THE USE OF TRANSCRANIAL DIRECT CURRENT STIMULATION (TDCS) TO EXPLORE HOW RISK CHARACTERISTICS INFLUENCE ATHLETIC PACING.

By

Michael William Simpson

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Abstract

Recent research investigating how differences between individual athletes influences the distribution of energy resources during an athletic task has highlighted the importance of risk in sports. Athletes with lower perceptions of risk display relatively faster initial pacing strategies than higher risk perceivers, yet it is not understood how risk has this effect within individual athletes. This thesis is directed at gaining further insight into how risk relates to pacing behaviour and is comprised of one literature review and one experimental study. The concept of risk is first introduced and associated with athletic pacing in the literature review where methods are also proposed which may help provide greater insight into risk related pacing behaviours (BART and DOSPERT as measures of risk behaviour and attitude, and tDCS as a risk modulation technique). The experimental chapter introduces the BART risk behaviour measure along with an already established measure of risk attitude in pacing research (the DOSPERT) to a time trial pacing context and demonstrates how different facets of risk have similar influences on pacing behaviour. tDCS is further used to modulate athlete risk taking behaviour to understand how a change in risk characteristics reflect in pacing behaviours.

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List of Abbreviations

AN = Anodal

BART = Balloon Analogue Risk Task

CA = Cathodal

CCT = Columbian Card Task

CDQ = Choice Dilemmas Questionnaire

CPF = Catastrophic Physiological Fatigue

dl = Dorsolateral

dlPFC = Dorsolateral Prefrontal Cortex

DOSPERT = Domain Specific Risk Taking

EEG = Electroencephalography

CGM = Central Governor Model

IGT = Iowa Gambling Task

MEG = Magnetoencephalography

MRI = Magnetic Resonance Imaging

NIRS = Near-Infrared Spectroscopy

PB = Personal Best

PET = Positron Emission Tomography

PFC = Prefrontal Cortex

RAS = Risk Avoidance Scale

RPE = Ratings of Perceived Exertion

SPECT = Single-Photon Emission Computed Tomography

SR-NIRS = Spatially resolved near-infrared spectroscopy

tDCS = Transcranial Direct Current Stimulation

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Chapter 1

Understanding the influence of risk in athletic pacing: Insights from a multidisciplinary construct.

Abstract

Individual perceptions of risk have been shown to influence athletic pacing strategy, where higher risk perceivers start slower than lower risk perceivers. However, it is not clear how risk has this effect within individuals. This literature review is directed at gaining further insight into what the risks are in a pacing context and how they may effect pacing behaviour; highlighting common associations between types of risk such as uncertainty, and how risks are acted upon in the form of affect. The second half of this review presents methods in which risk can be quantified, highlighting two key aspects of individual risk characterisation; risk behaviour, and risk attitude. The review then concludes by presenting a particular method (transcranial direct current stimulation; tDCS) that has gained recognition in both psychological and social science as a method for modulating risk characteristics, but has also seen recent introductions in the sport sciences.

Introduction

Athletic pacing describes the way in which energy expenditure is regulated by athletes to complete an exercise task in the fastest possible time using all available energy resources (de Koning *et al*., 1999; Foster *et al*., 2003). Athletic pacing strategy or the way in which athletes distribute their work and energy resources throughout an exercise task significantly effects performance (Abbiss and Laursen, 2008). Well trained athletes employ specific pacing strategies by deciding how and when to invest their energy in an attempt to optimise performance (Smits *et al*., 2014). If an athlete invests too much energy at the start of an event, they risk early exhaustion; yet if too little energy is invested, they risk underachieving and failing to realise their performance potential (Renfree *et* al., 2014). This presents two contentious areas of the pacing literature in regard to (i) what the best pacing strategy is; and (ii) how athletes actually regulate their pace.

Athletic pacing strategies

Pacing strategy describes the self-selected approach or tactics that an athlete adopts from the beginning of an event (Roelands *et al*., 2013). Yet identifying what strategy is optimal or best has proven difficult. Optimal pacing has been described as pacing behaviour that is most physiologically efficient (Tucker *et al*., 2006). Theoretically, this reflects an even or constant power output / velocity; observations that are based on critical power models and mathematical laws of motion (di Prampero *et al*., 1979; Morton *et al*., 2006; Fukuba and Whipp, 1999). For shorter duration events; such as the 100 m sprint (~ 10 sec), all-out strategies are seen to produce superior performances (de Koning *et* al., 1999), primarily due to the large amount of time spend in the acceleration phase (Foster *et al*., 2004). However, as event distances and durations increase, the disparity between strategies used to achieve superior performances also increases. In 400 and 800 m running races (~ > 2 min), positive,

fast start strategies are observed (and modelled - Prendergast, 2002) to produce superior performances (Watt and Gunby, 2016). Yet in longer events (< 2 min), the need for energy conservation is evidently recognised (de Koning *et* al., 1999; Abbiss and Laursen, 2008). Under stable external conditions (heat, wind, terrain, course elevation), a constant pace is again believed to be optimal (de Koning *et al*., 1999; Thompson *et al*., 2003), yet this is not consistently adopted. For example; during 20 km, laboratory based (stable condition) cycling time trials, Mattern *et al.* (2001) demonstrated starting 15 % below average trial speed resulted in superior performance times in comparison to 15 % above or even pace. Thomas *et* al. (2012) described improved performance times when athletes tapered their starting pace displaying a parabolic (Reverse-J) shaped strategy. However, Renfree *et al.* (2012) showed superior performances resulted from even pace strategies with an end spurt in the final 10 % of the task. Notably, improved performances came as a result of increased average power during the even pace phase, yet end-spurt power outputs remained similar.

Inferring an optimal pacing strategy is difficult, given that an optimal strategy is one that may allow an athlete to achieve the best possible performance. In this regard, discrepancies in an athletes' experience and physical capabilities will play a significant role in determining the optimal individual pacing strategy. For example, a young amateur 10,000 m runner wanting to perform a 400 m running race may not be suited to the typically observed positive strategies adopted in elite athletic performances due to likely differences in athlete performance capabilities (Watt and Gunby, 2016). 400 m runners may have a natural advantage of speed and explosive power, whereas the amateur distance runner may have a natural advantage of endurance. Differences in adopted strategies can also be observed between elite athletes. Angus (2014) illustrated that two world record marathon performances were performed with contrasting strategies. In 2008, Haile Gebrselassie (runner one) ran a world record time of 2:03:59, yet in 2011 and on the same course (Berlin), Patrick Makau (runner two) surpassed that with a time of 2:03:38; a 21 second improvement (equating to a 0.3 % reduction in time).

Runner one employed a variable pacing strategy where the oscillations exponentially increased, yet runner 2, a parabolic (U-shaped) strategy. While it is clear that a particular strategy may be commonly observed in a particular discipline or event parameter, it does not mean that it is the optimal strategy, and the best strategies are in fact ones tailored to an athletes' strengths and weaknesses, relative to the task they face.

Pace regulation

Perhaps the largest debate in pacing literature concerns how athletes regulate their energy expenditure throughout self-paced exercise. The ability to select and maintain an appropriate pacing strategy is paramount to successful performance (de Koning *et al*., 2011). Athletes must first select a strategy that conforms to their process or outcome goals, but is also tailored to their strengths, performance capabilities and event conditions. The role of pace regulation is to ensure energy is distributed in a manner where by maximal performance is achieved, yet the body's critical homeostasis is preserved (Tucker and Noakes, 2009). Current opinions regarding how athletes regulate energy expenditure vary in regard to the realm of consciousness regulatory control emanates from, yet many share similar primary mechanisms of regulation in regard to perceived exertion (Micklewright *et al*., 2016) - a psychophysiological cue of exercise intensity, thought to arise from integrated afferent feedback generated by peripheral physiological systems (St Clair Gibson *et* al., 2003 and 2006; St Clair Gibson and Noakes, 2004).

The central governor model (Noakes *et* al., 2004) proposes a subconscious controller located in the human brain regulates the recruitment of motor units and acts as a homeostatic preservation system. Despite the influence this model has had, its conception is troubling, given there is no anatomical structure denoted to this controller region and it further proposes that exercise intensities cannot be taken beyond critical levels, yet catastrophic failure of physiological systems do occur in exercise performances (all be it they are rare). Conversely, the psychobiological model (Macora, 2010) proposes motor unit recruitment is a consciously

resided process where athletes select behaviours based upon the effort required and the desire to achieve the outcome from such a behaviour (Pageaux, 2014). In these, and other pacing models (Tucker, 2009; Garcin et al., 2012; de Koning et al., 2011), perceived exertion plays a primary role in deciphering if exercise intensities are suitable. For example, the template matching model (Tucker, 2009) dictates that pace is altered to ensure perceptions of exertion match that of expected exertion, where if perceived exertion exceeds the forecasted exertion, the athlete will fatigue prior to end point. The application of such models to pacing behaviour has merit, given the scalar linear increase in perceived exertion so commonly witnessed in prolonged exercise (Crew *et* al., 2008; Faulkner *et* al., 2008; Joseph *et al*., 2008). The central governor, psychobiological and other models (Tucker, 2009; Garcin et al., 2012; de Koning et al., 2011; Edwards and Poleman, 2013), although may make reference to individual factors, fail to integrate how differences among individual athletes may influence pacing behaviour. Given the complex nature of pacing decisions (Renfree *et al*., 2014), it seems unlikely that athletic pacing is the product of a one-dimensional process dictated through one primary mechanism. Instead, it seems more plausible that a dynamic interaction between multiple processes, drawing upon various sources of information specific to the individuals' nature is likely to direct pacing decisions (Micklewright *et al*., 2016). As such, our understanding of how athletes regulate pace in endurance exercise is still poorly understood and remains contested. However, a new direction of pacing is focusing on the impact that differences between athletes has on pace regulation and has highlighted the importance of cognitive development (Micklewright *et* al., 2012; Chinnasamy *et al*., 2013), previous experience (Foster *et al*., 2009; Micklewright *et* al., 2010) and most recently, risk perception traits (Micklewright *et al*., 2015).

Greater levels of cognitive development in school children correspond to greater anticipation of exercise demands (Micklewright *et al.,* 2012) which may be important when considering 'optimal' strategies for younger athletes. Similarly, athletic experience seems to determine

how athletes interpret and subsequently act upon afferent feedback (Micklewright *et* al., 2010), where previous experiences in similar event parameters and conditions are used to forecast expected exercise intensities and durations (Mauger *et* al., 2009). Such individual factors represent a development process whereby cognitive development or experience fluctuate over time. Micklewright *et al*. (2015) however demonstrated how athlete risk perception traits associate with pacing behaviours - a characteristic that may be expected to remain stable over time (Johnson *et al*., 2004; Matthews *et al*., 2009). Lower risk perceiving athletes were shown to adopt a significantly faster (~ 8 %) initial pace than their higher risk perceiving opponents. Despite this discrepancy in pace, no differences in perceived exertion were exhibited between risk groups, suggesting athletes experienced the exercise similarly. While a between subject's design was needed in order to create different risk groups, it confounded the ability to infer how risk has this effect. Therefore, despite the intriguing insight provided into how differences between individual athlete risk perception traits influence pace behaviour, it still remains unclear as to how risk has this effect and warrants further investigation.

The concept of risk and its prevalence in pacing

Pacing choices made during exercise are recognised as involving varying degrees of risk (Renfree *et al.,* 2014), yet the concept of risk within pacing has seen very little explicit research, despite being referenced to in a number of articles. The next section will introduce the concept of risk and apply it to a pacing context where possible in order to provide clarity on risk in pacing and provide avenues to research risk in a pacing context.

In most contexts, the notion of 'risk' refers to a danger of unwanted or unfortunate events and is not a simple reference to uncertainty of possible outcomes. Risk, therefore, can be defined as the potential of [physical / social / financial] [harm / detriment / loss] due to a hazard within a particular time frame (Rohrmann, 2008). The term hazard subsequently refers to an event,

substance or situation that may become harmful for people, nature or human-made facilities; and represents a physical entity, while risk on the other hand is not. Risk is an inference about the implications of a hazard for the people exposed to it (Drottz-Sjöberg, 1991; Fischoff *et al*., 1984; Renn, 1992; Taylor-Gooby, 2002).

When applying such conceptualisations to a pacing context, athletic competition represents an environment plagued with hazards. A slippery running surface or hyper-thermic conditions (Ely *et* al., 2008) are evidently risk factors to an individual's pace and performance; yet are often beyond the athletes control. An athlete is however in control over the decisions they make regarding how and when to invest their energy (Smits *et al*., 2014). The primary risk faced by athletes when regulating exercise intensity has been described as the likelihood of experiencing catastrophic physiological fatigue (CPF) (Renfree *et al*., 2014), a physical occurrence presenting serious homeostatic disturbances and health compromising effects to an athlete's body and necessitating pace modification. However, experiencing catastrophe of any one physiological system represents perhaps the most extreme form of fatigue, something that is not common in athletic performances and may not be representative of the risks at the fore of athlete decision making. Instead, fatigue of a tapered nature (i.e. muscular fatigue due to reduced muscle glycogen) is more commonly experienced and perhaps a more common risk factor. Varying degrees of fatigue (both centrally and peripherally originated) do influence performance and pacing behaviour, yet the degree to which risk is appraised in such situations may be held in higher regard by different athletes. The way in which athletes act in accordance to this hazard presents further risk. For example, in a 5 km fun run, the primary goal of a well-trained runner may be to achieve a personal best performance time. In doing so, they select a pacing strategy believed to provide them with the best possible (optimal) performance (Renfree *et al*., 2014) which will likely be performed to levels at or around critical physiological thresholds (lactate and ventilatory thresholds). A relatively fast start would ensure they remain on track to achieve their performance goal, yet the risk of experiencing early fatigue is

increased. If the athlete starts slower, they reduce the risk of early fatigue, yet increase the risk of failing to achieve their performance goals. Conversely, a novice runner attempting the same 5 km fun run, whose goal is merely to complete the event, will be faced with the same hazard (fatigue), yet their risk factor may be different. Exerting themselves too much at any point in the race presents a risk of fatigue and possibly incompletion of the event. Under exertion however will reduce the risk of fatigue and still see goal attainment (event completion). Pacing choices are further diversified when considering personal motives such as financial backing that is reliant on successful and high performance; or social standing with other friends and competitors.

Examples provided above highlight just one of any number of situations where differences between athlete goals create a highly subjective environment in regard to risk appraisal and subsequent behaviour. The matter is further complicated when considering the value an athlete places on the end goal and their motivation to achieve it. Although it is important to understand what athletes must decide upon, perhaps a greater understanding of the types of risk faced by athletes may allow a more categorical understanding of how athletes behave in relation to risk.

Types of risk

The meaning of risk holds three central connotations; negative, positive and neural. Most risks refer to negative issues, yet risk can also represent uncertainty regarding choice outcome (representing a neutral connotation of the word). At times, even positive connotations of risk materialise in the form of a 'desired risk' (e.g. a thrill through risky actions) (Breakwell, 2007; Rohrmann, 2003).

Risks faced throughout endurance competition would appear to represent both negative and neutral risks. Despite athletes often being aware of the hazards they face in pursuit of maximal

performance, athletes do not often 'desire' to interact with hazards such as fatigue. Interacting with a hazard such as CPF very much represents a negative connotation of risk due to the homeostatic detriments it represents and pacing alterations necessitated. Athletes are further presented with neutral risks in the form of uncertainty (St Clair Gibson *et al*., 2006), where prospective decisions made regarding how much energy to expend in the early stages of an exercise task (Ulmer, 1996; Wittekind *et al*., 2009), and during the exercise task at the point of pace modification (St Clair Gibson *et al*., 2006). Ramifications of prospectively decided pacing decisions or online pace modifications only become apparent as the athletes' progresses through the task. Subsequently, peripheral physiological feedback is received regarding the effect of exercise intensity and subsequent proximity to the hazard (CPF) (St Clair Gibson *et al*., 2006). The effects of pacing decisions are not prospectively known, and therefore present an air of uncertainty regarding the outcome of the decision. Assessing how athletes behave when presented with the neutral risk of uncertainty in association with their pacing behaviour may provide further insight into how different facets of risk influence pace selection.

An athlete's awareness of their body's physiological status is widely regarded to be generated from afferent peripheral signals received by the brain, conveying information regarding changes in physiological status due to workloads implemented (Tucker, 2009; Noakes, 2004). Correctly interpreting such signals are key if athletes are to understand if the current work rate is sustainable for the exercise duration. To do this, judgements and evaluations of afferent information are required to infer if the work rate presents a risk; for example, will the continuation at a specific work rate lead to fatigue prior to the end of the task, necessitating reductions in exercise intensity and present the risk failure to achieve pre-set goals. Therefore, the ability to accurately assess afferent information and the risks presented (fatigue, losing, goal attainment failure) is of high importance and may depend on an individual's risk perception and risk tolerance characteristics (Taylor-Gooby, 2002).

What is risk perception?

Risk perceptions are analyses of the world based on an individual's experience and beliefs (Finucane & Holup, 2006; French et al., 2006; Slovic, 2000). Strictly speaking, risks cannot be perceived (like the mass of an object), as risk is a depiction of a reality that has not actually occurred; nonetheless, 'risk perception' has become the subject of the respective research topic. Risks are highly subjective and may be 'perceived' differently between individuals and are effected by three factor levels. Macro factors describe structural or institutional influences on an individual, whereas meso factors describe peer to peer or community influences. However, perhaps the most relevant factors to an individual's regulation of their own pace will be micro, psychological level factors.

