00)	(8.50)	(17.87)	(12.15)
	($n = 6$)	($n = 6$)	($n = 7$)	($n = 7$)
Mean	143.9	165.8	148.4	163.8
SD	17.76	13.06	19.17	15.36

Discussion

The purpose of Experiment 1 was to investigate manifestations of anxiety at the level of subjective experience and at the physiological level by means of heart rate, muscular activity, and blood lactate concentration. Self-report scores indicated that participants felt more anxious in the high condition than in the low condition. By comparison, the height of the scores suggests that participants felt more anxious than students who are about to enter a written examination (Houtman & Bakker, 1989); they felt about as anxious as novice teachers just before a lecture (Houtman, 1990); and they were less anxious than youth speed skaters prior to the start of a 1500 m race at a national championship (Bakker, Vanden Auweele, & Moormann, 1992). In addition to the subjective experience, heart rate appeared to be higher high on the wall than low on the wall. We found that these manifestations of anxiety went hand-in-hand with more muscle fatigue and a higher blood lactate concentration, indicating more muscle tension, as would also be expected when there is a renewed freezing of degrees of freedom.

An issue to pursue is whether these subjective and physiological changes associated with anxiety have repercussions at a (movement) behavioural level, the remaining level at which anxiety may manifest itself (e.g., Frijda, 1986). We addressed this issue in Experiment 2.

Experiment 2

A possible explanation for performance decrements coinciding with anxiety may be a regress to earlier stages of motor learning (e.g., Baumeister, 1984; Fitts & Posner, 1967; Hardy, 1999; Masters, 1992, 2000; Mullen & Hardy, 2000) characterised by higher muscle tension, and rigid and jerky movements. In Experiment 1 we showed that anxiety is accompanied by more muscle fatigue, indicating a higher muscle tension. In Experiment 2 we examined whether anxiety is also accompanied by rigid and jerky movements as would be expected if a regress to lower skill levels occurs. In order to do so we measured the fluency of participants' climbing movements by using a "geometric index of entropy" (Cordier et al., 1993, 1994). Just as the complexity of a spatial–temporal trajectory may be assessed by means of its dimensionality, the geometric index of entropy (in short, "entropy") can be used to assess the complexity of a spatial trajectory, or path (Cordier et al., 1993, 1994). In sport climbing the entropy can be defined as the fluency of the curvature that arises from the displacement of the body centre of gravity when climbing a route (Cordier et al., 1993, 1994; see Fig. 2). Mathematically, entropy (H) is described by the following equation (see Cordier et al., 1993, 1994):

$$H = \log_n(2L/c), \tag{1}$$

where L is the length of a curve, and c the convex hull of that curve (see Fig. 2).

Cordier et al. (1993, 1994) argued that there is a clear-cut correlation between the smoothness of a climber's trajectory and the climber's expertise. The more skilled a climber is, the more fluent the shape of his or her trajectory, and the lower the entropy of the trajectory. The authors indeed showed that entropy decreases as learning progresses, which is consistent with the decrease in dimensionality of spatiotemporal trajectories observed by Mitra et al. (1998) for intermediate learning. In Experiment 2 we use entropy and its mathematical components to empirically investi-

