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REVIEW

Current understanding in climbing psychophysiology research

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Abstract
The sport of rock climbing places a significant physiological and psychological load on participants. Psychophysiological analysis provides a unique insight into affective states arising from the demands of climbing, and the impact that they have on performance. This review provides an overview of climbing psychophysiology research completed to date. To summarise, an on-sight lead ascent of a route elicits the greatest psychophysiological response in climbers, whilst a red-point top-rope ascent produces the least. The effects of climbing stimuli on an individual's performance appear to be conditional on their experience. In general, experienced climbers show superior performance and are less anxious than their less practiced counterparts, with significantly lower cognitive and somatic anxiety, increased self-confidence and lower values of the steroid stress hormone cortisol. It is likely that the experience–stressor–performance relationship is due to advanced climbers' greater understanding of the risks associated with the sport, their habituation to the stressors gained through practice and their ability to perform well with higher levels of anxiety. This review outlines pertinent psychological climbing stimuli, summarises current methodologies and presents a detailed review of climbing psychophysiology research. It also concludes with suggestions for improving the depth and breadth of future research, including the need for the refinement of existing measures.

Keywords: *psychophysiology, rock climbing, experience, stimuli, stressors, anxiety*

1. Introduction

The challenges, or stimuli, of climbing include the significant physiological demands of the sport, including the difficulty, length and angle of a climb (Watts, 2004); the psychological demands, including the style of ascent, competition, height, fear of falling and climbing with an audience (Hague & Hunter, 2011); along with a significant element of skill (Seifert et al., 2013). These psychological stimuli must be responded to appropriately and effectively managed for athletes to complete a climb successfully (MacLeod, 2010). This review is concerned with research examining the ~~affect~~ of these psychological stimuli on climbers' physiology and performance. Through the psychophysiological analysis of the stimuli, researchers are provided with a unique insight into affective states arising from the demands of the sport, along with the impact that they have on individuals' performance (Draper, Jones, Fryer, Hodgson, & Blackwell, 2008; Hodgson et al., 2009).

Individual differences in interpretation mean that stimuli will not affect all climbers in the same way (Lazarus & Folkman, 1984). Stimuli may be perceived as benign, stressful (distress, anxiety inducing, resulting in a negative affective state) or positive (eustress, enhancing function and optimal arousal) (Apter, 1991). Distress and negative affect in response to a stimulus is likely due to a disparity between its demands and an individual's ability to

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meet them; conversely, eustress and positive affect are likely to arise when an individual is capable of meeting the demands of a stimulus (Lazarus & [AQ1] Folkman, 1984).

[AQ2] This review comprises four distinct sections. Section 2 summarises the key aspects of physiology and psychology research, which underpin our understanding of climbing psychophysiology. Section 3 addresses psychophysiological measures currently used in climbing research. Section 4 outlines relevant research that has been conducted in an applied climbing context. Finally, the Section 5 summarises future research directions.

2. The nature of climbing stimuli

The primary stimuli considered in this review relate to the significant psychological demands of climbing, in particular: the style of ascent; route knowledge and difficulty; and competition climbing and climbing with an audience (Section 2.1). This is followed by an outline of theories concerning the psychological bases of individual variation in responses (Section 2.2) and a summary of the relevant neurophysiological processes (Section 2.3).

2.1. Stimuli within the sport of climbing

2.1.1. Style of ascent. Climbing psychophysiology research has predominantly, but not exclusively, focused on alterations in the 'style of ascent' (e.g. Dickson, Fryer, Blackwell, Draper, & Stoner, 2012; Draper et al., 2012; Fryer, Dickson, Draper, Blackwell, & Hillier, 2012). The style of ascent describes the safety protocol protecting the climber in the event of a fall. Safety protocols include lower-height 'bouldering' routes, commonly protected by crash mats (Stiehl & [AQ3] Ramsey, 2004). Longer ascents may be protected by a 'top-rope' with which a fall is immediately arrested, considerably reducing the consequences (Bisharat, 2009). Alternatively, climbers may 'lead' a route, where a fall results in travelling some distance before being arrested by a trailing rope, attached to either intermittent pre-placed bolts, known as 'sport lead climbing', or climber placed protection 'traditional lead climbing' (Bisharat, 2009).

It is common for climbers to experience fear of falling, particularly whilst leading routes; this is especially common in lower-grade climbers (Hörst, 2008; MacLeod, 2010). MacLeod (2010) describes a fear of falling as a significant limiting factor in many climbers' performance. A fear of falling is a non-associative phobia, which may develop without the individual experiencing any direct or indirect trauma (Menzies & Clarke, 1993). Typically, the initial fearful response to falling will diminish over time due to habituation (Clarke & Jackson, 1983); however, poor habituates and individuals who do not get sufficient safe exposure may remain fearful (Clarke & Jackson, 1983). Climbers may habituate and desensitise themselves to falling through actively taking falls whilst practicing climbing, and through progressively increasing the fall length (Hörst, 2008; Macleod, 2010). [AQ4] Research is necessary to establish the effectiveness of fall training interventions, it is also not known if habituation to falling indoors transfers outdoors, to sport or traditional climbing, or vice versa.