Micro, psychological factors are composed of two sub-factors that guide individual risk perceptions. An individual's level of knowledge forms the first micro level abstraction, where individuals who are less informed of a situation take fewer risks. Conversely, individuals with greater knowledge promote a tolerance and willingness to engage in risky situations (Huang et al., 2013) which has been linked to the level of personal control one feels over a situation that lessens anxiety and causes an individual to become more relaxed towards engaging in unsafe behaviours. Such affirmations are also reflected in an athletic context where athletes are regarded to be objectively aware of exercise endpoint (Edwards and Polman, 2013). Such knowledge plays a vital role in the regulation of energy resources and the pacing strategy adopted (Baden *et al*., 2004), with knowledge of endpoint producing more aggressive and superior performances (Swart *et al*., 2009). Similarly, athletes with more experience of an exercise parameter have shown greater anticipation of exercise demands, displaying more aggressive pace behaviour (Mauger *et* al., 2009; Micklewright *et* al., 2010). Micklewright and colleagues (2010), who by deceiving experienced athletes of performance data and installing a new set of beliefs regarding their performance ability, observed successive exercise bouts

where athletes displayed increasingly riskier (faster and more aggressive) starting paces. Authors suggested mental representations aggregated from similar cycling experiences determined how cyclists interpreted afferent performance feedback data; therefore, the formation of a set of beliefs regarding previous experience was continually referenced to in the calculation of perceived exertion and pacing adjustments throughout subsequent races. This perhaps indicates that micro psychological factors play an influential role in risk based pacing decisions, where a set of installed belief systems promote a tolerance towards the risks inherent an activity though the false knowledge they acquired in previous experiences, leading to a greater propensity for taking risks.

The second micro level abstraction is optimism bias, which describes an individual's penchant beliefs that negative events are less likely to occur to them than to others; that they are more adept to avoiding the adverse effects of a negative event and therefore are more tolerable to risk (Weinstien, 1984). McCool *et al*. (2009) for example, demonstrated that individuals with higher risk tolerance levels and who took more risks were likely to underestimate one's vulnerability to a threat and the severity of it; yet also overestimated the efficiency of one's own ability to cope with the risk. Such optimistic biases may be reflected in inexperienced athletes, who lack effective anticipatory skills to apply knowledge regarding their performance capabilities to the task ahead (Micklewright *et al*., 2010). An optimistic bias may promote a tolerance towards the risks faced (early fatigue, reductions in work rate and losing the task) in belief that they will be able to achieve a superior performance, yet resulting in a more positive pacing strategy (Abbiss and Laursen, 2008). Psychological micro level factors may prove an important determinant of risk based pacing decisions and seems to centre on an athletes' experience.

How risk perceptions guide behaviour

Risk perceptions are thought to inform behaviour via two fundamental processes; risk-as-feelings that refer to instinctive, emotive and intuitive reactions to danger and risk-as-analysis that refer to reasoning and logical scientific deliberation (Slovic et al., 2004). Risk-as-feelings are generally employed throughout daily life given most assessments of risk are done quickly and automatically through an experiential mode of thinking (Slovic et al., 2004).

Strong visceral emotions such as fear and anger have been heavily linked with risk-as-feelings processing; where for example fear amplifies risk estimates and anger attenuates them (Lerner *et al*., 2003; Lerner and Keltner, 2000), yet such strong emotions are not common in every day risk assessments; especially when regulating exercise intensity. Softer feelings such as affect are instead thought to be experienced which guide judgements and decision making through feelings experienced with a given situation (Schwarz and Clore, 1988). Affect refers to the specific quality of the feeling state experienced, demarcating a positive or negative quality of a stimulus (Slovic *et al*., 2004). If feelings towards a situation are favourable (positive), risks are generally inferred as low, while the benefits as high; if feelings towards a situation are unfavourable (negative), risks are inferred as higher, while the benefits as lower (Alhakami & Slovic, 1994; Finucane *et al*., 2000).

Affect has shown to play a major role in pace regulation, and is proposed as a dominant regulator of self-paced exercise (Baron *et al*., 2009) that may surpass the importance of perceived exertion (Renfree *et al*., 2012). Athletes experiencing a greater positive affect response from an exercise task are more likely to increase exercise intensity, whereas negative affect responses characterise a loss of motivation and see reductions in exercise intensity (Baron *et al*., 2009). Through the provision of information that supplements an increase or decrease in perceived benefits, individual judgements regarding perceived risks for a given situation have shown to change (Finucane *et al*. 2000). This indicates that affect is not a simple

response to prior analytical evaluations, but rather an online influential bias on judgement itself. To decide on an initial pace, athletes may use a risk-as-feelings based approach to utilise known event information such as knowledge of the end point and physical ability. Similarly, athletes with varying degrees of awareness and experience may implicitly inform online pacing decisions via emotional experiences associated with feelings of exertion, anxiety and other typically experienced emotions throughout the course of an exercise task (Faulkner *et al*., 2008; St Clair Gibson *et al*., 2003; Parry *et al*., 2010). The role of affect in risk based pacing has not yet been investigated and may provide insight into the mechanism through which discrepancies in risk perception levels result in discrepancies in pace (Micklewright *et al*., 2015).

Summary

The risk an athlete faces during pace regulation is the likelihood of experiencing a negative event. What this negative event constitutes however is highly subjective, yet often relates to experiencing fatigue and the consequences it poses on goal attainment (Renfree *et al*., 2014). The types of risks posed to an athlete represent both negative and neutral risks, due to (i) the dangers of hazard interaction; and (ii) the uncertainty surrounding the likelihood of this hazard interaction (St Clair Gibson *et al*., 2006). Formation of athlete risk appraisals are likely to be dictated by the athletes' knowledge of event demands and personal performance capabilities, yet an athletes' affective response to both negative and neutral risks may form a key component in risk based pacing decisions. Such affirmations may seem obvious, however it is important for them to be understood in collective, rather than separate entities given they are all highly interlinked. It may therefore be important to understand if an athletes' behaviour when presented with risk uncertainty corresponds to their pacing behaviour and if their affective response can provide insight into the potential mechanism behind risk related pacing discrepancies.

The following section will provide an overview on how individual risk characteristics are investigated to provide potential applications for risk based pacing research.

Quantifying individual risk characteristics

Quantifying an individual's risk characteristics are achieved primarily through assessment of individual risk attitudes (Weber and Johnson, 2008). Risk attitudes reflect an individuals preferred level of risk and provide a detailed measure of what types of risk an individual is willing to accept and to what degree they will accept them. Measures of risk attitude fall into three categories (Weber and Johnson, 2008); two of which are subjective attitudes towards risk and behavioural measures of risk. A third category of risk attitude assessment describes personality traits related to risk, where individuals are asked to report personality traits related to risk taking. This however does not explicitly ascertain an individual's attitude towards a proposed situation and therefore will not be discussed further. Commonly used behavioural and risk attitude measures are presented in tables 1 and 2 respectively providing examples of their application within the literature to help inform their utility in application to pacing research.

Risk attitude

Risk attitudes have been likened to trait like properties of risk (Johnson *et al*., 2004), where attitudes towards risk and beliefs about enduring dispositions remain relatively stable within a specific domain (Matthews *et al*., 2009). Measures of risk attitude typically assess an individual's attitude towards a proposed situation through means of questionnaire based responses. As such, most measures are similar in design, yet differ regarding the context and response to the proposed situation. The Choice Dilemmas Questionnaire (CDQ; Kogan and Wallach, 1964) and Risk Avoidance Scale (RAS; Shure and Meeker (1967) are good examples of such measures that query the individual directly regarding risky situations. Measures such as

the Domain Specific Risk Taking (DOSPERT) questionnaire (Blais and Weber, 2006) differ slightly and assess the decision maker's appraisal of risk and benefit in order to infer their preferred level of risk.

The CDQ consists of 12 brief descriptions of everyday hypothetical situations in which choices must be made between risky and non-risky options. For example, subjects in the CDQ are asked to decide what the odds would need to be for them to select a riskier option, such as quitting their modest and stable job for a higher paying job with an uncertain future. Participants provide a rating (out of 10) where a lower number indicates higher risk taking. The CDQ has typically been used to assess risk taking in individuals versus groups and analysing shifts in risk taking attitudes. The RAS similarly assess risk taking propensity and was developed through factor analyses of prior scales to develop a 19 item inventory. Participants are required to answer the provided questions as either 'yes', 'cannot decide' or 'no' (equivalent to 1, 2 and 3 points respectively). More 'no' responses indicate risk averse, while more 'yes' responses indicate risk seeking.

The two instruments (CDQ and RAS) employ different configurations to assess risk taking propensity, yet are both well established and commonly used methods in older literature. The DOSPERT however is a relatively newer measure that assess both risk perception and propensity for risk taking over five domains. Using two, 30 item questionnaires with identical statements, participants are required to rate how risky the situation in that statement is, and how likely they are to engage in that situation using a seven-point scale (from 'not at all risky' to 'extremely risky and 'extremely likely' to 'extremely unlikely'). The DOSPERT has been used extensively since its conception and has shown high validity with various demographic groups

Table 1. Instruments to measure risk behaviour (risk preference) *

Name	Author	Measure	Scored	Internal / external Validation **	Literature applications
Angling Risk Task (ART)	Pleskac (2008)	Computer simulated task	Average adjusted number of fish caught during relative simulated weather conditions.	Yes / Yes	n/a
Balloon Analog Risk Task (BART)	Lejuez *et al.* (2002)	Computer simulated task	Average number of pumps for balloons that didn't explode.	Yes / Yes	Emotions and decisions: Heilman *et al*. (2010)
Bomb Risk Elicitation Task (BRET)	Crosetto & Filippin (2012)	Computer simulated or paper based task	Total number of boxes accrued. If 'theoretical' bomb is in selected box, money accrued is lost.	Yes / No	n/a
Columbia Card Task (CCT)	Figner *et al.* (2009)	Computer simulated task	Total amount of gain or loss. Hot task = online changing risk styles. Cold task = prior deliberative selection.	Hot CCT internally validated	Determinants of risk taking: Figner *et* al. (2009)
Cups Task	Levin & Hart (2003)	Physical task (Levin & Hart (2003) Computer simulated task (Levin et al., 2007)	Total number of risk choice categories chosen.	Yes / No	Risk experience on risk behaviour: Xue *et al*. (2010)
Devil's Task	Slovic (1966)	Physical choice task	Total number of switches before electing to stop	Yes / No	Narratives of risky decisions: Fernandez-Duque and Wifall (2007)
Distribution Builder	Goldstein *et al.* (2008)	Computer simulated task	Preferred probability distribution of retirement income as direct risk preference measure.	n/a	n/a

Dynamic Experiments for Estimating Preferences: Risk (DEEP Risk)	Toubia *et al.* (2013)	Binary choice	Accumulation of binary choice outcomes	Yes / Yes	Economic risks: Schley and Peters (2014)
Iowa Gambling Task	Bechara *et al.* (1994)	Computer simulated task	Total simulated money upon completion + within game risk selection.	Yes / Yes	Risk taking and trait impulsivity: Upton *et al*. (2011)
Multi-Outcome Risky Decision Task	Lopes & Oden (1999)	Paper based selection task	Accumulation of risk choice categories chosen.	No / No	Decision making mechanics: Brandstatter *et al*. (2006)
Reyna & Ellis Risk Task	Reyna & Ellis (1994)	Physical / visual choice task	Accumulation of certainty and gamble choices	n/a	Choice and judgement in children: Schlottmann and Tring (2005)
Risk-taking Propensity Measures	MacCrimmon & Wehrung (1985)	Likert scale	Response value given indicates risk propensity. High score indicates likeliness to accept risks	No / No	Risky decision influences: Sitkin & Weingart (1995)
Two-Outcome Risky Decision Task	Lauriola *et al.* (2007)	Binary choice	Accumulated risk choices converting into ambiguity preference	Yes / Yes	Risk perception and emotion: Leikas *et al*. (2009)

*Inventory list was partly informed by Columbia University's Centre for Research on Environmental Decisions (http://www.sjdm.org/dmidi/Risk_Attitude.html ; Accessed 04 April 2016)

** Internal and external validity reported in original publication unless otherwise stated.

Table 2. Instruments to measure risk attitudes*

Name	Author	Measure	Scored	Internal / external Validation **	Literature applications
Attitudes to Risk Taking	Grol *et al.* (1990)	Likert scale	Combined score of all items.	Yes / Yes	Risk taking and tolerance: Tubbs *et al*. (2006)
Business Risk Propensity Scale (BRPS)	Sitkin & Weingart (1995)	Likert scale	Accumulation of questionnaire scores. Higher score demarcates increased propensity / perception of risk.	n/a	Employment turnover: Vardaman *et al*. (2008)
Choice Dilemmas Questionnaire (CDQ)	Kogan & Wallach (1964)	Probability scale (1-10)	Accumulated minimum probability of success from scenarios	Yes / Yes	Risk attitudes: Ghosh and Ray (1992)
Cognitive Appraisal of Risky Events (CARE)	Fromme *et al*. (1997)	Likert scale	Accumulated subscale responses (not at all – extremely likely)	Yes / n/a	Adolescent risk taking: Galvan *et al*. (2007)
Domain Specific Risk Taking (DOSPERT) Scale	Blais & Weber (2006)	Likert scale	Accumulated subscale responses (higher score = higher risk perception / propensity)	Yes / Yes	Decisions under ambiguity and risk: Lauriola *et al*. (2007)
Passive Risk Taking Scale (PRT)	Keinan & Bereby-Meyer (2012)	Likert scale	Accumulation of passive risk subscale responses	Yes / Yes	n/a
Risk Avoidance Scale (RAS)	Shure & Meeker (1967)	Three-point rating scale (1=Yes, 2=undecided, 3=no)	Accumulation of subscale risk avoidance responses.	Yes / n/a	Manager and entrepreneur risk differences: Miner and Raju (2004)
Risk Propensity Scale	Nicholson *et al.* (2004)	Likert scale	Subscale means calculated. Higher score represents higher risk propensity.	Yes / No	Midwifery decision making: Styles *et al*. (2011)

Risk-taking Propensity	Jackson *et al.* (1972)	Likert scale	Subscale means calculated. Higher score represents greater desire for risk.	n/a	n/a
Risk-taking Propensity Measures	MacCrimmon & Wehrung (1985)	Choice ranking and Likert scale	Accumulation of ranked choices and subscale responses	n/a	Risk taking in health setting: Harrison *et al*. (2005)
Stimulating-Instrumental Risk Inventory	Zaleskiewicz (2001)	Likert scale	Two types of risk taking: Stimulation and instrumental. Accumulation of scale scores.	Yes / Yes	n/a

* Inventory list was partly informed by Columbia University's Centre for Research on Environmental Decisions (http://www.sjdm.org/dmidi/Risk_Attitude.html ; Accessed 04 April 2016)

** Internal and external validity reported in original publication unless otherwise stated.

(Weber *et al*., 2002; Blais and Weber, 2006), yet has also been used to illustrate differences in athletic pacing behaviour in relation to risk perception levels (Micklewright *et* al., 2015).

The DOSPERT appears to hold a higher degree of utility in comparison to other risk attitude assessments presented above given the board domains and response accuracy of the assessment. It would be interesting to understand if a particular domain, social risks for example, influenced pacing decisions where affirmations could then be applied towards risks of a particular nature influencing pace behaviours.

Risk behaviour

Behavioural measures of risk reflect more state like properties of the risk construct, where the stabilities in beliefs and behaviours typically expressed in trait measures (Johnson *et* al., 2004) are influenced by changes in state of mind and transient internal conditions (Eysenck and Eysenck, 1980). As such, behavioural measures of risk assess an individual's preference for risk established from actual choices made in a real or hypothetical task. Most behavioural measures of risk assess decisions made under uncertainty through either deliberate risk and benefit calculation (known as 'cold' decision making) or emotional reactions generated from each option (known as 'hot' decision making) (Seguin *et al*., 2007; Shafir *et al*., 1993), or a combination of the two factors (Rosenbloom *et al*., 2012; Yang et al., 2012). Measures such as the Balloon Analogue Risk Task (BART; Lejuez *et al*., 2002), Columbia Card Task (CCT; Figner *et al*., 2009) and the Iowa Gambling Task (IGT; Bechara *et al*., 1994) are commonly used in behavioural literature.

The BART is a measure of hot decision making where individuals are required to inflate a computerised balloon in return for a monetary based reward. The BART measures propensity towards risk by monetarily rewarding behaviours (balloon inflation) up until such behaviours result in poorer outcomes (balloon explosion and loss of accumulated money) (lejuez et al., 2002). In the BART, propensity for risk taking is measured from the onset, yet in tasks like the IGT, individuals

cannot express risk propensity until they have learnt the risks. The IGT also measures hot decision making processes through the selection of 100 cards from four separate decks. The goal is to maximise profit; with each deck containing various magnitudes of risk (i.e. reward / loss). Participants are unaware of the discrepancies in risk between the decks until they progress through the task, and therefore require online risk formations. The CCT is the newest of the three tasks and assesses both hot and cold decision making through the selection of cards with either positive or negative values. Participants are told prior to the task the number of 'loss' and 'win' cards. In the hot task, participants turn over cards one by one and choose when to stop. In the cold task, participants prospectively choose the number of cards they want to select without receiving feedback until the end.

Given the complex nature of decisions made throughout an exercise task and the consequential actions taken (Renfree *et al*., 2014), pacing may also be considered a measurable human risk taking behaviour. In this regard, understanding if more generalised measures of risk behaviour correspond to a complex risk behaviour such as pacing holds a high degree of utility in our ability to understand the specific nature of the risk pacing relationship, and will contribute to athlete profiling. The BART, IGT and CCT all measure unique, non-overlapping decision making processes (Buelow and Blaine, 2015) and may all provide different insights to how risk and reward is processed by individual athletes. For example, while pacing is understood to incorporate degrees of uncertainty (St Clair Gibson *et al*., 2006), athletes are also believed to be aware of the risks faced from the onset of exercise and make their choices accordingly. The BART similarly measures risk taking behaviour under uncertainty from the onset of the task and it may be expected that athletes displaying propensity for risk taking under uncertainty in the BART, display greater risk taking behaviours in their athletic task (i.e. faster relative starting pace).