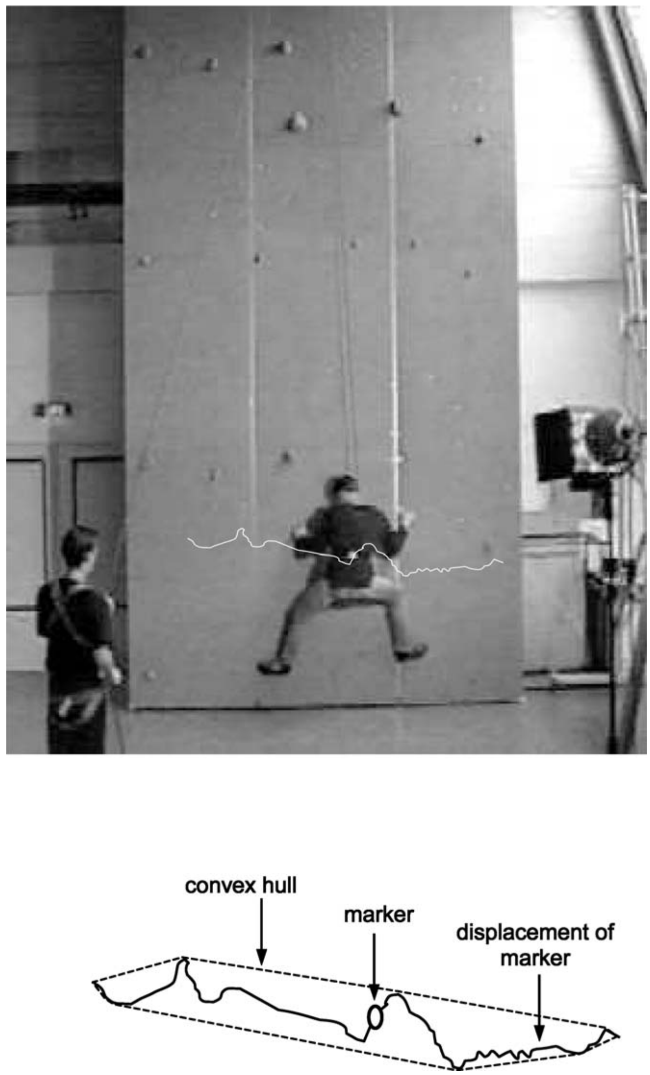

Fig. 2. Front view of the climbing wall with the marker curve. The low and high traverses were identical. The principle of assessing the index of geometric entropy is shown below the picture of the wall (cf. Cordier et al., 1993, 1994). (See text for more details.)

gate the idea that performance decrements associated with anxiety can be explained by a temporary regress to a movement execution associated with earlier stages of motor learning. If such a regress occurs, less fluent movements are expected, and hence, entropy should increase. Both a larger L and a smaller c will contribute to a higher entropy. Because we expected more rigid, jerky movements when anxious, we hypothesised that L would be larger, for the movement trajectory would be noisier. Due to a stiffening of the body, with movements of the centre of gravity taking place in a smaller motor work space, we also expected c to be smaller in the threatening condition than in the non-threatening condition. An increase in entropy as a result of anxiety would be consistent with the idea of a regress to earlier learning (Cordier et al. 1993, 1994).

Method

Participants

Seventeen college students, 11 male and six female, aged 19 to 26 years, volunteered to participate in the experiment. None of them participated in Experiment 1 and none had experience in climbing. All participants were naive to the purposes of the experiment.

The mean trait anxiety score for the male participants was 30.3 ($SD = 2.49$) and for the female participants 33.2 ($SD = 4.79$). The mean score of male participants was significantly different from the mean score for Dutch male college students ($M = 36.1$) obtained by Van der Ploeg et al. (1980) ($t = 7.73$, $P < 0.05$, t-test between a sample and a population mean, Thomas & Nelson, 1996). The mean score of the female participants was comparable with the mean score for Dutch female college students reported by Van der Ploeg et al. (1980) ($M = 37.7$) ($t = 2.30$, *ns*, *t*-test between a sample and a population mean, Thomas & Nelson, 1996). The results indicate that the participants had no extraordinary tendency to respond to situations perceived as threatening with an elevation in state anxiety (e.g., Smith et al., 1998).