The ~~affect~~ of fear of falling has not yet been examined in climbing psychophysiology literature, although contexts where it is inferred have been used (e.g. Draper et al., 2008). Alterations in height have also been used to manipulate anxiety levels, relying on individual's fear of falling and the presence of real physical danger to elicit negative affective states (Spielberger, 1966). These studies have examined the anxiety–performance relationship (Pijpers, Oudejans, Holsheimer, & Bakker, 2003), the affect of anxiety on visual attention (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008), anxiety-induced changes in movement in a whole body task (Pijpers, Oudejans, & Bakker, 2005) and the role of anxiety in perceiving and realising affordances (Pijpers, Oudejans, Bakker, & Beek, 2006).

2.1.2. Route knowledge and difficulty. A climber's prior knowledge of a route impacts the way in which the ascent is completed, along with altering the relative psychological load (Draper et al., 2008). The principal forms of ascent are 'on-sight', without any prior knowledge, on the first attempt; 'flash' competing a route with prior knowledge on the first ascent; or a 'red-point', repeat ascent of a whole or partially climbed route (Goddard & Neumann, 1993). [AQ5] An on-sight is often considered the purest form of ascent, although it is speculated that a red-point, at a climber's absolute maximum climbing grade, may prove to be a greater physiological and psychological challenge (Hague & Hunter, 2011). Within published climbing psychophysiology literature the antipodal conditions of on-sight and red-point have been used exclusively (e.g. Draper et al., 2008; Hardy & Hutchinson, 2007).

The size and quality of hand and footholds available, and their spacing and the length and angle of the climbing itself usually dictate a climbs' difficulty. Climbs are 'graded' for ease of compari- [AQ6] son, to judge performance and to allow climbers to choose suitable routes. Within climbing research the authors recommend the adoption of Draper, Canalejo, et al.'s (2011) convention for the summary of climbing grades and the standardised division of experience across these grades.

Climbing routes present a complex problem-solving task; the correct perception of affordances that a route offers plays a significant role in the success of an ascent (Pijpers et al., 2006). Affordances, in a climbing context, describe the link between the visual properties of holds and the more general climbing environment and the action, or actions, which may be performed with them (Gibson, 1979). The link may be based on stored information about a particular hold, but this is not always necessary (Humphreys & Riddoch, 2001). Significant differences between expert and more inexperienced climbers have been observed in the recall of information. Experienced climbers are able to recall more information, and clusters of information, and tend to fixate on the functional aspects of a climbing wall that are pertinent to a successful ascents of a route, whilst inexperienced climbers focus more on the holds themselves (Boschker, Bakker, & Michaels, 2002). It was also found, through the comparison of high and low traverse conditions, that anxiety narrows attention and a climber's emotional state plays an important role in the perception and realisation of affordances (Pijpers et al., 2006). Difficulties with the visual perception of climbing affordances may be compounded outdoors by the reduction in distinction of holds, in comparison to the typically coloured indoor holds, although due to the use of chalk outdoors, this may also vary (Luebben, 2004). Variation between rock types may also provide additional psychological difficulties with learning and perception of affordances and would be an interesting line of enquiry for future research.

2.1.3. Competition climbing and climbing with an audience. Competition is a potent psychological stimuli; a number of studies have examined competition climbers' precompetitive anxiety and affective states (Aşçi, Demirhan, Koca, & Dinc, 2006; Sanchez, Boschker, & Llewellyn, 2010). Climbing competitions, with few exceptions, take place on routes that are unknown to the competitors (International Federation of Sport Climbing [IFSC], 2007). Initial rounds of competitions allow those taking part to observe each other, gaining potentially useful information relating to the routes (Burbach, 2004). Climbers are placed into isolation in later rounds, forcing them to complete the routes on-sight. Emphasis is placed on climbing the routes without falling in order to receive the most points (IFSC, 2007); this places competitors under a great deal of pressure to perform optimally on their first attempt of the route (Goddard & Neumann, 1993).

Climbing is rarely completed in isolation; an audience, comprising of peers, spectators and/or competition judges, is usually present. To the authors' knowledge, research examining the effects of an audience on climbing performance has not yet been conducted. However, in other contexts, the performance of motor skills with audiences has been shown to produce varying responses. Murray (1983) demonstrated that executing a recently learnt motor skill in front of an audience was more effective for producing optimal performances than if it was completed in isolation; conversely, Butki (1994) demonstrated significantly inferior performance of a simple motor skill when it was completed in front of an audience. The issue is further complicated by the findings of Weinberg and Gould (2011), who demonstrated that the performance of new tasks with an audience negatively affected difficult skills, which had not yet been mastered, whereas for well-known or simple skills it helped performance. Climbing would provide an interesting medium in which to examine the ~~affects~~ of an audience on recently learnt and concrete motor skills.

2.2. *Manifestation of stress in response to stimuli and climbers motivation*

The interpretation of anxiety by climbers, the antecedents and benefits of optimal arousal and motivation for taking part in the sport may help to explain differences seen in individual's psychophysiology and its influence on climbing performance. This section will briefly outline several theories, applied in a climbing context, which explain aspects of the behaviour of climbers. Critically, climbing psychophysiology research has not discussed the results of studies in light of more general sport and pure psychology research; this section does not aim to present a comprehensive overview of theories, but instead start a discussion that may be addressed in future research.