As athletes progress through their exercise task, they are believed to become increasingly aware of the outcome of prospective pacing decisions and the degree of uncertainty is reduced (St Clair

Gibson *et al*., 2006). The IGT reflects a similar learning process where individuals become increasingly aware of the risks posed as the task progresses. It may be expected that behaviours presented in the IGT (perhaps a risk adverse response to increased loss cards drawn) corresponds to that of a negative event in a pacing task (such as a high RPE far from event completion). The IGT may provide further utility for understanding between trial risk-pacing associations, where behavioural responses to negative events in the IGT may correspond to differential pacing strategies adopted in subsequent pacing tasks.

To form coherent representations of an athlete's risk profile, using multiple risk based decision measures is advised as no single risk measure fully assesses the risk construct (Buelow and Blaine, 2015). The DOSPERT has already been used in a pacing context (Micklewright *et al*., 2015) and has proven effective in providing associations between levels of risk attitude and pacing behaviours, yet may be able to provide more domain specific insights into risk associations. Similarly, corresponding general risk behaviour measures such as the BART or IGT to a pacing context will allow a greater understanding of the relationship between the learning of risk and uncertainty with pacing behaviours. It is also interesting to note that pacing is employed to attain a goal that holds a degree of value. Behavioural risk measures also present similar dichotomy's whether it be a monetary value or an arbitrary score that the individual is seeking, it would be interesting to understand if pace corresponds to the value achieved in the generalised behavioural risk measure.

Modulating risk characteristics

The depth of risk research has undoubtedly been extended through the use of risk modulating methods. The ability to alter an individual's risk characteristics allows causality to be inferred with respect to how risk influences particular behaviours in particular situations. While risk is generally inferred as a personality trait (Johnson *et* al., 2004), which describes stabilities in behaviour and beliefs about enduring dispositions (Matthews *et al*., 2009); expressions of such traits are however

subject to transient states, where changes in state of mind or internal conditions (Eysenck and Eysenck, 1980) may cause positive or negative transient states of risk. In light of this, a variety of ways exist where risk can be modified, through both invasive and non-invasive methods. Illegal recreational compounds such as marijuana, cocaine and amphetamine have shown to elicit risk taking behaviour modulations (Bartzokis *et* al., 2000; Lane *et al*., 2005). Similarly, the use of legal narcotics such as alcohol see increases in risk taking behaviour. Such methods describe an invasive, globalised and substance dependent amplification of risk characteristics. Non-invasive measures have also been used to good effect in modulating individual risk, such as the subconscious priming of risk taking attitudes (Erb *et al*., 2002). However, perhaps the most promising method is neuro-cortical stimulation. Neuro-stimulation based techniques have been used to elicit both increases and in decreases in various facets of the risk concept depending on stimulation parameters (Levasseur-Moreau and Fecteau, 2012). Priming risk behaviours has seen little explicit attention in this literature, whereas neuromodulation has. Neuromodulatory techniques have helped underpin causal relationships between specific brain regions and decision making behaviours.

Here we present one particular method that has gained significant recognition for its use within behavioural sciences and has seen recent introductions to pacing research (Okano *et al*., 2013; Angius *et al*., 2015). Transcranial direct current stimulation (tDCS) is a safe, non-invasive, non-pharmacological and cost effective electrical stimulation technique proven to induce behaviour modifications.

tDCS delivers acute polarity dependant modulations to the resting membrane potential of cephalic neurons. This is achieved through the application of a weak, direct current applied at the scalp through a minimum of a two electrode montage; one anode and one cathode. Beneath the anode (AN), resting neural tissue is depolarised and therefore increases sensitivity to action potentials. Conversely, beneath the cathode (CA) neural tissue is hyperpolarised (Nitsche et al., 2008). Knowledge surrounding optimal tDCS stimulation parameters is still in its infancy and varies from 0.5

- 2 mA in intensity, and 3 - 20 min in duration between studies. Applications of tDCS within behavioural research generally target the prefrontal cortex (PFC) of the human brain; an area critically associated with decision making. In particular, the dorsolateral area (dl) of the prefrontal cortex (dlPFC) has been shown to play a major role in the maintenance and manipulation of multiple sources of information relative to decision making (Krawczyk, 2002; Kroger et al., 2002), as well as monitoring the status of competing decision options (Krawczyk, 2002).

(For simplicity, tDCS montages are described as, for example: 'AN left / CA right' for anodal stimulation of the left and cathodal stimulation of the right dlPFC)

Applications of tDCS to the dlPFC have been shown to influence risky lifestyle choices; such as reduced food (Fregni et al. 2008) and alcohol cravings (Boggio et al., 2008) along with increased cautiousness during driving simulations (Beeli et al., 2008a) following AN left or AN right. Similar reductions in risky behaviours have been seen in tasks designed to infer more specific brain-behaviour relationships and the types of risk individuals are willing to accept. Using the BART, Fecteau et al. (2007a) showed a reduction in risky decisions following AN left / CA right. Less balloon pumps were made and less money was accrued, however the opposite montage showed comparable behavioural changes. Similarly, this time using 'The Risk Task', Fectaeu et al. (2007b) showed increases in risk adverse responses when stimulating CA left / AN right.

Differential risk behaviours have been noted when using tDCS. Using the CCT; smokers and non-smokers exhibited a decrease in affect-based risk seeking following AN left / CA right (Pripfl et al., 2013), yet when the opposite tDCS montage was applied (CA left / AN right), deliberative risk decisions increased. Boggio et al. (2010a) similarly demonstrated increases in high risk behaviours following AN left / CA right; and Hecht et al. (2010) (using the same electrode montage), demonstrated an increase in impulsive decision making. When using subjects with habitual substance abuse, Boggio et al. (2010b) demonstrated marijuana users increased propensity for risk during The Risk Task following CA left / AN right, yet the opposite montage (AN left / CA right)

produced varying responses. Similarly, cocaine dependent users were shown to increase risk taking during the Game of Dice task, following AN left / CA right (Goroni *et al.,* 2014); whereas CA left / AN right decreased risk in both cocaine dependant and control subjects. However, both montages demonstrated decreased risk taking when assessed via the BART.

The above literature presents compelling evidence for the use of tDCS on the dlPFC as a risk modulating technique. Benefits of using a technique such as tDCS are that modulations of functional brain activity can be localised to the area of the brain that is critically associated to the relative psychological function. Substance induced behavioural changes however will generate a more global modulation of functional brain activity, and may impact on motor and ocular functions. However, it must also be recognised that tDCS has been used to target the dlPFC with similar stimulation parameters but to elicit other psychological functions. Pain perception and thresholds (Boggio *et al*., 2008b), depression (Kalu *et* al., 2012) and planning ability (Dockery *et al*., 2009) represent a selection of uses tDCS has been implemented for when targeting the dlPFC. It is therefore imperative to consider that a modulation of dlPFC activity will modulate all of the above and perhaps more functions which may collectively impact on an athletes' pace and performance when applied in a pacing context. Yet it is also important to consider that modulated risk behaviour may simply be the product of altered psychological functions, such as pain perception.

In light of this, it is clear that not all effects of tDCS modulations are homogenous with regard to the modulation of risk achieved; for example, AN left / CA right have shown to increase (Boggio *et al*., 2010a) and decrease (Fecteau *et al*., 2007a) various facets of risk. This can in part be explained by differences in population age and genders between studies but also the use of various assessment tools with different values; the appraisal of which may have been influenced by the tDCS intervention. However, another likely explanation for this is the variability in response to tDCS. While tDCS has been shown to induce polarity dependent modulations to neural tissue, the direction of that change has seen much variation due to a host of inter and intra individual factors. Variation in

anatomy, neurochemistry, genetics, psychological status, functional organisation of local circuits, development and ageing represent a selection of intra and inter individual factors that have shown to influence the direction and degree of modulation achieved by using tDCS (li et al., 2015).

Understanding the modulatory effect of tDCS

Matching age and sex both within and between experimental groups will help to account for inter-individual variability in response to tDCS by limiting developmental and biological differences. Yet this does not fully account for intra-individual variation. Therefore, to understand what effect the tDCS intervention has on an individual, it is imperative to check the neurophysiological response using some form of neuroimaging to measure the neural activity of targeted tissue. By doing so, an inference can be made regarding the effectiveness of the tDCS intervention.

Techniques currently available for non-invasive mapping of brain activity are divided largely into two groups depending on the underlying mechanisms of operation (Shibasaki, 2008). One group relies on electrophysiological, and the other on haemodynamic principles. Electrophysiological methods include electroencephalography (EEG) and magnetoencephalography (MEG); while haemodynamic methods include positron emission tomography (PET), single-photon emission computed tomography (SPECT), magnetic resonance imaging (MRI) and near-infrared spectroscopy (NIRS).

Haemodynamic changes correspond well to neuronal activity (neurovascular coupling), which is especially reflected in the synaptic environment rather than spiking activity (Mangia *et* al., 2008) and therefore provides an effective surrogate measure of neuronal activity. All of the above methods are applicable to quantifying the effect of tDCS response in some form (Kwon *et* al., 2008; Marshall *et al*., 2011), yet typically require the individual to remain motionless during measurements. MEG, MRI and PET / SPECT scanning are all large, costly methods that require the individual to be fitted to the imaging modality and are highly sensitive to motion artefact. EEG and NIRS on the other hand are comparatively more compact, portable and relatively cost effective systems that are applied to the individual. EEG provides a sensitive frequency and amplitude based measure of evoked potentials

related to a sensory stimulus yet is highly susceptible to motion and ocular artefacts. NIRS meanwhile offers relative and absolute measures of haemodynamic properties and is relatively robust to motion artefact.

NIRS as a tDCS modulation check

Here we present the case for the use of NIRS as a modality to understand the modulatory effects of tDCS. tDCS induced modulations of functional brain activity have shown to reflect in haemodynamic properties where anodal stimulation increases oxygenated haemoglobin (Merzagora *et* al., 2010) and cerebral blood flow (Zeng *et al*., 2011). Two commonly used near-infrared spectroscopic techniques provide unique observational platforms to infer modulations to functional brain activity. The modified beer-lambert law (MBLL) generates sensitive and relative changes in oxy and deoxy-haemoglobin (Boas *et* al., 2001). Spatially resolved spectroscopy (SRS) however produces absolute values of tissue oxygenation and blood volume and provides a unique opportunity to remove optodes to apply an intervention, and then re-apply the optodes to record any modulatory effect (Suzuki *et al*., 1999; Myers *et al*., 2009). NIRS has an excellent temporal resolution (~ 1 ms) (Ferrari and Quaresima, 2012), yet is generally regarded as having poor spatial resolution which primarily due to the limited depth of cortical tissue that NIRS can penetrate (Ye *et al*., 2009). This depth limitation is due to an increased scattering of near-infrared light in deeper cortical tissue (Ye *et al*., 2009), however, for outer layers of the cerebral cortex, NIRS provides reasonable spatial resolution (~ 1 cm) (Ferrari and Quaresima, 2012) making make it suitable to measure dlPFC activity.

NIRS has been used previously to document cerebral oxygenation and blood volume changes during submaximal (Ide et al., 1999), maximal (Gonzales-Alonso et al., 2004; Ogoh et al., 2005) and supramaximal exercise (Shibuya et al., 2004); and also neurocognitive functions associated with exercise (Cui *et* al., 2011; Endo *et* al., 2013; Yanagisawa *et* al., 2010). This further bolsters the utility of NIRS in a pacing context and may allow for monitoring of tDCS induced modulations in real time during an exercise task; a function that is not feasible with EEG, MRI, PET / SPECT or MEG.

Conclusions

The influence of risk in pace regulation is intriguing, we understand that risk is associated with the way an athlete regulates their pace during an exercise task, yet our understanding of how risk has this effect remains unclear. In this review, we have highlighted how athletes may face different types of risk (negative, neutral) and an athletes' affective states may provide insight into the mechanism through which risk influences pace behaviour. The inclusion of various risk quantification measures will further diversify the nature of our understanding of the risk-pacing relationship through the use of risk attitude and behaviour measures with different risk inference properties.

The use of attitude and behavioural measures of risk will deepen our understanding of risk in pacing, yet the use of a risk modification technique such as tDCS provides a unique opportunity to infer causality with regard to how a change in risk changes pace behaviour. By applying tDCS to an area such as the dlPFC, we could expect an athletes risk taking behaviour to change, and for this change in risk characteristics to correspond to changes in pace behaviour.

Chapter 2

The influence of individual risk characteristics on athlete pacing behaviour: a tDCS study.

Abstract

Objective: To investigate how athlete risk attitude and behaviour characteristics influence pacing behaviour using transcranial direct current stimulation (tDCS) to alter dlPFC functional activity and modulate athlete risk characteristics.

Methods: A two-way within and between subjects' design was employed. Thirteen experienced male cyclists performed four, 16 km self-paced cycling time trials in the fastest time possible. RPE and affect were collected at every 2 km. The BART was used to measure athlete risk behaviour characteristics, and the DOSPERT to measure risk attitude. tDCS was used to modulate risk characteristics through modulated dlPFC functional activity and NIRS was used to check the neurophysiological modulation of tDCS.

Results: No difference between higher and lower risk groups for pace, RPE, hazard score or affect; although higher and lower risk groups display differential starting pace variance. tDCS has no effect on dlPFC blood volume following tDCS intervention and there were no changes in risk, pace, RPE, hazard score or affect between conditions. Increased BART risk taking score between sham tDCS and active tDCS conditions negatively correlated with changes in relative starting (0-2 km) pace, (r_{10} = -0.688, P = 0.03), RPE (r_{11} = -0.614, P = 0.05) and hazard score (r_{11} = -0.614, P = 0.05), but not affect. No association was seen between a change in DOSPERT score and pace, RPE, hazard score or affect.

Conclusions: Risk does not influence pace at a group level yet initial pacing variance between higher and lower risk groups appears to vary. Changes in BART risk taking behaviour negatively associates with starting pace, perhaps due to differences in value computation between the tasks indicating differences between individuals influences initial pace behaviour.

Introduction

Athletic pacing describes a process whereby athletes regulate the distribution of energy resources throughout an exercise task in order to achieve maximal performance while preserving body homeostasis (de Koning *et al*., 1999; Foster *et al*., 2003; Tucker and Noakes, 2009; Roelands *et* al, 2013). The specific nature by which athletes perform this regulation is hotly debated, yet it is widely agreed that an athletes' perception of exertion plays a major role in pace regulation. Perceived exertion is a psychophysiological cue of exercise intensity, thought to arise from integrated afferent feedback received by the brain from peripheral physiological systems (St Clair Gibson *et* al., 2003 and 2006). The template matching model proposed by Tucker (2009) suggests pace is regulated to maintain a scalar linear increase in perceived exertion throughout exercise, where if perceived exertion drops below, or exceeds that of forecasted exertion, efferent drive and pace will be modified. The rather more controversial central governor model (CGM; Noakes *et* al., 2004) proposes an unspecified subconscious brain region regulates pace by altering motor unit recruitment and inducing perceptions of exertion to ensure physiological systems never exceed critical thresholds. The hazard score model (de Koning *et al*., 2011) instead uses the perceived exertion scale in a metric with the fraction of event distance remaining to generate a 'hazard score'. A score below 1.5 indicates a positive change in pace, whereas between 1.5 and 3 no change, and a score above 3 indicates a negative change in pace. Explicitly recognised in this hazard score model is the risk of accruing a high score at the start of an exercise task, indicating the exercise intensity is not sustainable for the event duration.

The selection and maintenance of an effective pacing strategy is vital for success, particularly during the early stages of an exercise task. If an athlete starts too fast, they risk exhausting metabolic reserves too early and fatiguing (Thompson *et al*., 2003); yet starting too slow risks underperforming (Abbiss and Laursen, 2008). The notion of risk; where by the likelihood of an unwanted or unfortunate event occurring (Rohrmann, 2008) is explicitly referenced to in much pacing literature,

yet only one study has explicitly investigated the influence of risk on pace behaviour. Micklewright *et al*. (2015); investigating how different levels of risk perception between athletes influences pacing behaviour, highlighted that lower risk perceiving athletes adopt faster initial pacing strategies than higher risk perceivers (~ 8 %). Despite discrepancies in initial pace, performance remained similar between risk groups, as did perceived exertion, suggesting athletes experienced the exercise similarly. Due to the similarities in subjective scores between risk groups, and the nature of the study (between-subjects), it is hard to infer how risk has this effect in individual athletes yet highlights the nature by which individual differences may influence pace selection, an area that seems to have been overlooked in previous pacing literature. This study is therefore aimed at furthering our understanding of this association by employing a mixed study design and assessing how differences in risk characteristics, both within and between condition influences pace selection.

Appraisals of risk form just one component of the risk concept and it is important to note that these appraisals must be acted upon. As such, understanding how risk taking behaviour associates with pace selection will deepen our understanding of how differences in athlete risk characteristics influence pace behaviour; after all, the act of pacing can also be viewed as a measure of risk taking. Micklewright *et al*. (2015) used the domain specific risk taking (DOSPERT) scale to quantify athlete risk perceptions. The DOSPERT is a self-report questionnaire that requires individuals to report how likely they are to engage in, and how risky they appraise, a given situation to be. The DOSPERT reflects trait like properties of risk perception and propensity attitudes that are seen to remain stable within respective risk domains (Blais and Weber, 2006). The balloon analogue risk task (BART; Lejuez *et al*., 2002) - a behavioural measure of risk taking - requires individuals to inflate a computerised balloon in return for a monetary reward, yet if the balloon explodes, all money accrued for that balloon is lost (a negative risk). The BART measures risk taking behaviour when presented with uncertainty (a neutral risk) and may correspond well with pacing behaviour given the uncertainty incorporated into pacing decisions (St Clair Gibson *et* al., 2006). Uncertainty is believed to be at its greatest at the start of an event given the magnitude of influences that may occur during

the task. It may therefore be expected for the two tasks to correspond; with high BART risk taking reflecting in high risk pace decisions (fast start).