Experimental set-up

Participants again climbed on the climbing wall in a high and low condition. This time the wall was not inclined but vertical and no time constraints were imposed. Again two identical, horizontal routes (traverses) were mounted on the wall each consisting of six hand holds and five foot holds (see Fig. 2). As in Experiment 1, the mean height of the foot holds of the low traverse was 0.3 m (*low* condition). The mean height of the foot holds of the high traverse was not as high as in Experiment 1 because at this height (5.1 m) it was not possible to make the required video recordings to determine entropy. Therefore, the mean height of the foot holds of the high traverse was 3.7 m (*high* condition). To enable participants to start climbing in the high condition a large stepladder was used. The stepladder had a small platform that allowed the participants to rest after having climbed it and to start the high traverse in the same physical condition as in the low traverse.

As in Experiment 1 participants wore well-fitting climbing shoes and an integral harness connected to a climbing rope. The same security procedure as in Experiment 1 was used, but now this was done in both the high and the low condition to ensure similarity of the conditions (apart from the height, of course). This is especially relevant in this experiment because the presence of the security rope might, in principle, have an effect on the entropy, the most relevant dependent variable. All climbs were recorded using an S-VHS camcorder (sampling rate of 50 Hz) placed 12 m in front of and perpendicular to the climbing wall at a height of 2 m.

Procedure

Participants were tested individually and on a single day. The experiment lasted approximately two hours. The entire procedure was explained to each participant. Participants were then asked to read and sign a statement of informed consent and to fill out the Dutch version of the STAI A-Trait scale (Van der Ploeg et al., 1979).

After participants had put on their climbing shoes and harness, and placed the Sporttester, they practised climbing on the wall (low traverse). Climbing advice was given to participants when needed. Practice periods lasted from 5 to 10 minutes and stopped when participants were able to successfully complete the traverses on the wall. In this way it was ensured that participants had mastered the task and that an eventual failure of a participant to complete the task in either condition would not be due to lack of experience with the task. After practising participants were allowed 20 minutes to fully recuperate.

Five minutes before each condition, the participant was positioned in front of the wall, either on the floor or the stepladder. Two minutes before the climb participants were asked to indicate how anxious they were at that moment by filling out the anxiety thermometer (Houtman & Bakker, 1989). Then, the participant was connected to the rope. Use of chalk was permitted. The participant was instructed to begin when ready by taking the starting position on the wall. Participants were in the starting position when they had placed their right hand on hold number 6 (see Fig. 1), their left hand on hold number 7, their right foot on hold number 1, and their left foot on hold number 2. In the high condition, as soon as the participant had taken this position, the stepladder was removed to make sure that in the event of a fall he or she would not hit it.

The participants resumed the same position after they had climbed the traverse two times. Hence, participants climbed the traverse from the right to the left (ending with right hand on hold 10, left hand on hold 11, right foot on hold 4, and left foot on hold 5; see Fig. 1), and back to the right again. Immediately after the climb, the participants were asked to recall how anxious they had felt during climbing and to record this on the anxiety thermometer. The mean of the two anxiety scores (before and after the climb) was used as an anxiety score for that climb (and thus, for that condition).

After a recuperation time of about one hour the procedure was repeated, but now participants climbed in the other condition (high if they had started low; low if they had started high). The order of high and low conditions was reversed with every new participant.

Dependent variables

Trait and state anxiety and heart rate were measured in the same way as in Experiment 1. As explained in the introduction to Experiment 2, we used the geometric index of entropy (Cordier et al., 1993, 1994) to measure participants' fluency of movements. To calculate the entropy, a marker was mounted at the participant's back (see Fig. 2). The marker was attached to a belt that was secured around the participant's waist. Afterwards, the position of the marker was determined from video (using WINanalyze software package, version 1.4 3D by Mikromak GmbH) so that the length of the marker line, the convex hull, and the entropy could be calculated.

Because climbing time was not standardised as in Experiment 1 we also determined climbing time from video to determine whether anxiety had an effect on the speed of climbing. It was defined as the sum of the time needed to climb the two traverses (from the right to the left, and back) in each of the two conditions. Time started as soon as participants released one of the holds in the starting position; thus, as soon as the first movement was initiated. When the participant had returned to the starting position after climbing the two traverses, the time was stopped.