2.2.1. Reversal theory. Climbers are required to effectively manage and respond to the significant risks associated with the climbing environment, in order to ensure their own safety (British Mountaineering Council, n.d.); an individual's response to risk depends on their ability to interpret, organise and execute an appropriate response. There are several theories that attempt to explain the stimuli–performance relationship and differences in the positive or negative affect individuals' experience, including Apter's (1989) reversal theory. Reversal theory is composed of bistable, telic and paratelic states; the telic state is characterised by planning and evaluating an activity on where it may lead in the future, whilst the paratelic

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state is spontaneous, evaluating an activity on the pleasure it gives at that moment (Apter, 1989).

Key to reversal theory is an individual's interpretation of stimuli as benign, stressful or positive. Reversal theory allows for individuals to display different personalities at different times depending on their interpretation (Apter, 1989). If the needs of the particular state, which the individual is experiencing, are fulfilled, then positive affect will result; conversely, if the needs are frustrated, then negative affect will result (Shepherd, Lee, & Kerr, 2006). The individual may also reverse back to a previous state at any given time if 'triggered' by an environmental event. In order to reduce anxiety, negative affect may be overcome not only by reducing arousal but also by inducing a reversal so that pleasant excitement is experienced instead. In a climbing context, climbers needlessly confront themselves with risk in order to achieve high arousal, this high arousal may be experienced as anxiety, but if the danger or challenge is overcome there may be a switch to the paratelic curve, resulting in excitement as intense as the anxiety (Shepherd, Lee, & Kerr, 2006). More generally, it has been found that those who are paratelic-dominant tend to choose and participate in risky and explosive sports, whereas a telic-dominant prefers safe and endurance sports (Chirivella & Martinez, 1994).

2.2.2. Flow experience. The potential for achieving a positive 'optimal experience', synonymous with a 'flow' state, resulting from successfully overcoming a challenge, provides a possible explanation for climbers motivation and their propensity for risk taking. Flow is defined as a state of optimal functioning and is characterised by deep involvement in an activity, feelings of immersion, loss of perspective of time and effortless ease and fluency of movement (Csikszentmihalyi, 1990). It is speculated that climbers may be motivated by flow, rather than directly by the risk that they take, although risk is still an integral part of the experience (Schüler & Nakamura, 2013). Flow is more likely to be experienced when there are clear goals, which are focused on aspects of their performance other than purely the outcome of the climb, a balance between challenge and skill and the possibility of immediate feedback (Delle Fave, Massimini, & Bassi, 2011; Hooper, Collins, & Eklund, 1998).

The importance of climbers' experience, for the correct appraisal of risk and their own competence, has been highlighted by Schüler and Nakamura (2013). Behind the 'lighter' optimal emotional state they describe a 'darker' side. In this darker state the individual is so involved in the activity that nothing else matters, they will complete the activity even if it results in great personal loss, they are addicted to the activity and may endanger their own physical integrity for the sake of experiencing flow (Schüler & Nakamura, 2013). Fear may be an emotional prerequisite for flow in beginner climbers, it has been found that flow experiences lead to the lowering of risk awareness and inappropriate risk taking, resulting in climbers 'letting-go' and 'just going for it' (Hooper et al., 1998; Schüler & Nakamura, 2013), whereas experience protects climbers from risk-taking behaviour, providing them with a more accurate appraisal of the correct balance between challenge and skill, which is influenced by past performances and their own perception and control of emotional arousal (Hooper et al., 1998; Schüler & Nakamura, 2013). Interestingly it was also found that climbers on traditional routes, in comparison to outdoor sport climbs, also experienced the same perceptions of danger and presented the same tensions as beginner climbers did when they were compared to their more experienced counterparts (Hooper et al., 1998).

2.2.3. General motivation. High achievement in climbing, with few exceptions, does not offer any extrinsic material rewards (Robinson, 1985). Climbers take part in the sport under their own volition, making choices that may increase the risk, including the style, difficulty, risk and exposure of ascents. Climbers' enjoyment of the sport appears to be unrelated to the associated fear, pain and strenuous muscular effort required (Hooper et al., 1998). With this in mind, climbers of all abilities take part, by choice, in riskier ascents, where the consequences of mistakes are more severe, likely motivated by the opportunity for optimal experiences, rather than the risk itself (Schüler & Nakamura, 2013). Climbers draw enjoyment from overcoming intense effort and through their own personal improvement (Papaioannou, Kourtesopoulou, & Konstandakatou, 2005). It is believed that competence, combined with hard effort, is a decisively important factor that leads to both successful ascents and the development of self-confidence in climbers (Papaioannou et al., 2005).

2.3. Neurophysiological response

The neurophysiological mechanisms and processes responsible for the cognitive, somatic and behavioural responses to stressors are complex (Gray & McNaughton, 2003). A brief outline of the response to a stressor, as described by Steimer (2002) begins with basolateral complex of the amygdala receiving the external stimuli, which is relayed by the thalamus, along with contextual information from the hippocampal formation and more elaborate cognitive information from the prefrontal cortex. The prefrontal cortex modulates the physiological, neuroendocrine and behavioural response, as well as being responsible for anxiety conditioned responses. The emotional stimuli received by the basolateral complex of the amygdala are processed, before the central nucleus of the amygdala activates different midbrain regions and nuclei, which provide the response to the initial anxiety stimulus. The central nucleus of the amygdala activates the locus ceruleus, the central and peripheral noradrenaline systems and the hypothalamus, activating the hypothalamo–pituitary–adrenocortical (HPA) axis, and sympathetic activation resulting in increases in respiratory rate, heart rate and blood pressure. Additionally, the central nucleus of the amygdala also directly activates midbrain regions responsible for 'fight or flight' responses. Activation of the HPA axis is responsible for neuroendocrine stress response and the release of glucocorticoids, including cortisol.