In order to understand how a change in risk influences athlete pacing we propose to use transcranial direct current stimulation (tDCS), a neurostimulatory technique proven to alter human risk taking behaviours (Levasseur-Moreau and Fecteau, 2012). Through the application of two electrodes (one anode and one cathode), a weak electrical current is passed through targeted cortical tissue, modulating the resting membrane potential of cephalic neurons (Nitsche et al., 2008). Below the anodal electrode, functional activity is facilitated (depolarised); yet below the cathode, it is inhibited (hyperpolarised) (Nitsche et al., 2008). When used to target the dorsolateral prefrontal cortex (dlPFC) - an area associated with higher cognitive functions such as action planning (Frith and Dolan, 1996), value computation (Sokol-Hessner et al., 2012) and working memory (Frith and Dolan, 1996) – both risk adverse (Pripfl et al., 2013) and risk seeking (Boggio et al., 2010a) behaviours have been induced. Of particular interest is the increased risk taking behaviours exhibited following anodal tDCS to the left dlPFC (Boggio et al., 2010a; Hecht et al., 2010; Goroni et al., 2014) and provides an opportunity to modulate athlete risk taking behaviours.

It is reasonable to expect tDCS of the dlPFC to induce risk based behavioural changes given its uses in behavioural literature (Levasseur-Moreau and Fecteau, 2012), however, it must also be recognised that tDCS has been used to target the dlPFC for other means such as pain perception (Boggio *et al*., 2008b) and planning ability (Dockery *et al*., 2009). Therefore, excitability changes in this area may induce wider modulations to psychological processes and perceptual systems that may inform athlete decision making. Furthermore, an innate amount of variability is understood to exist in the direction and degree of response from tDCS interventions both between, and within individuals (Li *et al*., 2015). Therefore, we will check the modulatory effect of tDCS by using the Spatially Resolved Near-Infrared Spectroscopy (SR-NIRS) optical imaging technique to assess changes in cerebral blood volume, a surrogate measure of functional brain activity (Grubb *et al*., 1974; Leenders *et al*., 1990;

Davies *et* al., 2015). (A description of the applicability of SR-NIRS to assess a tDCS modulation is given in the methods section under the 'Spatially Resolved – Near Infrared Spectroscopy (SR-NIRS) for measuring tDCS modulated functional brain activity' section)

Athlete risk perceptions are understood to associate with pacing behaviours (Micklewright *et al*., 2015), yet it is not clear how risk has this effect in individual athletes. In this study we will assess how athlete risk perception, propensity and taking characteristics associate with pacing behaviours both within and between athletes. Perceived exertion and hazard score will be measured to understand if perceptions of exercise intensity differ between levels of risk. We will also measure athlete affective states; the specific quality of feeling experienced (positive or negative) from a stimulus (Slovic *et al*., 2004). Affect is instrumental in the formation of risk appraisals (Alhakami and Slovic, 1994; Finucane *et al*., 2000) and has been associated with pace selection (Baron *et al*., 2009). Negative affect promotes higher risk perceptions and is associated with decreased exercise intensity; whereas greater positive affect lowers risk perceptions and corresponds with higher exercise intensities (Alhakami and Slovic, 1994; Finucane *et al*., 2000; Baron *et al*., 2009). We hypothesise that, (A) higher risk taking, lower risk perception, and higher risk propensity athletes will adopt a faster initial pace and experience greater positive affect than lower risk takers, higher risk perceivers and lower risk propensity athletes, yet RPE and hazard score will remain similar between groups in accordance with previous research (Micklewright *et al*., 2015). We further hypothesise that, (B) an increase in risk taking behaviour, risk propensity and decrease in risk perception will correspond to an increased initial pace; and RPE, hazard score and affect will positively correspond with these changes.

Methods

Participants

Thirteen experienced male cyclists (age, 33.5 ± 6.7 yrs; stature, 178.6 ± 5.7 cm; mass, 73.7 ± 9.8 kg) without a history of neurological or psychiatric disorders and naive to tDCS were recruited in this study. The study was approved by the University of Essex Ethics Committee and all subjects provided written informed consent and completed a transcranial direct current stimulation screening questionnaire before taking part.

Design

A two-way within and between subject's experimental design was employed where participants were required to visit the laboratory on four separate occasions separated by a minimum of 48 hours. Visits one (fam1) and two (fam2) served as familiarisation trials where subjects first completed either the BART (fam1) or the DOSPERT (fam2), followed by a five-minute self-paced warm up. When instructed, subjects then completed a 16 km self-paced time trial and were instructed to complete it in the fastest time possible. Visits three and four consisted of exactly the same procedures, except that the type of tDCS intervention changed (explained below in the 'Transcranial Direct Current Stimulation' section). Firstly, baseline bilateral dlPFC THI was measured for three minutes, followed by thirteen minutes of either active or sham anodal tDCS to the left dlPFC (counter balanced). Following tDCS, post intervention bilateral dlPFC THI was measured for a further three minutes which was then followed by the completion of the BART and DOSPERT risk tasks. Subjects then completed a five-minute self-paced warm up, followed by the completion of a 16 km self-pace time trial. Participants were instructed to complete the trial in the fastest time possible. Subjective scores (RPE and affect) were taken at every two kilometre interval. Risk measures (BART and DOSPERT) were used on different familiarisation trials in order to limited confounding learning effects of the tasks.

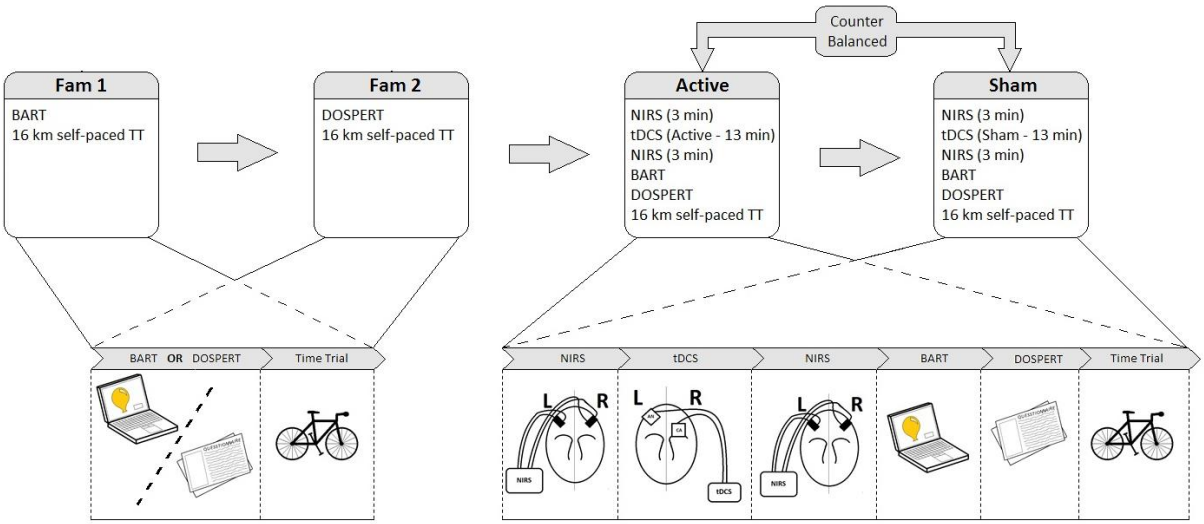

Figure 1. Experimental overview and schematic illustration of experimental procedures

Spatially Resolved – Near Infrared Spectroscopy (SR-NIRS) – Equipment and Data Collection

SR-NIRS is a depth resolved optical imaging technique that shines near-infrared light into targeted tissue and processes the attenuated light as it re-emerges to generate a tissue haemoglobin index (THI). Changes in bilateral dlPFC THI were continuously recorded using a NIRO-200 spectrophotometer (Hamamatsu Photonics KK, Tokyo, Japan). This spectrophotometer is a 3-wavelength, continuous wave system that uses the spatially resoled spectroscopy (SRS) method to determine THI. Near-infrared light is delivered via a fibre optic bundle at 778, 812 and 850 nm wavelengths and terminates at an emission probe. A detection probe is situated 40 mm from the emission probe and houses two aligned photograph detectors, separated by 4 mm. This emission / detector probe coupling forms one channel. Two channels were used; channel 1 was placed over the left (F3) and channel 2 was placed over the right (F4) dlPFC according to the 10-20 international system of marker placements (Klem, 1999). Data were collected at 6 Hz and processed in real time using a customised code implemented in Matlab 7.0.4 software (The MathWorks Inc., MA, USA). To reduce motion artefact, participants were asked to minimize head and body movements and were given instruction to breathe gently and regularly whilst resting. Offline data processing was

performed using a customised code implemented in Matlab 8.6.0 software to reduce data to a 2 Hz sample rate and allow for the removal of outliers and smoothing of data.

Spatially Resolved – Near Infrared Spectroscopy (SR-NIRS) for measuring tDCS modulated functional brain activity

tDCS modulated brain activity reflects in the haemodynamics of the targeted tissue. Anodal tDCS shows to increase oxygenated haemoglobin (Merzagora *et* al., 2010) and regional cerebral blood flow (Zeng *et al*., 2011). The THI measure generated from SR-NIRS is a scaled measure of tissue blood volume generated through a metric of a constant, but unknown tissue parameter (Suzuki *et al*., 1999) and the real blood volume signal strength (Myers *et al*., 2009). Blood volume is often used in conjunction with cerebral blood flow to measure basal brain activity (Grubb *et al*.,1974; Fox and Raichle, 1986; Leenders *et al*., 1990) and reflects the supply and demand of oxygen. The use of blood volume is typically as a surrogate measure of blood flow (Grubb *et al*., 1974), and therefore is a surrogate measure of functional brain activity. Given THI is a scaled measure of the real blood volume, it is represented in arbitrary units, yet provides an indirect measure of blood flow and vasomotor activity in observed tissue (Davies *et* al., 2015; Franceschini *et al*., 1999) and may allow for the quantification of tDCS induced haemodynamic changes. SR-NIRS has an advantage over other trend NIRS measurements in that the spatially resolved method results in an absolute number, requiring no baseline measurement. This means in principle that the NIRS optodes can be removed before – and replaced after – tCDS treatment without compromising the NIRS measurement of tDCS induced blood volume changes (and hence enable measurement of a surrogate of changes in functional brain activity).

Transcranial Direct Current Stimulation

tDCS was applied using a battery-driven electrical stimulator (HDCstim, Neuronika, Milano, Italy) connected to a pair of thick (3 mm) saline-soaked synthetic surface sponge electrodes (35 cm^2 Each)

placed on the scalp. For active stimulation, the anode was placed over the F3 position and the cathode was placed over the contralateral supraorbital area in accordance to the 10-20 international marker system. This electrode montage is designed to elicit an upregulation in the left dlPFC only due to the reference electrode (cathode) placement. Electrodes were held in place with rubber head bands and then held firmly to the scalp using a large, thin rubber head band. Active stimulation lasted for 13 minutes at a constant current of 1 mA (with a 30 second phase in / phase out transition for a total stimulation time of 840 seconds); total current density equalled 0.02857 mA/cm^2. These stimulation parameters have been used previously to elicit sustained facilitatory effects for one hour (Monte-Silva *et al*., 2013). The sham stimulation protocol mirrored active stimulation parameters, yet stimulation ceased following the 30 second phase in period. This has been shown as an effective method of providing tDCS sensations without inducing any significant modulatory effect allowing for effective placebo trials (Gandiga *et al*., 2006).

Risk Measures

The Balloon Analogue Risk Task (BART) (Lejuez *et al*., 2002) employed in this study required participants to inflate a computerised balloon presented on a laptop in front of them by pressing a key on the response pad to select the 'inflate' button on screen. Each balloon could explode at any point between 1 and 128 pumps with an average explosion point of 64 pumps. Each pump earnt £0.05 which was stored in a 'temporary bank'. At any point, the participant could stop pumping and collect the money, transferring the accumulated money from that balloon to a 'permanent bank'. In contrast, when a balloon explodes, the accumulated temporary money is lost and the next trial (balloon) begins. Information regarding explosion points were not provided to participants. The variable of interest is the 'total number of adjusted pumps' (i.e. the number of pumps per balloon for balloons that did not explode).

The Domain Specific Risk Taking (DOSPERT) questionnaire (Blais and Weber, 2006) employs a seven point Likert-scale questionnaire that consists of two identical sets of 30 questions. Participants were first required to complete 30 questions rating how likely they are to engage in the situation described. Participants then answered a second, identical set of 30 questions rating how risky they perceived the activities to be. Scores are summed for each questionnaire to generate a separate risk perception and propensity score.

Time trial cycle ergometery

Time trial tasks were completed using a Velotron cycle ergometer (RacerMate, USA). The ergometer was fully customised to the participant's requirements (Peddle fitting, saddle and handle bar adjustments). There are discrepancies in the gear changing operation between the Velotron ergometer and a standard road bike; therefore, the warm up also served as a familiarisation of ergometer gear changing. Following the completion of the warm up, participants were given the chance to ask questions about the ergometer or experimental process. Participants were then instructed to complete the 16 km cycling time trial in the fastest possible time. Elapsed distance in kilometres was presented to participants throughout warm up and the time trial. Investigators remained out of sight and partitioned from the participant using screens. There was no pacing/performance guidance given, or verbal communication with participants other than the collection of subjective data. The only audible noise was the mechanics of the Velotron ergometer.

Perceived exertion, hazard score and affect

At the end of every two kilometre segment during each time trial, participants were asked to provide an overall RPE and affect score. RPE was administered using the Borg 6-20 scale (Borg, 1982) and affect was measured using the feeling scale (Hardy and Rejeski, 1989). Participants were familiarised with the RPE and affect scales prior to the time trials and the scales were administered in accordance to standardised instructions. Hazard score was subsequently calculated for each two

kilometre segment as RPE multiplied by the percentage of remaining distance (de Koning *et al*., 2011).

Data analyses

A median split of risk scores were used to subdivide athlete data into higher and lower BART risk taking, DOSPERT risk perception and DOSPERT risk propensity groups. Correlations between the change in THI, risk and pacing related variables between sham tDCS and active tDCS conditions were calculated by correlating the difference between the active tDCS value and the sham tDCS value; for example:

[Active tDCS THI] – [Sham tDCS THI] correlated with **[Active tDCS BART] – [Sham tDCS BART]**

Between risk group and condition variance in cycling speed was normalised by calculating the two kilometre percent deviation from overall average cycling speed.

Statistics

Differences between higher and lower BART risk takers, DOSPERT risk perceivers and DOSPERT risk propensity group scores were analysed using an independent samples t-test. A two-way between subject's ANOVA was used to assess two kilometre segment differences in pace, RPE, hazard score and affect between higher and lower risk groups. A Pearson's correlation test was used to assess the relationship between risk scores and initial (0-2 km) pace, while differences in initial pace (0-2 km) variance between higher and lower risk groups were analysed using a one-tailed F test.

Changes in THI from baseline following tDCS in the sham tDCS and active tDCS conditions were analysed using a paired samples *t* test. Differences in risk score between conditions were analysed using a one-way repeated measures ANOVA. A two-way repeated measures ANOVA was then used to analyse two kilometre segment differences in pace, RPE, hazard score and affect. Intra-individual relationships between changes in THI and changes in risk score (BART, DOSPERT) between sham tDCS and active tDCS conditions were analysed using a two-tailed Pearson's correlation test.

Similarly, the relationship between changes in risk score (BART, DOSPERT) and changes in pace, RPE, hazard score and affect in the first 0-2 km segment of the time trials between sham tDCS and active tDCS conditions were analysed using a two-tailed Pearson's correlation test. As pace data (cycling speed) were normalised, the sum of all segment points equalled zero, therefore no condition main effects are presented. All results are expressed as means ± 1 SD and effect sizes as eta squared (η^2). An alpha level of 0.05 was used to indicate statistical significance.

Results

BART Risk Taking. An independent samples t-test showed total adjusted pumps for lower and higher BART risk taking groups were significantly different in fam 1 (650 ± 99 Vs 862 ± 54; t_{10} = -4.6, P = 0.001), Sham tDCS (735 ± 111 Vs 928 ± 46; t_{10} = -3.0, P = 0.003) and Active tDCS (782 ± 83 Vs 939 ± 46; t_{10} = -4.0, P = 0.002).

A two-way within and between subject's ANOVA showed no risk taking group-by-distance interaction, or condition main effect, but did show a significant distance main effect for pace, RPE, hazard score, or affect in fam 1, Sham tDCS and Active tDCS conditions (Figure 2; See table 3 for statistical results).

DOSPERT Risk Perception. Risk perception scores for higher and lower risk perception groups were significantly different in fam 2 (111 ± 9 Vs 142 ± 16; t_8 = -4.1, P = 0.001), Sham tDCS (116 ± 13 Vs 144 ± 11; t_{11} = -4.1, P = 0.002) and Active tDCS (113 ± 13 Vs 147 ± 13; t_{11} = -4.7, P = 0.001).

A two-way within and between subject's ANOVA showed no risk perception group-by-distance interaction, or condition main effect, but did show a significant distance main effect for pace, RPE, hazard score, or affect in fam 2, Sham tDCS and Active tDCS conditions (figure 3; See table 4 for statistical results).