Statistical analysis

The effects of Height (low condition, high condition) were tested using one-tailed paired *t*-tests. Effect sizes of within factor (ES_w) were calculated to provide an estimation of the meaningfulness of a difference between two means (Mullineaux, Bartlett, & Bennett, 2001; Thomas &

Nelson, 1996). An effect size of 0.2 or less, about 0.5, and 0.8 or more, represents small, moderate, and large differences, respectively (Cohen, 1988).

Results and discussion

Anxiety thermometer scores and heart rate

Participants reported significantly more anxiety in the high condition ($M = 4.6$, $SD = 1.72$) than in the low condition ($M = 2.1$, $SD = 1.13$), $t(16) = -10.10$, $P < 0.001$, $ES_w = 2.19$. The mean heart rate also differed significantly between conditions, $t(15) = -6.29$, $P < 0.001$, $ES_w = 0.99$, being higher in the high condition ($M = 130.4$ bpm, $SD = 18.75$) than in the low condition ($M = 112.4$ bpm, $SD = 18.24$). Thus, despite a somewhat lower height of the traverse in the high condition compared to that of the high condition in Experiment 1, the results indicate that the anxiety manipulation was again successful.

Entropy

Table 2 displays the entropy (H), the length of the climbing trajectory (L), as well as the convex hull (c) per condition. The mean entropy was significantly higher in the high ($M = 1.11$) than in the low condition ($M = 1.01$), $t(16) = -2.80$, $P < 0.01$, $ES_w = 0.95$, indicating a less fluent dis-

Table 2
Geometric index of entropy (H), length of the climbing trajectory (L), and convex hull of the climbing trajectory (c) for the low and high condition; L and c are reported in metres

Participant	Low condition			High condition		
	H	*L*	*c*	*H*	*L*	*c*
1	0.97	5.9	4.5	0.99	6.4	4.7
2	0.96	6.2	4.8	1.11	6.9	4.5
3	1.15	7.3	4.7	1.16	7.2	4.5
4	1.09	7.5	5.0	1.09	7.2	4.9
5	0.95	6.4	5.0	1.09	7.2	4.8
6	0.97	6.2	4.7	1.13	6.7	4.3
7	0.94	6.7	5.2	1.07	7.0	4.8
8	0.94	5.8	4.5	1.46	9.2	4.3
9	0.87	5.8	4.9	0.87	5.6	4.7
10	1.10	6.7	4.4	1.13	6.8	4.4
11	1.30	9.0	4.9	1.15	7.0	4.4
12	1.05	7.1	5.0	1.27	8.4	4.7
13	1.03	7.1	5.1	1.04	6.8	4.8
14	0.96	6.7	5.2	1.03	6.9	4.9
15	0.91	6.4	5.2	1.14	7.4	4.8
16	0.98	6.4	4.8	1.13	7.0	4.5
17	1.07	7.0	4.9	1.05	7.0	4.8
Mean	1.01	6.7	4.9	1.11	7.1	4.6
SD	0.104	0.77	0.23	0.124	0.77	0.20

placement of the centre of gravity under the influence of anxiety. Table 2 shows that 11 of 17 participants demonstrated a lengthening of the climbing trajectory in the high condition, suggesting that the course of the body's centre of gravity seems to be somewhat more erratic when climbing in the high condition, though the difference in L between high and low conditions was only marginally significant, $t(16) = -1.40$, $P = 0.09$, $ES_w = 0.48$. Moreover, the convex hull in the high condition appeared to be significantly smaller than in the low condition, $t(16) = 5.60$, $P < 0.001$, $ES_w = 0.97$, further explaining the higher entropy. The smaller convex hull indicates that the climbing trajectory was flattened in the high condition compared to the low condition, while the climbing routes were identical. Thus, displacements of the centre of gravity covered a smaller motor work space high on the wall.