3. Measures of anxiety in current climbing literature

Through quantifying the neurophysiological and psychophysiological responses to climbing stimuli, it is possible to gain an insight into climbers' psychological performance. Research into psychophysiology, within climbing, has used a number of scales measuring arousal, anxiety and the direction of responses, including the Competitive State Anxiety Inventory and revisions (CSAI-2: Martens, Burton, Vealey, Bump, & Smith, 1990; CSAI-2R: Cox, Martens, & Russell, 2003), the Rock Climbing Anxiety Inventory (RCAI: Hardy & Hutchinson, 2007), the Profile of Mood States (POMS: McNair, Lorr, & Droppleman, 1981) and the Positive and Negative Affect Schedule (PANAS: Watson, Clark, & Tellegen, 1988). Further to this, the steroid hormone 'cortisol' has been used as an objective marker, through the comparison of basal and activated levels in response to climbing stimuli (Wittert, Livesey, Espiner, & Donald, 1996).

3.1. *Self report tools*

3.1.1. The Competitive State Anxiety Inventory. The CSAI was developed as a valid and reliable self-report tool for anxiety by Martens et al. (1990). The refined CSAI-2R (Cox et al., 2003) has been the instrument of choice for the measurement of anxiety in climbing (Aras & Akalan, 2011; Dickson, Fryer, Blackwell, et al., 2012; Draper et al., 2008, 2012; Draper, Dickson, Fryer, & Blackwell, 2011; Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; Fryer, Dickson, Draper, Blackwell, et al, 2012; Fryer, Dickson, Draper, Eltom, et al., 2012; Hodgson et al., 2009; Maynard, MacDonald, & Warwick-Evans, 1997; Sanchez et al., 2010). It provides insight into the anxiety subcomponents of cognitive anxiety (e.g. I am concerned about losing), somatic anxiety (e.g. My body feels tense) and self-confidence (e.g. I'm confident about performing well), and the relationship between these three components and performance. Confirmatory factor analysis by Cox et al. (2003) and Raudsepp and Kais (2008) found a good fit of the collected data to the model with comparative fit index (CFI) values of 0.95 and 0.96, non-normed fit index (NNFI) of 0.94 and root mean squared error of approximation (RMSEA) of 0.054 and 0.046, respectively.

3.1.2. The Rock Climbing Anxiety Inventory. The RCAI is a development of Hardy and Whitehead's (1984) inventory, by Hardy and Hutchinson (2007). It measures cognitive anxiety, somatic anxiety and activation. To date, as far as the authors are aware, the RCAI has only been used in the initial study by Hardy and Whitehead (1984) and the more recent study by Hardy and Hutchinson (2007). It is likely that the limited use of the RCAI is due to the prevalence of the CSAI-2R within climbing research. Principal components analysis by Hardy and Hutchinson (2007) revealed three factors with eigenvalues greater than 1.00, accounting for 72% of the variance in the data. Cronbach's alphas for the final subscales were reported as acceptable with cognitive anxiety ($\alpha = 0.71$), somatic anxiety ($\alpha = 0.92$) and activation ($\alpha = 0.80$).

3.1.3. Profile of Mood State. The POMS questionnaire (McNair et al., 1981) is reasonably common in climbing psychophysiology literature (Draper et al., 2010; Draper, Dickson, et al., 2011; Fryer, Dickson, Draper, Blackwell, et al., 2012). The POMS measures individuals' perception of fatigue, vigour, anger, depression and tension. Research evidence suggests that mood state can influence physiological performance, and thus have an affect on climbing performance (Beedie, Terry, & Lane, 2000; McMorris et al., 2006). The reliability of the POMS has been confirmed by Grove and Prapavessis (1992), through comparing the mood states of winners and losers; it was found that all subscales, except fatigue, produced significant differences between these groups. Cronbach's alphas for the POMS subscales were largely satisfactory, with α values ranging from 0.664 to 0.954, with a mean of 0.798.

3.1.4. Positive and Negative Affect Schedule. Finally, the PANAS (Watson et al., 1988) is based on a bidimensional theory of emotion, which hypothesises that individuals can experience a mixture of positive and negative affect during a specific time period. Participants rate the extent to which they are experiencing each emotion just before performing; PANAS has found limited use in climbing research (Aşçi et al., 2006; Sanchez et al., 2010). PANAS internal consistency for the measurement of both positive and negative affect has been reported as adequate, with α values between 0.84 and 0.90 (Watson et al., 1988).

3.2. Physiological and biochemical measures

3.2.1. Sampling and assay of cortisol. The most commonly used biochemical marker of stress is the steroid hormone cortisol (hydrocortisone; Wittert et al., 1996). Cortisol is secreted by the adrenal cortex under the influence of the HPA axis in response to psychological and/or physiological stress (Wittert et al., 1996). Within climbing psychophysiology research, cortisol has been extensively used as a marker of stress (Aras & Akalan, 2011; Dickson, Fryer, Blackwell, et al., 2012; Draper, Dickson, et al., 2011; Fryer, Dickson, Draper, Blackwell, et al., 2012; Fryer, Dickson, Draper, Eltom, et al., 2012; Hodgson et al., 2009). The sampling and assay of cortisol is normally conducted on either salivary or plasma samples. Salivary cortisol is often used when the invasive collection of blood samples is not practical, or possible; however, saliva cortisol assay is less desirable, and its reliability may be questioned, due to the large degree of day-to-day intra-individual and inter-individual variation that is present (Hayes, Grace, Kilgore, Young, & Baker, 2012). However, plasma sampling is more invasive than saliva samples; Dickson, Fryer, Draper, et al. (2012) provide an overview of the sampling of plasma cortisol in a climbing context, suggesting the first toe as valid alternative sampling site for plasma cortisol, as the commonly used fingertip is inconvenient for climbers.