DOSPERT Risk Propensity. Risk propensity scores for higher and lower risk propensity groups were significantly different for fam 2 (99 ± 10 Vs 124 ± 12; t_{11} = -4.2, P = 0.002), Sham tDCS (93 ± 10 Vs 123 ± 9; t_{11} = -5.7, P = 0.000) and Active tDCS (97 ± 15 Vs 127 ± 8; t_{11} = -4.4, P = 0.001).

A two-way within and between subject's ANOVA showed no risk propensity group-by-distance interaction, or condition main effect, but did show a significant distance main effect for pace, RPE, hazard score, or affect in fam 1, Sham tDCS and Active tDCS conditions (Figure 4; See table 5 for statistical results).

Table 3. Statistical results of two-way within and between subjects' ANOVA on high and low risk taking groups created via a median split of BART risk taking scores during three 16 km cycling time trials.

			Two-Way ANOVA												
			Distance Main				Risk Main				Distance * Risk				
		Figure		F	df	P	η2	F	df	P	η2		F	df	P	η2
Fam 1	Pace	2.A1	GG	9.6	3,27	>0.001	0.49	-	-	-	-	GG	1.1	3, 27	0.35	0.10
	RPE	2.A2	GG	36.3	2, 19	>0.001	0.78	0.0	1,10	1.00	0.00	GG	1.4	2, 19	0.28	0.12
	Hazard Score	2.A3	GG	798.3	2, 23	>0.001	0.99	0.1	1,10	0.73	0.01	GG	0.6	2, 23	0.55	0.06
	Affect	2.A4	GG	6.5	3, 25	>0.01	0.39	0.0	1,10	0.85	0.00	GG	0.3	3, 25	0.81	0.03
Sham tDCS	Pace	2.B1	GG	6.3	2, 22	>0.01	0.39	-	-	-	-	GG	0.6	2, 23	0.57	0.06
	RPE	2.B2	GG	55.8	2, 24	>0.001	0.84	0.0	1,10	0.85	0.00	GG	0.6	2, 24	0.60	0.06
	Hazard Score	2.B3	GG	610.1	2, 19	>0.001	0.98	0.1	1,10	0.73	0.01	GG	0.3	2, 19	0.58	0.05
	Affect	2.B4	GG	7.4	2 ,21	>0.01	0.42	0.3	1,10	0.59	0.03	GG	0.4	2, 21	0.71	0.04
Active tDCS	Pace	2.C1	GG	4.3	2, 24	0.02	0.30	-	-	-	-	GG	1.3	2, 24	0.29	0.12
	RPE	2.C2	GG	58.9	3 ,28	>0.001	0.86	0.0	1,10	0.96	0.00	GG	1.2	3, 28	0.32	0.11
	Hazard Score	2.C3	GG	789.2	2, 22	>0.001	0.99	0.1	1,10	0.74	0.01	GG	1.0	2, 22	0.40	0.09
	Affect	2.C4	GG	12.4	2, 20	>0.001	0.55	0.0	1,10	0.87	0.00	GG	0.7	2, 20	0.51	0.06

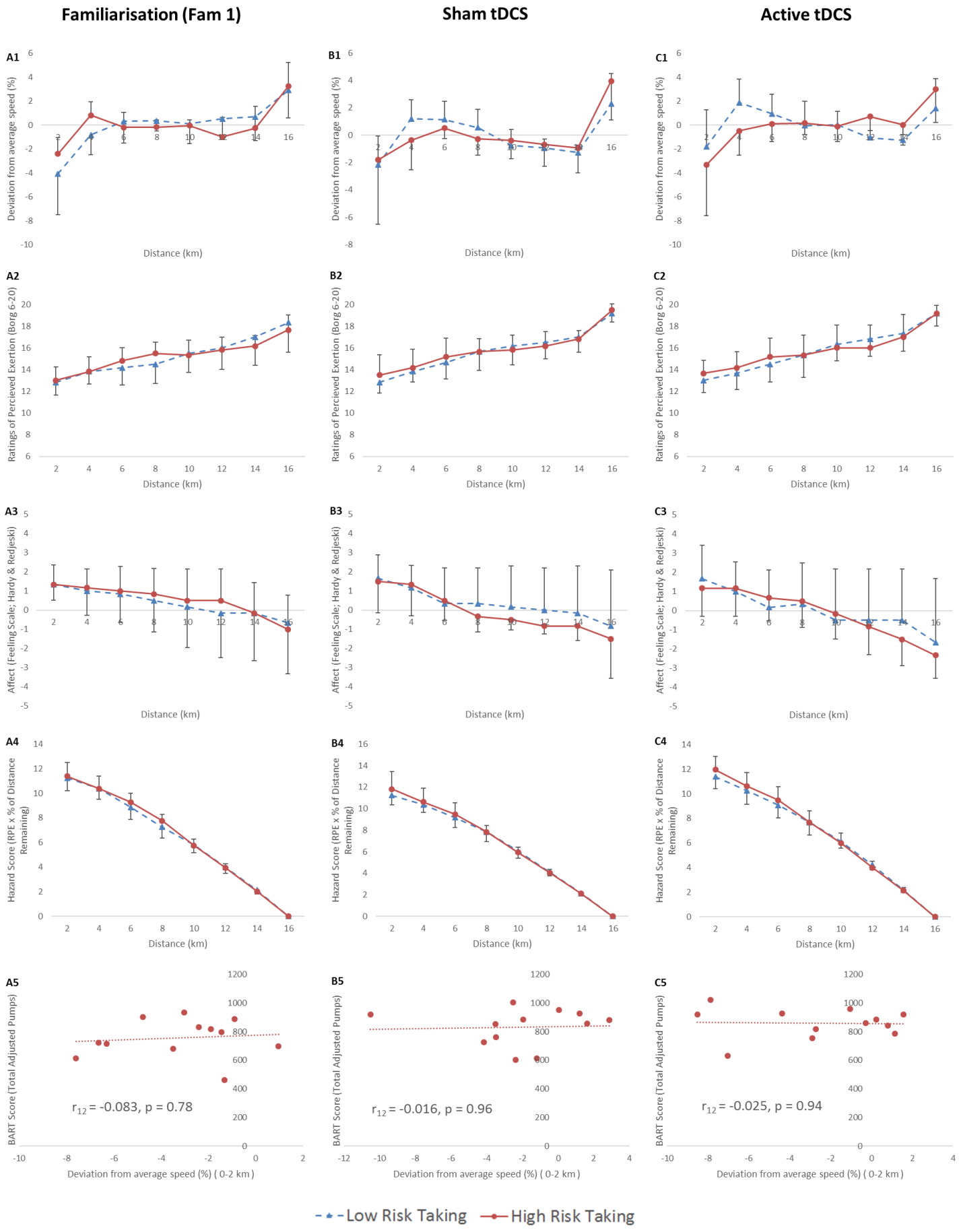

Figure 2. Pace (1), RPE (2), hazard score (3), affect (4) and BART risk taking correlations with initial pace (5) between higher and lower BART risk taking groups in three, 16 km cycling time trial conditions; fam 1 (A), sham tDCS (B) and active tDCS (C)

Table 4. Statistical results of two-way within and between subjects' ANOVA on high and low risk taking groups created via a median split of DOSPERT risk perception scores during three 16 km cycling time trials.

				Two-Way ANOVA											
				Distance Main				Risk Main				Distance * Risk			
		Figure		F	df	P	η2	F	df	P	η2		F	df	P	η2
Fam 2	Pace	3.A1	*GG*	14.0	2,26	>0.001	0.56	-	-	-	-	*GG*	0.5	2,26	0.80	0.05
	RPE	3.A2	*GG*	58.3	3,28	>0.001	0.84	3.7	1,11	0.08	0.25	*GG*	0.2	3,28	0.84	0.02
	Hazard Score	3.A3	*GG*	617.3	2,21	>0.001	0.98	3.4	1,11	0.09	0.24	*GG*	1.7	2,21	0.21	0.13
	Affect	3.A4	*GG*	11.0	2,21	0.001	0.50	1.5	1,11	0.24	0.12	*GG*	0.2	2,21	0.85	0.01
Sham tDCS	Pace	3.B1	*GG*	6.5	2,23	0.005	0.37	-	-	-	-	*GG*	0.3	2,23	0.78	0.02
	RPE	3.B2	*GG*	48.9	2,24	>0.001	0.82	0.1	1,11	0.83	0.01	*GG*	0.3	2,24	0.78	0.02
	Hazard Score	3.B3	*GG*	570.9	2,20	>0.001	0.98	0.0	1,11	0.85	0.00	*GG*	0.2	2,20	0.82	0.02
	Affect	3.B4	*GG*	8.9	2,25	0.001	0.45	0.0	1,11	0.95	0.00	*GG*	0.8	2,25	0.47	0.07
Active tDCS	Pace	3.C1	*GG*	5.5	2,24	0.009	0.33	-	-	-	-	*GG*	0.4	2,24	0.73	0.03
	RPE	3.C2	*GG*	51.6	3,33	>0.001	0.82	0.3	1,11	0.6	0.03	*GG*	0.9	3,33	0.45	0.08
	Hazard Score	3.C3	*GG*	712.5	2,21	>0.001	0.99	0.1	1,11	0.76	0.01	*GG*	0.4	2,21	0.66	0.04
	Affect	3.C4	*GG*	14.1	2,24	>0.001	0.56	0.6	1,11	0.45	0.05	*GG*	0.5	2,24	0.61	0.05

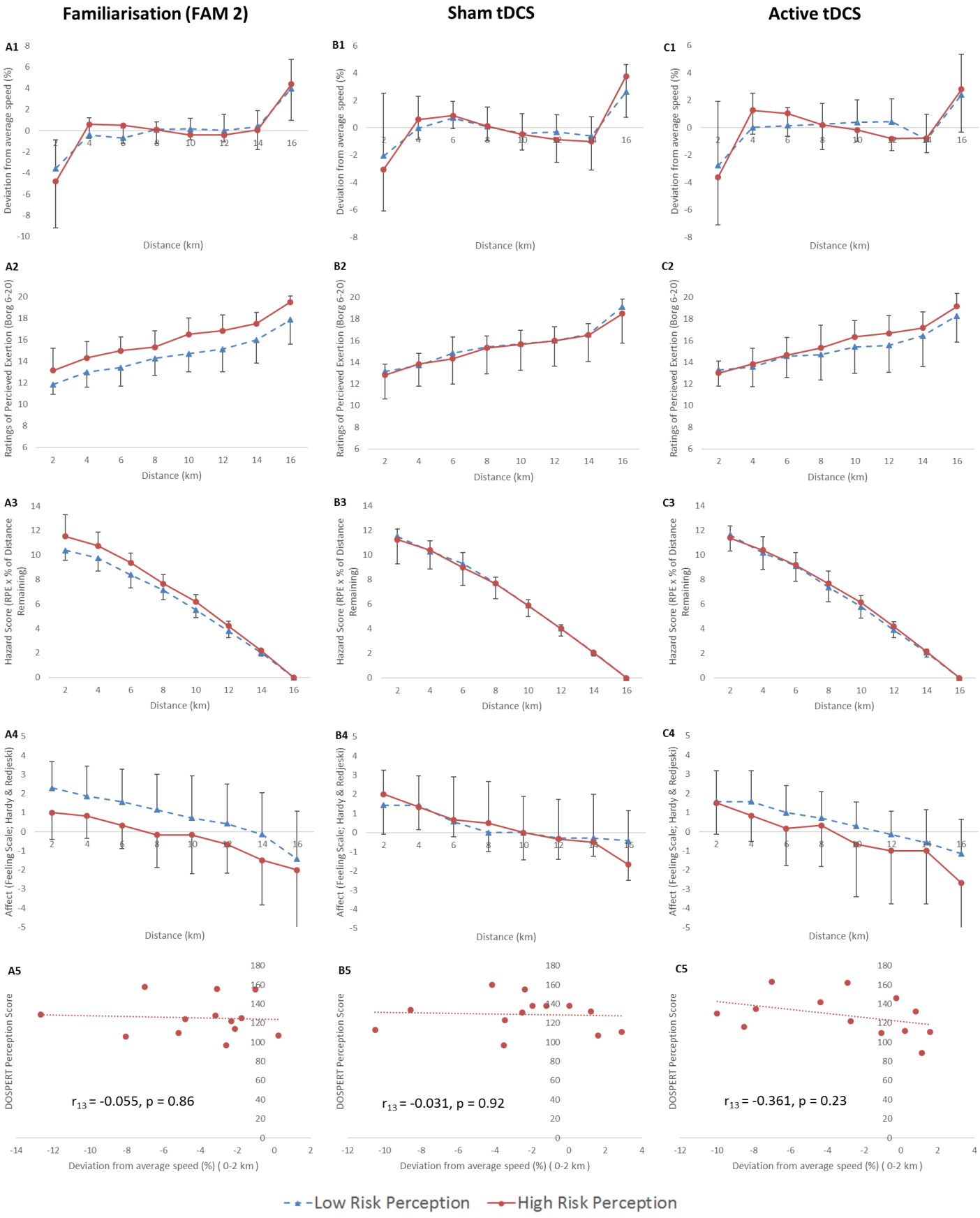

Figure 3. Pace (1), RPE (2), hazard score (3), affect (4) and BART risk taking correlations with initial pace (5) between higher and lower DOSPERT risk perception groups in three, 16 km cycling time trial conditions; fam 1 (A), sham tDCS (B) and active tDCS (C).

Table 5. Statistical results of two-way within and between subjects' ANOVA on high and low risk taking groups created via a median split of DOSPERT risk propensity scores during three 16 km cycling time trials.

				Two-Way ANOVA												
				Distance Main				Risk Main				Distance * Risk				
		Figure		F	df	P	η2	F	df	P	η2		F	df	P	η2
Fam 2	Pace	4.A1	GG	13.9	2,27	>0.001	0.06	-	-	-	-	GG	0.5	2,27	0.62	0.05
	RPE	4.A2	GG	59.2	2,27	>0.001	0.84	0.5	1,11	0.48	0.05	GG	0.4	2,27	0.74	0.03
	Hazard Score	4.A3	GG	547.3	2,19	>0.001	0.98	0.4	1,11	0.55	0.03	GG	0.3	2,19	0.72	0.03
	Affect	4.A4	GG	11.2	2,21	0.001	0.50	0.1	1,11	0.73	0.01	GG	0.4	2,21	0.66	0.04
Sham tDCS	Pace	4.B1	GG	6.4	2,24	>0.01	0.37	-	-	-	-	GG	0.0	2,24	0.87	0.01
	RPE	4.B2	GG	48.8	2,25	>0.001	0.82	0.1	1,11	0.83	0.01	GG	0.2	2,25	0.82	0.02
	Hazard Score	4.B3	GG	567.4	2,21	>0.001	0.98	0.0	1,11	0.86	0.00	GG	0.1	2,21	0.88	0.01
	Affect	4.B4	GG	8.8	2,25	>0.01	0.45	0.4	1,11	0.54	0.04	GG	0.6	2,25	0.56	0.05
Active tDCS	Pace	4.C1	GG	5.2	2,25	0.01	0.32	-	-	-	-	GG	0.4	2,25	0.68	0.04
	RPE	4.C2	GG	48.9	3,34	>0.001	0.82	1.6	1,11	0.23	0.13	GG	0.3	3,34	0.80	0.03
	Hazard Score	4.C3	GG	740.4	2,23	>0.001	0.99	1.3	1,11	0.27	0.11	GG	0.8	2,23	0.47	0.07
	Affect	4.C4	GG	13.6	2,24	>0.001	0.55	0.3	1,11	0.59	0.03	GG	0.4	2,24	0.71	0.03

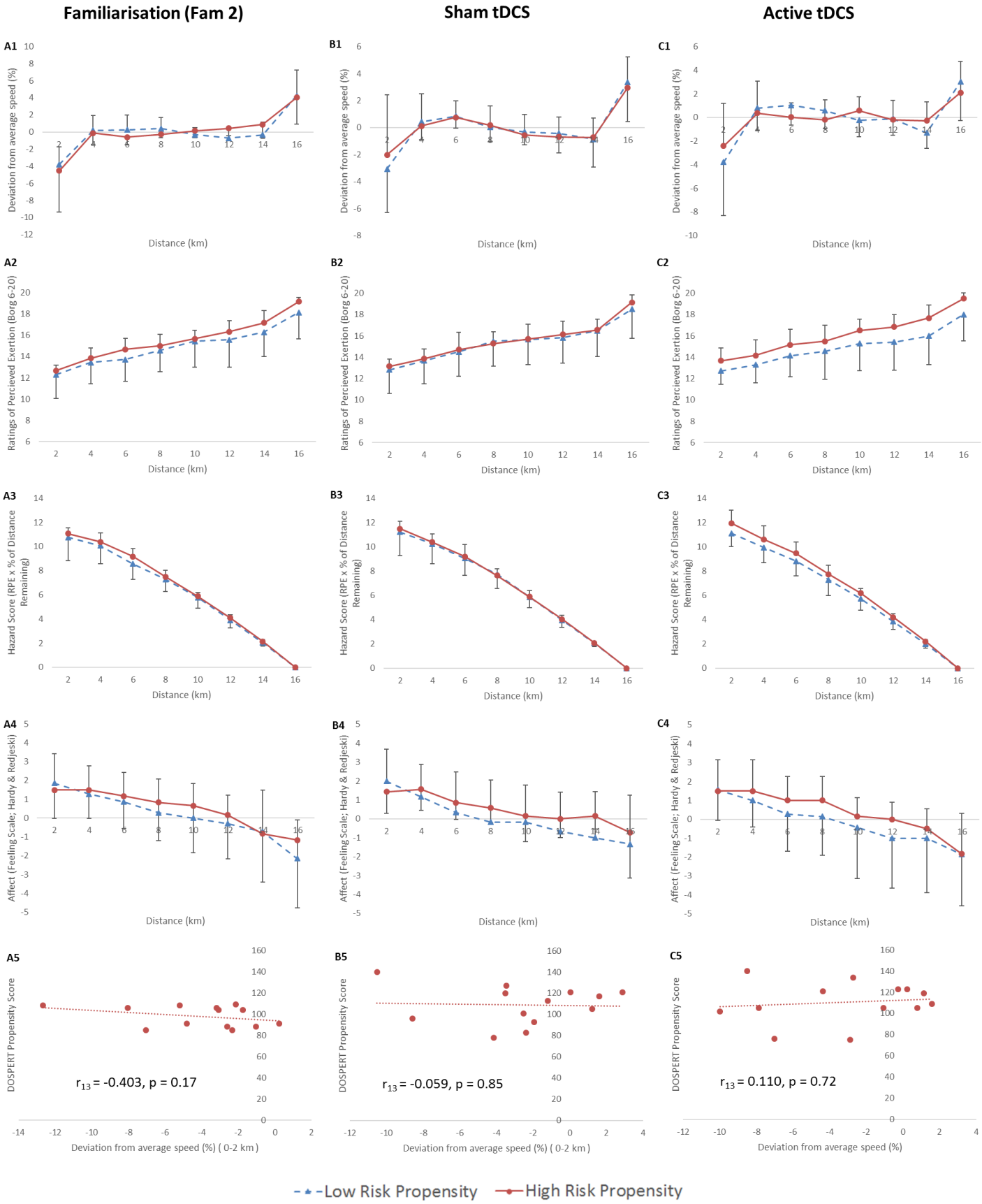

Figure 4. Pace (1), RPE (2), hazard score (3), affect (4) and BART risk taking correlations with initial pace (5) between higher and lower DOSPERT risk propensity groups in three, 16 km cycling time trial conditions; fam 1 (A), sham tDCS (B) and active tDCS