Climbing time

Table 3 shows the climbing time per condition. It appeared that the average climbing time increased significantly and by almost 50% from 29.5 s in the low condition to 43.1 s in the high condition, $t(16) = -5.59$, $P < 0.001$, $ES_w = 2.02$. Possible reasons why these climbing times were so much longer will be briefly discussed in the General discussion. Note that the longer climbing time may partly explain the higher heart rates.

Together, the results clearly indicate that participants' climbing behaviour in the high condition differed from that in the low condition.

Table 3
Climbing time (s) for the low and high condition

Participant	Climbing time	
	Low condition	High condition
1	24.8	29.1
2	26.9	36.4
3	42.6	43.3
4	32.5	37.0
5	35.4	59.6
6	43.8	58.1
7	24.4	38.4
8	27.8	68.1
9	19.2	23.3
10	32.3	58.7
11	30.1	46.7
12	28.4	46.7
13	19.8	35.0
14	25.3	36.2
15	28.8	44.4
16	33.1	40.6
17	26.9	31.3
Mean	29.5	43.1
SD	6.72	12.11

General discussion

The main aim of this study was to examine the relationship between anxiety and motor performance. More specifically, we investigated the processes underlying the often-noticed impairment of performance associated with anxiety. To examine anxiety–performance relationships we investigated possible manifestations of anxiety at three levels: the level of subjective experience, the physiological level, and the behavioural level. Based on the literature on anxiety (e.g., Hardy, 1999; Masters, 1992; Mullen & Hardy, 2000), we argued that anxiety might disrupt movements leading to a type of movement behaviour characteristic of earlier stages of learning that would be characterised by stiffening of the body, and more rigid and jerky movements.

To manipulate anxiety we used height on a climbing wall. This manipulation offered a way to test participants in a natural, ecologically valid situation that is both safe and frightening (Baddeley, 1972; Idzikowski & Baddeley, 1987). In Experiment 1 we showed that with this manipulation, anxiety manifested itself both at the level of subjective experience as indicated by the higher anxiety scores, and at the physiological level as indicated by the higher heart rates, higher blood lactate concentrations, and more muscle activity. Because climbing times were standardised these changes could not be the result of, for instance, faster climbing (earlier fatigue) or slower climbing (e.g., with longer grasping of the holds and more fatigue). Thus, participants seemed to perform the climbing task in the threatening condition with more muscle tension than in the non-threatening condition.

In Experiment 2 we addressed the question whether the physiological changes found in Experiment 1 were also manifest in participants' overt movement behaviour. To examine this question we determined the fluency of the climbing movements by measuring the entropy. We found a higher entropy of climbing trajectory when participants climbed high on the climbing wall, indicating a less smooth displacement of the body's centre of gravity that is also characteristic of less skilled climbing behaviour (Cordier et al., 1993, 1994). The higher entropy appeared to be the result of a somewhat longer climbing trajectory of the body's centre of gravity (L, see Fig. 2) and, especially, a smaller convex hull (c, see Fig. 2). Together these results show a noisier movement pattern and the use of smaller motor work space to climb an identical route.

In addition, when no time constraints were imposed (Experiment 2), climbing time appeared to be no less than 46% longer in the high condition than in the low condition. Thus, apart from spatial changes, the temporal patterning of climbing movements changed as well. Other than noticing that a longer climbing time fits well with a more rigid, jerkier and less efficient movement pattern, it is difficult, with the variables measured in this study, to explain why this change in climbing time occurred. With entropy we investigated the movements of the centre of gravity but our results remained mute about the movements made with the limbs. Did participants make more limb movements, for instance? Did they grasp the holds longer? Or did they move slower from hold to hold? To gain further insight into the anxiety–performance relationship we investigated these questions in a follow-up study (Pijpers, Oudejans, McGuigan, & Bakker, 2002). The preliminary results indicated that there were more explorative hand and foot movements—in part, this might explain the increase in entropy—and that movements from one hold to another were actually slower in the high-anxiety condition than in the low-anxiety condition. These findings may partly explain the longer climbing times under anxiety-provoking conditions. Additional research is required into the relation between entropy changes as found here and the changes in limb movements as found in our follow-up study.