There are several issues with the assay of cortisol, beyond the difference between saliva and plasma sampling. Cortisol exhibits diurnal variation, with peak concentrations seen in the morning and reduced concentrations in the evening and overnight (Touitou & Haus, 2000). Hayes et al. (2012) found large inter-individual variation. Furthermore, cortisol reactivity in response to stimuli has been shown to differ between individuals (Smyth et al., 1998). Research has also questioned the emotions that cortisol measures, with Pollard (1995) suggesting that increased cortisol concentration might be indicative of arousal rather than just stress or anxiety. Pollard (1995) reviewed studies which have used cortisol as a stress marker, suggesting that although laboratory studies of acute stress have shown increases in cortisol concentrations, there was evidence that strong emotional arousal of any type may increase cortisol levels. Similarly, Brown, Sirota, Niaura, and Engebretson (1993) indicated that strong positive emotions might also elicit an increase in cortisol concentration. Further research is necessary to assess the impact of individual and diurnal variation in cortisol, responses to climbing specific stressors and the investigation of alternative biochemical markers.

4. Climbing psychophysiology

A number of studies have used psychophysiological techniques to examine the effects of climbing stimuli on climbers. A comprehensive literature search was conducted using PubMed, psycINFO and Google Scholar, using the following combinations of key-words: ~~“Rock Climbing” or “Climbing” with each of the following terms “Psychophysiology”, “Anxiety”, “Plasma Cortisol”, “Cortisol” “CSAI-2R”, “Physiology” and “Psychology”~~. [AQ10] Results, from the search, were included based on the following criteria: (1) directly related to climbing, either indoors or outdoors, and (2) discussed climbing psychophysiology explicitly in the title or text, and or (3) discussed variables pertaining to psychophysiology, and or (4) used climbing tasks designed to elicit variations in stress. A summary of the 12 papers found using this [AQ11] search are presented in Table I.

4.1. Outline of climbing psychophysiology literature

Within climbing psychophysiology (Table I) researchers have assessed style of ascent (e.g. Dickson, Fryer, Blackwell, et al., 2012), differences between on-sight and red-point climbs (e.g. Draper et al., 2008), variation between successful and unsuccessful climbers (e.g. Draper, Dickson, et al. 2011) and the ~~affect~~ of competition (e.g. Sanchez et al., 2010). This research will be discussed in the following section.

4.1.1. Style of ascent. The style of ascent, with lead and/or top-rope conditions, is widely used as a stimulus and potential stressor in climbing literature (Dickson, Fryer, Blackwell, et al., 2012; Draper et al., 2010, 2012; Draper, Dickson, et al., 2011; Fryer, Dickson, Draper, Blackwell, et al., 2012; Hardy & Hutchinson, 2007). In further two studies, a more contrived top-rope with a trailing lead rope has been used (Aras & Akalan, 2011; Hodgson et al., 2009). Alternatively, Pijpers et al. (2003) used a high and low traverse protected by a top-rope. Within these studies climbing experience varied (Table I),

[AQ23] [AQ22]

Table I. Overview of current climbing psychophysiology research.

Author (publishing date)	Participants (male♂ female♀)	Ability (Ewbank-converted)	Ability (Draper et al., 2011)	Context
Draper et al. (2012)	13♂ 6♀	RP 19–23 OS 18–19	Intermediate	LC or TR; OS
Fryer, Dickson, Draper, Eltom, et al. (2012)	18♂ 3♀	RP 23-25 OS 21–22	Intermediate/ advanced	LC or TR; OS
Dickson, Fryer, Blackwell, et al. (2012)	14♂ 1♀	OS 26.1 RP 28.7	Advanced	LC or TR; OS
Aras and Akalan (2011)	22♂ 4♀	15–17	Lower grade	LC and LCTR; 50% OS, 50% RP; randomised order
Draper, Dickson, et al. (2011)	12♂ 6♀	OS 18.4 RP 20.7	Intermediate	LC or TR; OS; success or failure
Draper et al. (2010)	9♂	19–23	Intermediate	LC and TR; 50% OS, 50% RP; randomized order
Sanchez et al. (2010)	19♂	26–31	Advanced/elite	Belgian climbing competition
Hodgson et al. (2009)	12♂	?	Intermediate *-as stated by paper*	LC, TR and LCTR; RP
Draper et al. (2008)	10♂	14–15	Lower grade	LC and repeat LC of same route
Hardy and Hutchinson (2007)	54♂	15–23	Lower grade/ Intermediate	Traditional outdoor LC and TR
Aşçi et al (2006)	37♂ 10♀	?	Intermediate - *taken from route grades*	Speed and difficulty climbs under competition conditions; OS
Pijpers et al. (2003)	16♂ 14♀	Non-climber	Lower grade	Low and high traverse