Post Hoc analyses show group variance in pace between higher and lower BART risk takers were significantly different in fam 1 ($F_{5,5}$ = 6.1, P = 0.03), yet sham tDCS ($F_{5,5}$ = 4.9, P = <0.05) and active tDCS conditions ($F_{5,5}$ = 1.9, P = 0.25) showed no difference (Figure 5a). Variance in initial pace between higher and lower DOSPERT risk perception groups showed no difference in fam 2 ($F_{5,6}$ = 2.7, P = 0.13), sham tDCS ($F_{6,5}$ = 2.2, P = 0.20) or active tDCS ($F_{6,5}$ = 1.8, P = 0.027) conditions (figure 5b). Initial pace variance between higher and lower DOSPERT risk propensity groups were significantly different in fam 2 ($F_{5,6}$ = 5.7, P = 0.03), yet no differences were displayed for sham tDCS ($F_{6,5}$ = 1.9, P = 0.25), or active tDCS ($F_{6,5}$ = 1.6, P = 0.32) conditions (figure 5c).

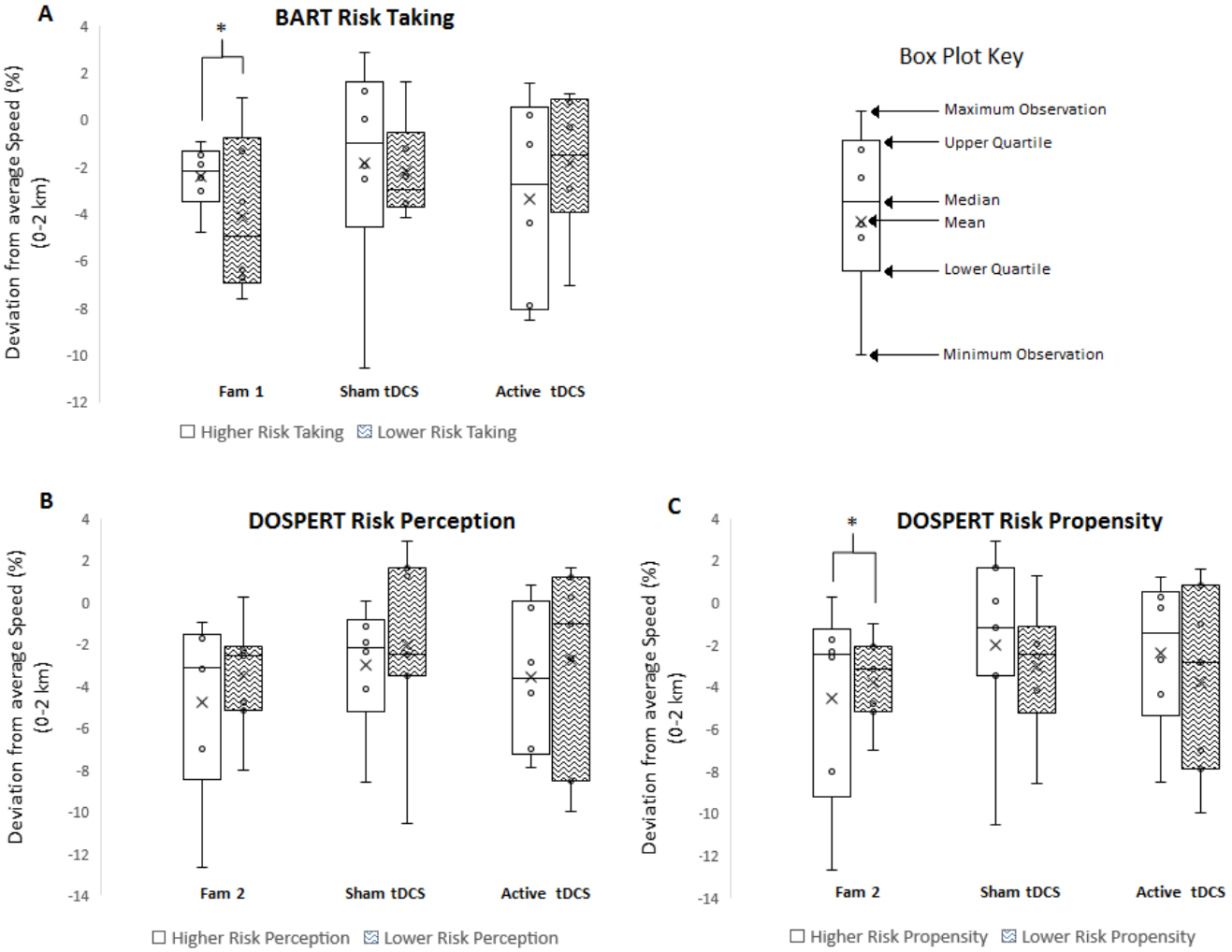

Figure 5. Variance of initial (0-2 km) pace (deviation from average speed %) between higher and lower BART risk taking (A), DOSPERT risk perception (B) and DOSPERT risk propensity (C) groups in fam 1 (BART), fam 2 (DOSPERT), sham tDCS and active tDCS conditions. (* indicates statistically different group pace variance)

Tissue haemoglobin index. Due to errors in the data files of two participants (one in the sham tDCS and one in the active tDCS condition), their data could not be used in the respective analyses. A paired samples *t*-test showed THI did not significantly change from baseline following tDCS intervention in both the left (6.6 ± 23.1) and right (8.4 ± 38.5) dlPFC in the sham trial tDCS trial (t_{11} 1.0, P = 0.35 and t_{11} 0.8, P = 0.47 respectively; Figure 6a.) confirming the placebo tDCS intervention had no modulatory effect on THI. Similarly, no significant change in THI from baseline was seen in both the left (4.5 ± 18.0) and right (-3.9 ± 21.3) dlPFC in the active tDCS condition (t_{11} 0.9, P = 0.41 and t_{11} -0.6, P = 0.54 respectively; Figure. 6b.) suggesting active tDCS had no modulatory effect on dlPFC blood volume.

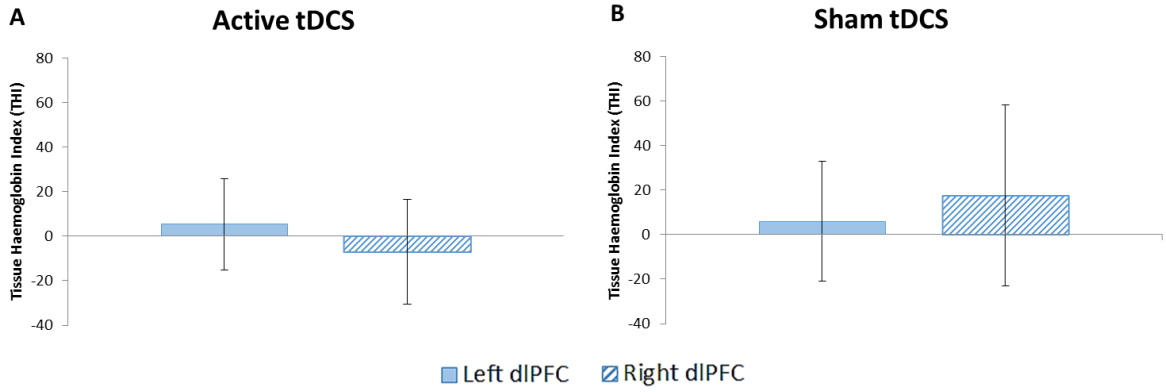

Figure 6. Change in THI from baseline following tDCS in the left and right DLPFC in sham (A) and active (B) tDCS conditions.

Risk. One participant was removed from group BART data analyses due to a score exceeding two standard deviations from the mean in the sham tDCS trial. A one-way repeated measured ANOVA showed no significant difference in BART risk taking scores between fam 1 (777 ± 99), sham tDCS (832 ± 129) and active tDCS (860 ± 104) trials ($F_{2,22}$ = 3.2, P = 0.06, η^2 = 0.22) (figure 7a), although it did approach significance. A one-way repeated measured ANOVA showed no significant difference in DOSPERT risk perception scores between fam 2 (125 ± 20), sham tDCS (129 ± 18) and active tDCS (128 ± 21) trials ($F_{2,24}$ = 0.6, P = 0.54, η^2 = 0.05) (figure 7b). A one-

way repeated measured ANOVA also showed no significant difference in DOSPERT risk propensity scores between fam 2 (110 ± 17), sham tDCS (109 ± 18) and active tDCS (111 ± 19) trials ($F_{2,24} = 0.4$, $P = 0.69$, $\eta^2 = 0.03$) (figure 7c).

Performance and pacing. One participant was removed from data analyses due to outlying pace data that exceeded two standard deviations. A one-way repeated measured ANOVA indicated there was no significant difference between average speed of fam 1 (35.5 ± 2.3), fam 2 (36.2 ± 2.1), sham tDCS (63.1 ± 2.5) and active tDCS (36.2 ± 2.8) trials ($F_{3,33} = 1.2$, $P = 0.34$, $\eta^2 = 0.10$). For pace, a two-way repeated measures ANOVA showed no significant condition-by-distance interaction (GG; $F_{4,,47} = 1.3$, $P = 0.30$, $\eta^2 = 0.10$) between fam 1, fam2, sham tDCS and active tDCS conditions, but did show a significant distance main effect (GG; $F_{3,29} = 0.6$, $P = >0.001$, $\eta^2 = 0.59$), meaning pace changed throughout the course of the time trials regardless of condition (Figure 8a).

Ratings of perceived exertion. There was no condition-by-distance interaction for RPE (GG; $F_{6,69} = 1.3$, $P = 0.26$, $\eta^2 = 0.11$) and no condition main effect ($F_{3,33} = 0.3$, $P = 0.81$, $\eta^2 = 0.03$), but there was a distance main effect (GG; $F_{2,22} = 63.1$, $P = >0.001$, $\eta^2 = 0.85$), indicating RPE increased regardless of condition (Figure 8b).

Hazard score. There was no condition-by-distance interaction (GG; $F_{4,49} = 1.3$, $P = 0.30$, $\eta^2 = 0.10$) and no condition main effect for hazard score ($F_{3,33} = 0.7$, $P = 0.54$, $\eta^2 = 0.06$), but there was a significant distance main effect (GG; $F_{2,20} = 800.0$, $P = >0.001$, $\eta^2 = 0.10$), meaning hazard score decreased during the time trials (Figure 8c).

Affect. There was no condition-by-distance interaction for affect (GG; $F_{6,61} = 1.9$, $P = 0.10$, $\eta^2 = 0.15$) and no condition main effect ($F_{3,33} = 1.1$, $P = 0.36$, $\eta^2 = 0.09$), but there was a distance main effect (GG; $F_{2,20} = 15.8$, $P = >0.001$, $\eta^2 = 0.59$), meaning regardless of condition, affect decreased during the time trials (Figure 8d).

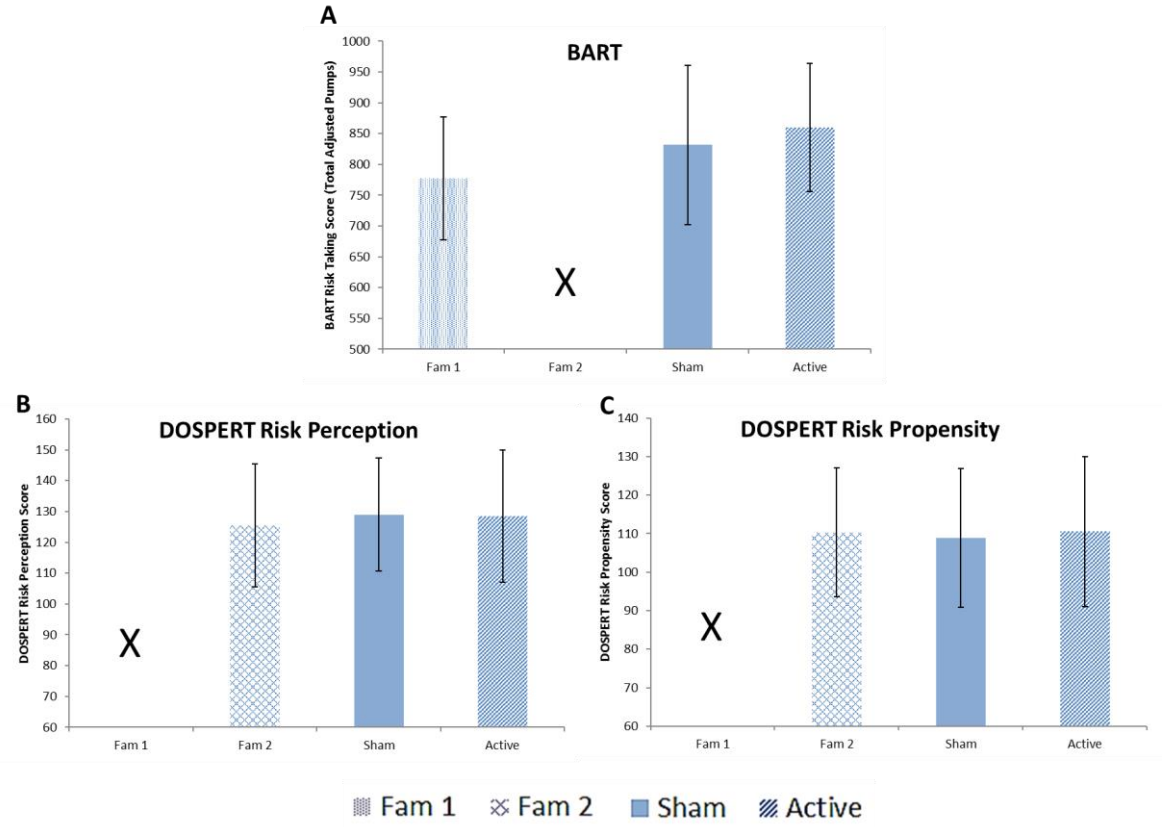

Figure 7. BART risk taking (A), DOSPERT risk perception (B) and DOSPERT risk propensity (C) scores in Fam 1, Fam 2, Sham tDCS and Active tDCS conditions.

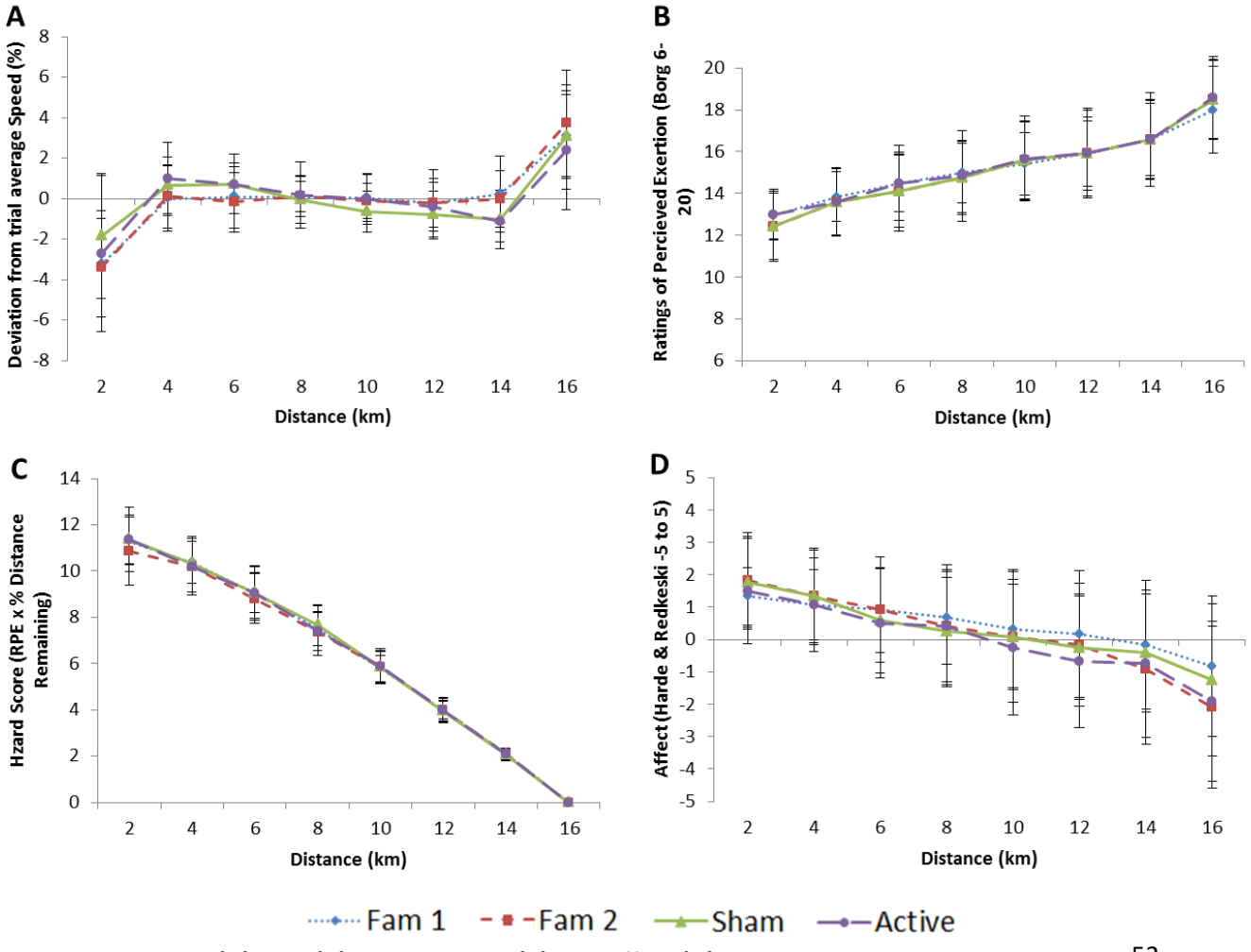

Figure 8. Pace (A), RPE (B), Hazard Score (C) and Affect (D) taken at 2 km intervals during a 16 km self-paced cycling time trial.