All in all, the results support our hypotheses so that we can conclude that anxiety manifests itself at the level of subjective experience, at the physiological level as well as at the behavioural level. Furthermore, because anxiety resulted in an increase in muscle tension, longer climbing times, and an increase in entropy, we can also conclude that the physiological and movement behavioural changes displayed under anxiety conditions reflect a regress to a movement execution also characteristic of earlier stages of skill acquisition.

Our results are in line with those of Weinberg (1978), Weinberg and Hunt (1976), Beuter and Duda (1985), and Beuter et al. (1989) who also found spatio-temporal changes in movement patterns under the influence of anxiety. In addition, the results are in accordance with the self-focus model of choking (Baumeister, 1984) or the conscious processing hypothesis (Masters, 1992; Mullen & Hardy, 2000) in which anxiety is assumed to evoke an inward focus of attention on the step-by-step execution of the movement. Consequently, movement control involves more cognitive processes.[5] As a result, just as when learning a new skill, parts of the body, or sometimes even the whole body, are held rigid. Or, in Bernstein's (1967) terms, one could say that excessive biomechanical degrees of freedom are frozen. From a dynamical systems perspective one could argue that more active dynamical degrees of freedom are required to describe the resulting spatial trajectory. Most important for now, it seems that performing a learned task in a threatening situation can be considered as performing a "new", unfamiliar task for which a new solution has to be found.

This idea provides a simple explanation as to why repeated exposure to anxiety-provoking situations results in a decrease in the effects of anxiety on performance (e.g., Frijda, 1986). Apart from habituation (less anxiety), one learns to execute the task under the influence of anxiety. In the beginning anxiety provides a new condition for which a new perceptual-motor solution has to be found. After repeated exposure one not just learns to execute the task, but one learns to execute the task under those specific conditions, that is, under the influence of anxiety. This would explain the well-known phenomenon that even experienced artists before coming on stage and experienced athletes before an important match or race are still very anxious, even though this normally does not impair their performance. They have learned to perform well under conditions of anxiety. Performing under pressure is no longer new and unfamiliar.

As a final point, the role of perceptual processes, not investigated so far, should be taken into consideration in the anxiety–performance research as well. Williams and Elliott (1999) noted that "successful performance in sport requires skill in perception, as well as the efficient and accurate execution of movement patterns" (p. 362). These authors found with respect to karate that high levels of anxiety increased the rate of visual scanning and the number of fixations on opponents' arms and fists, and as such their research is exemplary for the role of perception in anxiety–performance relationships. Hardy and Hagtvet (1996) alluded to this possible role of perception in the anxiety research by asserting that realistic attempts to model the anxiety–performance relationship need to consider the changes in perceptual processes that may accompany anxiety

[5] As an aside, these processes might perhaps also contribute to the longer climbing times, as performance involving these processes will take more time than a more automated execution of the task.

and underlie performance effects. However, only a few studies have assessed the effects of anxiety on perceptual processes in general, and almost no previous research has examined the effects of anxiety on perceptual processes in sport (Williams & Elliott, 1999).

In conclusion, research into anxiety–performance relationships may profit from the use of process measures. The use of outcome measures may provide indirect support for the idea that performance is affected by anxiety, but it does not allow conclusions as to why and how anxiety affected the actual movement execution (e.g., Bennett, 2000). Insight into these latter issues may have consequences for designing anxiety-reducing techniques. Thus, to answer the question why anxiety may impair sport performance it does not suffice to just explore the effects of anxiety on one's global performance. Instead, the intermediate steps between heightened anxiety and the eventual performance should also be investigated. In this respect, much work remains to be done in order to obtain a thorough insight into anxiety–performance relationships in sport.

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