Notes: LC, lead climb; TR, top rope; LCTR, lead climb with TR; OS, on-sight; RP, red point.

with non-climbers (Pijpers et al., 2003), lower-grade climbers (Aras & Akalan, 2011; Draper et al., 2008; Hardy & Hutchinson, 2007), intermediate climbers (Draper et al., 2010, 2012) and advanced level climbers (Dickson, Fryer, Blackwell, et al., 2012; Fryer, Dickson, Draper, Blackwell, et al., 2012). The experience stated above, may differ from the experiences given in the original papers, as the abilities have been standardised, for ease of comparison, using the grading charts set out by Draper, Canalejo, et al. (2011). It should also be noted that no indication of climbing grades were given by Hodgson et al. (2009), other than the vague description of 'intermediate'; as with other papers, it is likely that the ability of participants according to Draper et al.'s grade tables were lower.

Significant differences in psychophysiological responses, between potentially anxiety inducing conditions, in non-climbers have been found by Pijpers et al. (2003), in lower-grade climbers by Hardy and Hutchinson (2007) and in intermediate climbers by Hodgson et al. (2009). Pijpers et al. (2003) found significantly greater heart rate (HR), movement entropy and blood lactate in high over low traverse conditions. Hardy and Hutchinson's (2007) first study demonstrated significantly greater Rating of Perceived Exertion (RPE), HR and RCAI measures of cognitive and somatic anxiety and activation, between an outdoor lead at a climbers limit minus two grades and at their on-sight limit; whilst Hardy and Hutchinson's (2007) third study showed significant elevation of cognitive anxiety and effort and reduction in activation and performance between a top-rope then top-rope climb and a lead then top-rope climb. Finally, Hodgson et al. (2009) demonstrated significantly increased somatic anxiety and decreased self-confidence, as reported by the CSAI-2R, and increased plasma cortisol concentration between a top-rope and lead climb.

Conversely, no significant differences between potentially anxiety inducing conditions, for intermediate climbers (Draper et al., 2012) and advanced climbers (Dickson, Fryer, Blackwell, et al., 2012; Fryer, Dickson, Draper, Blackwell, et al., 2012), have been demonstrated. Draper et al. (2012) did not report any significant alterations in the three components of the CSAI-2R of cognitive anxiety, somatic anxiety or self-confidence and no difference in measures of capillary cortisol, between top-rope and lead conditions. Draper, Dickson, et al. (2011) showed no significant differences in subjective mood state as measured by POMS, with alterations in style of ascent, between a lead and top-rope climbs, although no further details were given. Dickson, Fryer, Blackwell, et al. (2012) observed similar measures between a lead and top-rope condition of cognitive and somatic anxiety, all components of the NASA-TLX, VO_2 and HR; however, the CSAI-2R did report significantly lower self-confidence for the lead condition. Fryer, Dickson, Draper, Blackwell, et al. (2012) found a significant difference in climb time and HR at select points, but no difference in any components of the CSAI-2R, blood lactate or VO_2, between either an on-sight top-rope or lead climb.

To summarise the outcomes of previous climbing psychophysiology research, a relationship between high and low stress conditions and climbers' experience may be inferred. It would appear that as ability and/or experience increases, the difference in psychological anxiety in response to climbing stimuli decreases. Specifically, all climbers at or beyond an intermediate level, climbing at grades greater than approximately French 5 or Ewbank 18, showed no significant difference in measures of anxiety. This is an unexpectedly low grade, it is speculated that a reasonably fit non-climber would be able to climb at, or exceed, a grade of French 5. This draws into question the sensitivity of the measures used, particularly the commonly used CSAI-2R and the stress hormone cortisol.

Anecdotal evidence, cited by Dickson, Fryer, Blackwell, et al. (2012), supports the experience–anxiety relationship, reporting that climbing coaches do not see any change in the mind-set of experienced climbers with different forms of ascent. It is likely that this is due to experienced climbers being more accustomed to leader falls through habituation, as lead climbing and falling are often incorporated into their training (Fryer, Dickson, Draper, Blackwell, et al., 2012). Their habituation allows them to recognise the disparity between inflated perceived levels of risk that a lead condition provides and the actual level of risk that they are exposed to (Fryer, Dickson, Draper, Blackwell, et al., 2012; Dickson, Fryer, Blackwell, et al., 2012). Furthermore, it is possible that climbers have learnt to execute movements whilst still under the influence of elevated levels of anxiety, suggesting that more experienced climbers are still anxious, but that the anxiety does not impair their performance to the same degree (Pijpers et al., 2003).

To date, published research on the style of ascent in climbing, with the exception of Hardy and Hutchinson (2007), has been conducted exclusively on artificial walls. It is likely that this is due to the ease of data collection, potential safety issues and, possibly, the assumption that there are no physiological or psychological differences between indoor and outdoor climbing. In more general climbing research, only four other papers have collected data on natural rock (Booth, Marino, Hill, & Gwinn, 1999; Bunting, Little, Tolson, & Jessup, 1986; Bunting, Tolson, Kuhn, Suarez, & Williams, 2000; Williams, Taggart, & Carruthers, 1978). Further research is necessary in this area, as outdoor traditional and sport climbing affords unique opportunities for the study of psychophysiology and climbing performance, including decisions about the objective dangers, route finding and learning on real rock, which are not present indoors (Lewis & Cauthorn, 2002).