Intra-individual effects of tDCS on THI, risk and pacing.

Differences in THI at the post tDCS intervention level between the sham tDCS and active tDCS conditions were correlated against the difference in risk scores from BART and DOSPERT measures between sham tDCS and active tDCS conditions.

Data from two participants were not included in these analyses due to errors in their NIRS data files and a further two participant's data were removed from analyses of the right dlPFC THI change due to outlying changes in THI that exceeded two standard deviations from the mean.

Changes in THI and BART risk taking scores. Two participants were removed from analyses due to BART scores that exceeded two times the standard deviation from the mean. A strong positive correlation was seen between changes in left dlPFC THI and changes in BART risk taking score between sham and active tDCS conditions ($r_9 = 0.618$, P = 0.08; Figure 9a), yet this was not significant. No significant correlation was seen between changes in right dlPFC THI and BART risk taking score ($r_7 = -0.440$, P = 0.32; figure 9b).

Changes in THI and DOSPERT risk perception scores. One participant was removed from analyses due to a change in DOSPERT risk perception score that exceeded two times the standard deviation of the mean. No association was seen between changes in left ($r_{10} = 0.486$, P = 0.16; Figure 9c) or right ($r_8 = 0.265$, P = 0.53; figure 9d) dlPFC THI and DOSPERT risk perception scores between sham tDCS and active tDCS conditions.

Changes in THI and DOSPERT risk propensity. No association was seen between changes in left ($r_{11} = -0.203$, P = 0.55; Figure 9e) or right ($r_9 = -0.524$, P = 0.15; figure 9f) dlPFC THI and DOSPERT risk propensity scores between sham tDCS and active tDCS conditions.

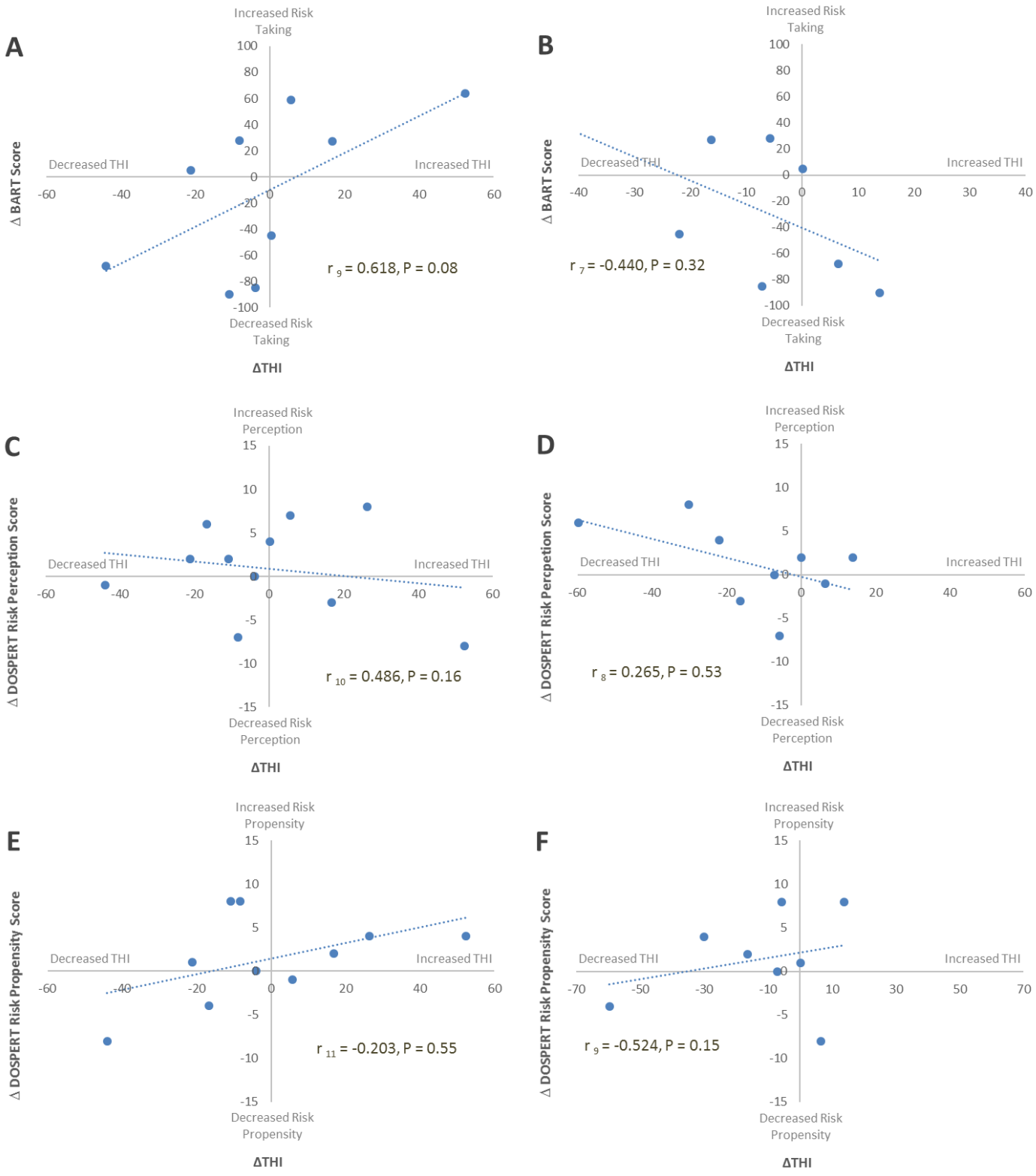

Figure 9. Associations between changes in Left dlPFC THI and BART risk taking (A), DOSPERT risk perception (C) and DOSPERT risk propensity (E) scores between sham tDCS and active tDCS conditions. Associations between changes in right dlPFC THI and BART risk taking (B), DOSPERT risk perception (D) and DOSPERT risk propensity (F) scores between sham tDCS and active tDCS conditions.

Initial pace and subjective scores in relation to changes in risk scores. Changes in initial (0-2 km) pace and subjective scores correlated against changes in BART risk taking and DOSPERT risk perception and propensity scores between sham tDCS and active tDCS conditions. One participant was removed from all pace correlation analyses due to changes in pace that exceeded two standard deviations from the mean.

BART. Two participants were removed from BART correlation analyses due to outlying changes in BART score that exceeded two standard deviations from the mean. A significant negative correlation was seen between changes in BART risk taking score and changes in initial (0-2 km) pace (r_{10} = - 0.688, P = 0.03; Figure 10a), RPE (r_{11} = -0.614, P = 0.05; Figure 10b) and hazard score (r_{11} = -0.614, P = 0.05; Figure 10c) between sham and active tDCS conditions. No significant association was seen between changes in BART risk taking score and changes in affect (r_{11} = - 0.221, P = 0.51; Figure 10d).

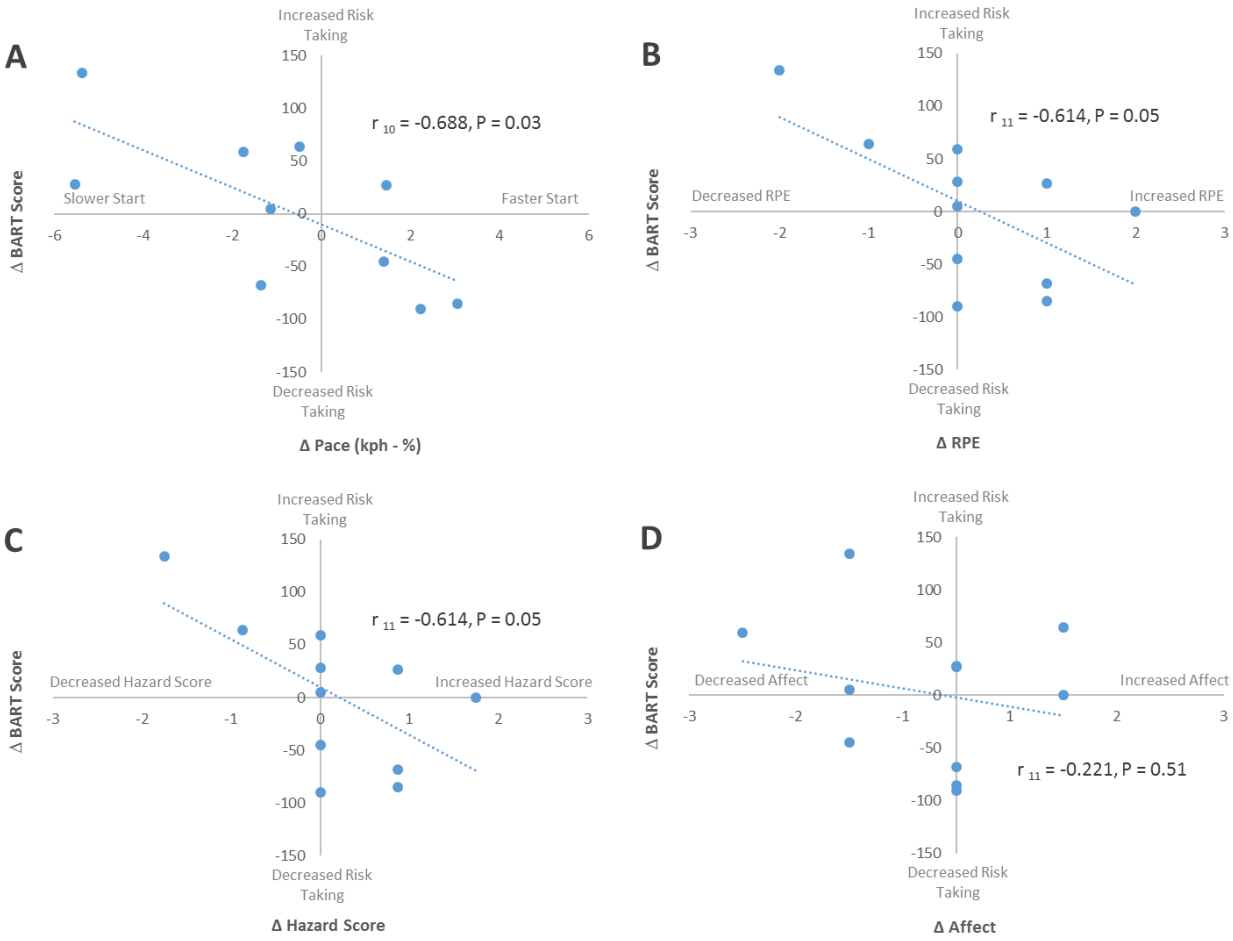

Figure 10. Association between a change in BART risk taking score and a change in pace (A), RPE (B), hazard score (C) and affect (D) between sham tDCS and active tDCS conditions.

DOSPERT risk perception. One participant was removed from DOSPERT risk perception analyses due to outlying changes in DOSPERT risk perception score that exceeded two standard deviations from the mean. No significant association was seen between changes in DOSPERT risk perception scores and changes in initial (0-2 km) pace (r_{12} = - 0.079, P = 0.82; figure 11a), RPE (r_{12} = - 0.006, P = 0.99; figure 11b), hazard score (r_{12} = - 0.006, P = 0.99; figure 11c) and affect (r_{12} = 0.344, P = 0.27; figure 11d) between sham tDCS and active tDCS conditions.

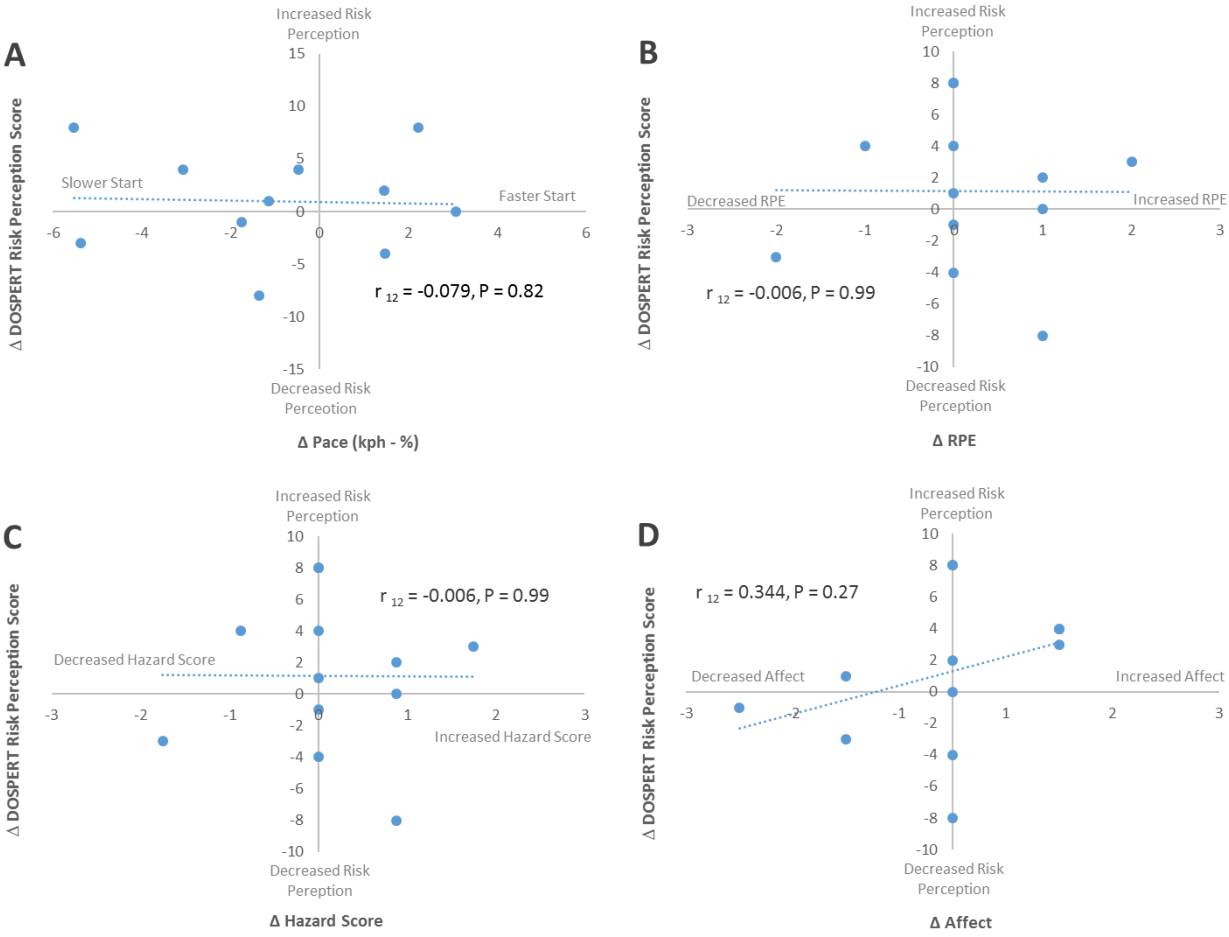

Figure 11. Association between a change in DOSPERT risk perception score and a change in pace (A), RPE (B), hazard score (C) and affect (D) between sham tDCS and active tDCS conditions.

DOSPERT risk propensity. No significant association was seen between changes in DOSPERT risk propensity scores and changes in initial (0-2 km) pace (r_{12} = - 0.151, P = 0.64; figure 12a), RPE (r_{13} = - 0.341, P = 0.26; figure 12b), hazard score (r_{13} = - 0.341, P = 0.26; figure 12c) and affect (r_{13} = - 0.458, P = 0.12; figure 12d) between sham tDCS and active tDCS conditions.