4.1.2. Route knowledge. Alterations in climbers' route knowledge, with either on-sight or red-point ascents, have been used to manipulate the amount of stress experienced. Draper et al. (2008) and Hardy and Hutchinson's (2007) third study both investigated the difference between an initial on-sight and a repeat ascent of the same route. Draper et al. (2008) found an on-sight lead climb condition more stressful and anxiety inducing than a subsequent red-point climb of the same route, with greater climbing time, cognitive and somatic anxiety as measured by the CSAI-2R and elevated HR and VO_2, in lower-grade climbers. This supports the earlier findings of Hardy and Hutchinson (2007), who established that cognitive anxiety, as reported by the RCAI, was equally elevated in an on-sight ascent in comparison to a subsequent repeat red-point top-rope ascent, regardless the style of ascent of the initial route; they theorise that the reduction in anxiety, with a repeat ascent, is due to both a reduction in the effort required and a learning effect, which subsequently reduces physiological and psychological load. It is also possible that experienced climbers have become conditioned to increasing their effort for on-sight climbs in comparison to those completed as a red-point, in order to ensure success, rather than anxiety-induced effort (Hardy & Hutchinson, 2007).

Whilst not entirely supporting the findings of the studies cited previously, Hodgson et al. (2009) speculate that, following an initial on-sight ascent, a repeat ascent of a route is open to interpretation by the climber. The repeat ascent of the route may either be perceived as inducing somatic and cognitive anxiety, resulting in greater markers of anxiety, or, conversely, be perceived more positively and result in feelings of higher self-confidence, whilst still eliciting relatively higher cortisol concentrations (Hodgson et al., 2009). This may depend on the difficulty of the climb and the initial amount of anxiety experienced on the first ascent. This would be an interesting line of enquiry for future research. It would also be of interest to investigate the dynamics of change in psychophysiology, over further repetitions of the same climb. Repetition of a route has previously been used to elicit a greater physical response in climbers, but data were not collected on each individual repetition of the route (Sherk, Sherk, Kim, Young, & Bemben, 2011). This will allow a better understanding of the relationship between anxiety and performance, how these factors are mediated by the experience of the route and how learning affects psychophysiological responses to stressors.

Differences in the psychophysiological response provoked by repeat ascents exposes potential issues with the methodology of three studies by Aras and Akalan (2011), Draper et al. (2010) and the second study in Hardy and Hutchinson (2007). These studies investigated anxiety in randomised conditions of lead, and a subsequent ascent of either a top-rope or a top-rope with a trailing lead rope; however, unlike Hodgson et al. (2009), no familiarisation trial was used in any of these studies. Thus, participants climbed either the lead or top-rope condition on-sight, before randomly repeating the same route in the alternative condition, as a red-point. As previously discussed, from the findings of Draper et al. (2008) and Hardy and Hutchinson's (2007) third study, it is known that an on-sight condition affects the physiological and psychological response of climbers differently to a red-point ascent. It is speculated that the lack of familiarisation, or a paired sample methodology, may have obscured trends that may otherwise have been found. As such, the findings of the research should be treated with caution; these studies were excluded from the earlier analysis in Section 4.1.1.

4.1.3. Competition and successful versus unsuccessful ascents. Performance differences between those who successfully complete an ascent and those who fall en route have been investigated by both Draper, Dickson, et al. (2011) and Sanchez et al. (2010). In both studies, significant differences between successful and unsuccessful climbers were found in climbing time, experience and pre-climb CSAI-2R measures of anxiety. Draper, Dickson, et al. (2011) reported that unsuccessful climbers climbed slower, taking longer to reach each bolt, than those who successfully completed the route; successful participants climbed faster and more efficiently, rather than in a more conservative considered approach (Draper, Dickson, et al., 2011). In contrast, Sanchez et al. (2010) found that successful competition climbers completed the most difficult part of the route significantly slower than their unsuccessful counterparts. Thus, expert climbers, in comparison to Draper et al.'s intermediate climbers, chose to climb slower and more carefully to control their equilibrium, although they were not necessarily more fluent than those who were unsuccessful. It was also shown, as previously established with differences in the style of ascent, that successful climbers were significantly more experienced, in terms of years participating in the sport and years lead climbing (Draper, Dickson, et al., 2011). It is likely that the more experienced climbers had reached an autonomous stage of learning, which had a stress-proofing effect, thereby increasing the likelihood of a successful ascent (Draper, Dickson, et al., 2011). Aşçi et al. (2006) highlighted further differences in psychological states preceding a climbing competition between male and female climbers: female climbers experienced significantly greater negative affect in comparison to male climbers, before both a speed and difficulty competition; additionally, a difference between the two competition types was also apparent.

In addition to differences in climbing time and experience, both Sanchez et al. (2010) and Draper, Dickson, et al. (2011) examined the psychological states preceding an on-sight ascent. Sanchez et al. (2010) discovered that, even when differences in baseline ability were accounted for, successful climbers reported higher levels of pre-performance somatic anxiety, which correlated positively with the final route scores. In addition to these findings, pre-performance emotions were also significantly associated with the participants' movement behaviour, as shown by increases in entropy (Sanchez et al., 2010). It has previously been stated that successful athletes are able to maintain a more positive affective state prior to competition than those who are less successful (Treasure, Monson, & Lox, 1996). This is supported by Sanchez et al., (2010), who observed that superior performers were climbers who experienced simultaneously high levels of somatic anxiety and positive affect. Similarly, Draper, Dickson, et al. (2011) found that whilst there were no significant differences in the subjective feelings of somatic or cognitive anxiety, as reported by the CSAI-2R, there were significant differences in reported self-confidence. Successful climbers reported much greater feelings of self-confidence before completing a climb, which may have improved route-planning decisions and the choice of technique and tactics employed, and, as a result, directly improved their performance (Draper, Dickson, et al., 2011).

4.2. Alterations in movement performance

Inappropriately high levels of anxiety have been shown to increase movement time, visual fixation, decrease visual search rate (Nieuwenhuys et al., 2008) and increase muscle tension (Pijpers et al., 2003). Approaches to quantify movement quality include measurement of the fluency of participants climbing movements by calculating the geometric index of entropy of the climber's trajectory (Cordier, France, Bolon, & Pailhous, 1993) and observing the proportion of time spent moving and maintaining static positions (Fryer, Dickson, Draper, Blackwell, et al., 2012). It is thought that alterations in physical behaviour from anxiety are caused by a reduction in information processing efficiency and regression to an earlier stage of motor learning, negatively influencing a climber's movement behaviour (Nieuwenhuys et al., 2008; Pijpers et al., 2003). Pijpers et al. (2003) suggested that under pressure an inward focus of attention occurs, resulting in more conscious control of the execution of well-learnt motor skills. Pijpers et al. (2003), as with

Dickson, Fryer, Blackwell, et al. (2012) and Draper et al. (2012), conclude that practice reduces the effects of motor learning regression, through a combination of habituation and learning to perform the task under the influence of higher levels of anxiety. These findings further support the benefits of experience: through becoming habituated with taking lead falls and the automation and stress proofing of movement skills, more advanced climbers are able to make tactical decisions regarding the route, holds and rests, minimising the physiological and psychological stress of a given climb.

5. Summary of future research directions

Climbing psychophysiology has emerged as a significant and distinct area of research over recent years. Further investigation of the effects of climbing specific psychological stimuli on performance will help us to further understand the relationship between individual climbers' experience and their ability to appropriately respond to stimuli. Importantly, it will also inform how climbers with less experience may improve their climbing performance. There are several areas of climbing psychophysiology research that would benefit from attention, both concerning climbing specific questions and more general psychophysiological methodologies.

Psychophysiology methodologies will benefit from research and refinement, especially concerning their sensitivity to differences between anxiety and arousal. In particular, assessing the sensitivity of the hormone cortisol and its ability to quantify stress responses in climbing; along with considering more sensitive alternatives, such as Leukocyte Coping Capacity (Shelton-Rayner, Mian, Chandler, Robertson, & Macdonald, 2012). Similarly, the investigation of potential alternative anxiety inventories to the CSAI-2R may help to clarify responses; alternatives may include the recently developed Three-Factor Anxiety Inventory (Cheng, Hardy, & Markland, 2011).

Several climbing-specific psychophysiology issues would benefit from further investigation: one area in particular, is the affect of the outdoor climbing environment on performance. Whilst only five papers (Booth et al., 1999; Bunting et al., 1986, 2000; Hardy & Hutchinson, 2007; Williams et al., 1978) have looked at climbing outside, only Hardy and Hutchinson (2007) have examined climbing psychophysiology. Furthermore, to our knowledge, as yet there has not been any research conducted comparing climbing indoors and outdoors. Similarly, differences in route finding, the perception of affordances and learning between indoor and outdoor climbing would be of interest. Finally, improving our understanding of the process by which climbers become habituated to taking lead falls indoors, and how/if this habituation transfers to other environments, would be of benefit to both climbers and coaches. [AQ12]

6. Conclusion

To conclude, the affects of climbing stimuli on an individual's performance appear to be conditional on their experience, with more experienced climbers suffering less anxiety and fewer decrements in performance. It is likely that the experience–stressor relationship is due to advanced climbers' greater understanding, and rationalisation of the risks associated with the sport, habituation to the stressors gained through practice and an ability to perform with higher levels of anxiety. However, it is speculated that individuals' responses to stimuli are more complex than those reported by the CSAI-2R anxiety inventory and the psychophysiological stress marker cortisol. Beyond an intermediate level of climbing ability (French 5 or Ewbank 18) no significant differences between lead and top-rope conditions have been found using these measures, with the exception of Hodgson et al. (2009). [AQ13] The lack of significance beyond an intermediate level is unexpected, given the low cut-off grade between lower-grade and intermediate climbers, drawing into question the sensitivity of the measures used. It appears that these measures are not subtle enough to differentiate between climbing groups and experience on a single climb and that they are also unable to explain all of the intra- and inter-individual variation seen in responses. Assessment of the viability of more subtle anxiety indices and psychophysiological markers is necessary, as previously discussed.

The findings of climbing psychophysiology research hold significant implications for coaching climbers: through seeking to reduce the disparity between individuals' expectation and the reality of climbing stimuli and promote a balance between anxiety and self-confidence, it will be possible to evoke positive emotions towards the task and enhance performance. For researchers, whilst several areas have been highlighted for further study, it is likely that research will also need to return to mainstream anxiety research to explore and develop more subtle, sensitive measures, beyond those that are currently in use. It is hoped that this will allow us to gain further understanding of the subtlety and complexity of psychophysiological responses to climbing stimuli.

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