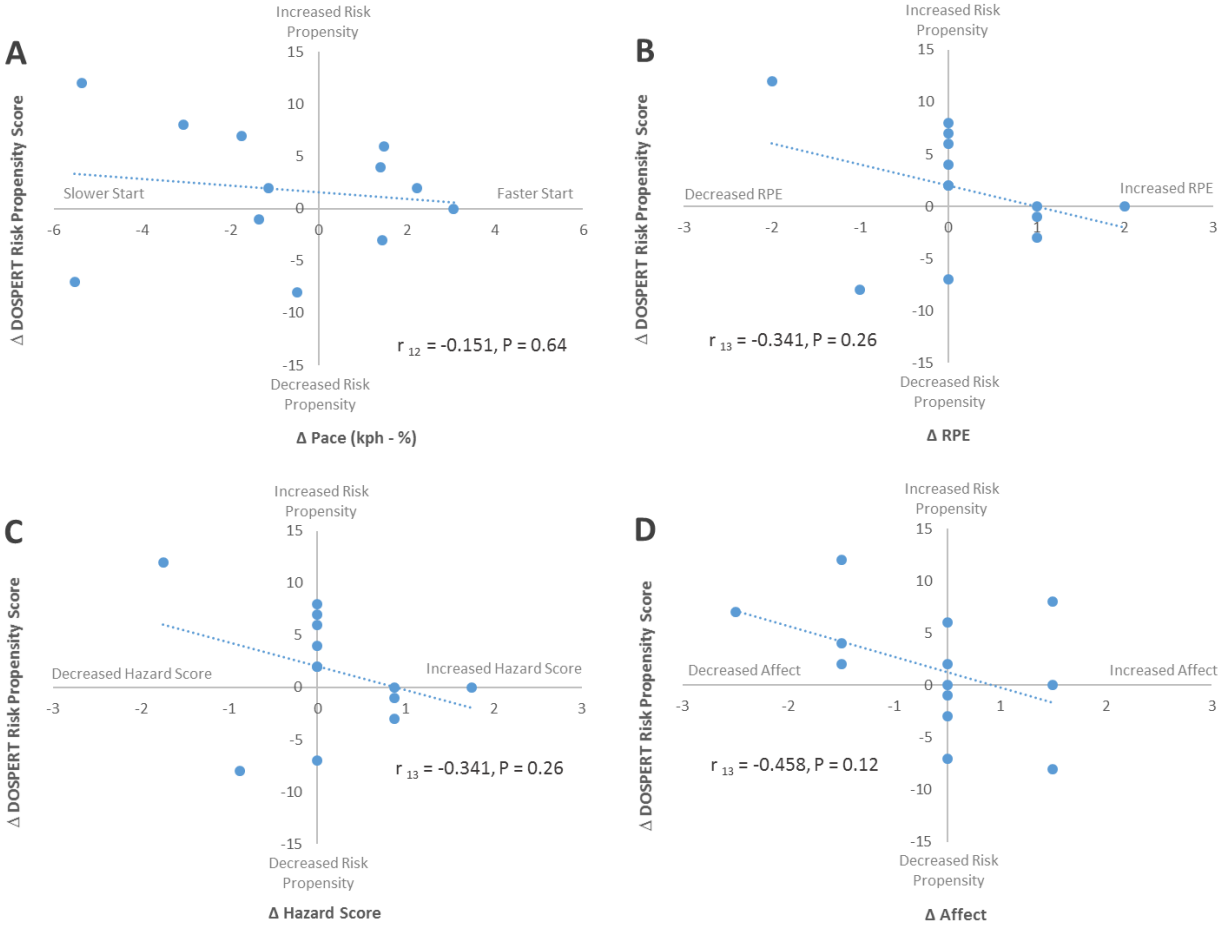

Figure 12. Association between a change in DOSPERT risk propensity score and a change in pace (A), RPE (B), hazard score (C) and affect (D) between sham tDCS and active tDCS conditions.

Discussion

This study aimed to further understand the association between risk and pacing behaviour and identify how risk influences pace selection. The main findings presented in this study are that athlete risk taking, perception and propensity characteristics do not associate with pacing behaviours at a group level, yet higher and lower risk groups display different initial pace variance. Further to this, increased individual risk taking behaviour associated with a decreased relative starting pace.

Pacing behaviour between higher and lower risk taking, risk perceiving or propensity groups did not differ. Similarly; RPE, hazard score and affect all remained similar between risk groups. We hypothesised higher risk takers, lower risk perceivers and higher risk propensity groups would start faster than the convers risk group, yet this is not founded in our results and we therefore reject part A of our hypothesis. Our findings indicate that risk does not associate with pacing behaviour and contrasts that of previous literature (Micklewright *et al*., 2015). Associations described by Micklewright *et a*l. (2015) were presented from a larger sample size than the present study, yet similar associations may be expected to reflect in a smaller population and perhaps indicates the fidelity to which risk influences pacing. However, it important to point out that differences - whether it be in pace (Micklewright *et* al. (2015) or group pace variance (present study) - always occurs at the beginning of the exercise, highlighting perhaps the importance of inter-individual differences and initial pace selection. Although pace between risk groups did not differ, it is interesting to note the degree of variability in starting pace between higher and lower risk groups and the relationship that unfolds between conditions. Higher BART risk takers in fam 1 (figure 5a) show significantly less group variance in pace than lower risk takers, perhaps indicating higher risk taking athletes are more consistent in their approach to the time trial; demonstrating a more uniform pacing behaviour than lower risk takers. However, this relationship is not consistent between trials;

and instead the variance of pace in the higher BART risk taking groups increases from fam 1, to sham tDCS and active tDCS trials. Conversely, pacing variance in the lower BART risk taking groups decreased from fam 1 to sham tDCS and active tDCS. This trend is similarly reflected in higher and lower DOSPERT risk perceiving and propensity athletes, where lower risk perceiving (figure 5b) and propensity (figure 5c) athletes in fam 2 show considerably smaller pace variance than higher risk perceiving and propensity athletes. This perhaps indicates that the level of measured risk taking, perception or propensity has a dynamic effect on pacing variance in conjunction with the level of experience an athlete has in a particular exercise environment. For example, lower risk perceiving athletes in fam 1 appear to adopt similar pace strategies, yet as they progress between conditions, developing a greater understanding of specific exercise demands, group pacing variance increases. This indicates lower risk perceiving athletes pace variance increases with experience perhaps suggests they are more willing to try a different strategy to achieve a better performance. However, these observations have been made only by looking at inter-quartile ranges presented in figure 5, and as higher and lower risk groups may have contained the same or different athletes between conditions, it is not possible to statistically confirm these trends in group pace variance. Future research may consider screening athletes prior to inclusion in the study to create highly contrasting risk groups and assess how group pace variance fluctuates between multiple trials.

We further sought to understand how changes in an athlete's risk taking, perception and propensity characteristics result in different pacing behaviours by using tDCS to target the dlPFC. Between conditions, BART and DOSPERT scores remained unchanged at a group level; and this stability is reflected in unchanged pacing behaviour between all four trials at a group level. RPE, hazard score and affect also remain unchanged between fam 1, fam 2, sham tDCS and active tDCS conditions, indicating that athletes experienced each condition similarly. Given the stability in risk taking, perception and propensity between conditions, it is not surprising that pace behaviour remained consistent and we therefore reject part B of our hypothesis.

At a group level we are unable to infer causality with regard to how risk influences pacing behaviours as risk characteristics between conditions did not change. This may question the effectiveness of our tDCS intervention with regard to the modulatory effect tDCS had on dlPFC functional activation, and the subsequent effect on risk behaviours. However, tDCS has proven to modulate functional brain activity (Li *et al*., 2015), and the dlPFC is causally linked with risk based decisions and behaviours (Krain *et* al., 2006). Following tDCS, THI did not change in either sham tDCS or active tDCS conditions (figure 6) which at face value suggests tDCS was not effective. However, perhaps a more likely explanation is that THI may not have been suitable for monitoring tDCS induced function brain activity changes or that an unknown amount of variability may have encroached the THI data due to the optode removal and replacement process. However, when associating the change in THI and risk between sham tDCS and active tDCS conditions, an intra-individual effect seems to have occurred whereby increases in left dlPFC THI appear to positively correlate with increased BART risk taking score (figure 9a). This perhaps suggests THI is better suited for assessment of momentary brain activity states, yet may lack the fidelity to assess functional changes in brain activity. We further associated changes in BART and DOSPERT risk measures with changes in starting pace (0-2 km) between sham tDCS and active tDCS conditions given the large degrees of variation in both measures. We see that an increase in BART risk taking score between sham tDCS and active tDCS conditions associates with a decrease in relative starting pace (figure 10a). This seems somewhat contradictory, considering that an increase in BART risk taking score indicates an increase in risk taking behaviours under uncertainty (Lejuez *et al*., 2002), whereas a decreased initial pace would suggest reduced risk taking under uncertainty (St Clair Gibson *et al*., 2006). The corresponding negative association between RPE and BART risk taking further indicates that athletes were aware of the discrepancies in exercise intensity. Such associations were not founded in DOSPERT risk perception or propensity changes which is indicative of the

nature of risk the DOSPERT risk measure, given the trait like properties characterised (Johnson *et al*., 2004).

Despite the contradictory association presented between BART score and initial pace, it presents intrigue into why the two behaviours are negatively associated. As previously postulated, athletes are faced by uncertainty regarding the outcome of their pacing choice at the beginning of an event (St Clair Gibson et al., 2006) and the BART presents uncertainty of balloon explosion points. It may be presumed the two tasks would positively associate with one another, where increased risk taking under uncertainty would reflect in both tasks. This however was not supported and we postulate two possible explanations centred on either the differences in appraised value that each task holds, or a change in pacing strategy adopted between conditions.

Value computation describes a process whereby the worth of a particular action is calculated relative to its likely outcome and is the cornerstone to much economic and psychological goal directed decision making theory (Rangel and Hare, 2010); such as Expected Utility Theory (Von Neumann and Morgenstern, 1945) and Prospect Theory (Kahneman and Tversky, 1979). Goal directed choices, such as maximising monetary reward in the BART, or achieving a personal best (PB) time in a cycling time trial, would require expected outcome valuation and expected action cost to generate an expected action value (Padoa-Schioppa, 2011; Rangel and Hare, 2010). Individuals are believed to compare such action values in goal directed decision making where riskier behaviours are more likely to be selected to accrue outcomes with a higher personal value (Slovic et al., 2005; Furby and Beyth-Marom, 1992). For example, a cyclist would be more likely to select a pacing strategy with a faster start if it is forecasted to achieve a personal best performance time even if entails high physiological costs and a risk of failure, compared against a strategy that may possibly achieve a personal best time but with a low risk of failure.

In the present study, athletes voluntarily participated for the explicit reason of time trailing, where desired goals can be presumably affixed to that of time trial performance. The BART however, (a measure of monetary based risk taking behaviour) was performed with a fictitious monetary reward and all that participants stood to gain or lose was the achievement of a greater score. Therefore, the reward of achieving a relatively high performance in competitive athletes may represent a considerably higher value than that of the decisions made in a fictitious monetary task. While this may explain the discrepancies between how the tasks may be appraised, it does not explain how a decrease in BART risk taking associates with increased starting pace.

Here we suggest that perhaps computation of action values associated with each respective task shifted somewhat between trials. For example, an increased relative starting pace and decreased BART score may be the product of increased awareness of the personal value of task outcomes. Where athletes display riskier behaviours to achieve a higher performance in a time trial task, and less risk in a fictitious task with little personal reward. Conversely, where awareness of personal outcome values is reduced, increased propensity for risk is displayed in the BART and reduced risk in the time trial.

Value computations are critically associated with activity of (among others) the dlPFC (Saraiva and Marshall, 2015; Sokol-Hessner et al., 2012; Hutcherson et al., 2012), which serves to modulate value encoding streams from other cortical regions (Rudorf and Hare, 2014). Therefore, given the nature of intervention provided in this study, it should not be ruled out that tDCS may have had a profound effect on a psychological process (such as value computation) beyond the recognition of the implemented measures. Therefore, it is plausible that a modulation of dlPFC activity induced differential levels of value computation between trials, leading to differential pacing behaviours.

While shifts in value computation seem a viable explanation, it must also be considered that athletes may have been explicitly adopting a different pacing strategy. For example, a shift from a parabolic, to a more even strategy, where a decreased relative starting pace gave way for a more even pace but at a higher velocity, which may also be considered a risky strategy.

When considering the findings of the current study in conjunction with existing pace literature, it is interesting to note that our findings cannot be accounted for in any previous pace regulation models. Our results highlight that differences between individual athletes - in respect to trait characteristics - influence athletic decision making. It is also important to note that the differences presented in this study and by Micklewright *et* al. (2015) occur at the beginning of the exercise task; the point at which athletes are faced with the largest degree of uncertainty and therefore risk (St Clair Gibson *et al*., 2006). This is something that seems to have been overlooked in previous pacing models where an emphasis has been placed on the axiom that the perceived exertion construct is the primary regulating mechanism for pace. As such, current understanding with respect to how athletes make decisions regarding pace (in particular initial pace) appears vague.

The central governor model (CGM; Noakes *et* al., 2004) claims initial pace is set by the brain 'in anticipation' of exercise demands relative to expected task duration, yet does not specify how this computation is calculated beyond the feed-forward regulation of motor unit recruitment by a subconscious controller region. While the acclamation of 'anticipated' exercise demands is made by the CGM, nowhere in this model is there an allowance for differential interpretation of task related feedback and individual factors leading to different pace behaviours. Unfortunately, this lack of clarity is reflected in a number of pace models where the scalar linear increase in perceived exertion commonly observed in exercise performances (Faulkner *et al*., 2008) overshadows the decisional process that must take place; such as the RPE template model (Tucker, 2009) and estimated time limit model (Garcin *et al*., 2012). The

hazard score model presented by de Koning *et al*. (2011) attempts to understand this decision process, yet is based on the same scalar linear increase of perceived exertion and merely dictates the risk an exercise intensity poses in relation to the amount of event completed. This model therefore fails to determine how this information may have been interpreted differently according to, for example, differential risk trait characteristics - as presented in this study.

Perceptions of exertion undoubtedly hold a strong relationship with spatial and temporal aspects of an exercise task (Faulkner *et al*., 2008). However, such generalisation that have become the core of many pacing models lack the precision to expose actual pace decisions made and are too linear in their approach. This is exemplified when considering the similar perceived exertion responses generated from differential work rates presented by Micklewright *et al*. (2015). Using derivatives of task-related feedback in a feed-forward mechanism rather than understanding how athletes interpret and act upon the information exposed to them has led to a singular dimensional approach to pace regulation, rather than a dynamic approach that would be required to explain results presented in the current study. This is particularly exemplified as such models cannot explain 'bad' pacing decisions, given that pace should be modified to maintain a scalar linear increase in perceived exertion. However, by accounting for differences between individuals, suboptimal pacing decisions could be ascribed to differential pace selection biases such as risk traits, or computed value of the behaviour outcome.

A recent proposal by Smits *et al.* (2014) highlights the complex nature of decisions made during an exercise task and explicitly recognises individual factors in behaviour selection. The affordance-competition hypothesis; a conceptualisation of ecological psychology, serves to explain how athletes interpret and act upon environmental information. This framework highlights the interdependence between perception and action (Micklewright *et* al., 2016), with the prefrontal area of the human brain interjecting individual preferences in behaviour

selection. Such models help us to understand how athletes behave in response to their competitive environment; a similar account should also be taken to understand isolated pacing decisions relative the nature of individual athletes'.

The development of pace research has undoubtedly been informed by the relationship of perceived exertion with exercise tasks (Faulkner *et al*., 2008), yet to understand with greater confidence and accuracy; accounting for individual differences in pace regulation is need. Integrating individual factors and decision making processes into our understanding of pace regulation will allow a greater degree of flexibility in understanding pace behaviours in real-life, competitive scenarios (Micklewright *et al*., 2016). The need for pace regulation models capable of individualisation is evident and a rich psychological, economic and neuroscientific literature will help inform such conceptualisations. Such models need not be overly sophisticated or complex, but instead need to allow for differential pace behaviours to be explained via a number of inter-individual factors; such as risk or value computation.

Future research concerning the manifestation of risk in pacing behaviour should seek to understand how processes that inform human risk taking behaviours translates into the pacing context. Value computation highlights just one computational complexity of the decision making construct that may affect an athletes' behaviour. Motivational forces for example may also play a significant role in an athletes' risk based behaviours (Redish *et al*., 2015) and has previously been postulated as a regulatory factor (Marcora, 2010).

Conclusions

In this study we have presented evidence that differences between athlete risk characteristics do not influence pacing behaviours at a group level; however instead, subtler differences are evident in the variance of starting pace between higher and lower risk taking, perception and propensity groups. We further demonstrated that a change in measured risk taking characteristics associates with a change in starting pace behaviour that may be attributable to

differential value computations. This study has indicated that the association between risk and pacing behaviour is dynamic and highly intra-individual. Therefore, future research must consider accounting for this by increasing the fidelity to which the concept is both investigated in pace regulation and incorporated into the wider pacing literature.

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Appendix

Transcranial Direct Current Stimulation Adult Safety Screen Questionnaire

(Please answer all questions honestly by ticking the appropriate box)

	Yes	No
Do you have epilepsy or have you ever had a convulsion or a seizure?	☐	☐
Does anyone in your family have epilepsy?	☐	☐
Have you ever had a head trauma that was diagnosed as a concussion or was associated with loss of consciousness	☐	☐
Do you have any hearing problems or ringing in your ears?	☐	☐
Do you have cochlear implants?	☐	☐
Do you have metal in the brain, skull or elsewhere in your body (e.g., splinters, fragments, clips, etc.)? If so, specify the type of metal:……..	☐	☐
Do you have an implanted neurostimulator (e.g., DBS, epidural/subdural, VNS)?	☐	☐
Do you have a cardiac pacemaker or intracardiac lines?	☐	☐
Do you have a medication infusion device?	☐	☐
Are you taking any medications? (If yes, please list) …….. ……	☐	☐
Have you ever undergone tDCS in the past? (If so, please state if any problems occurred) ……..	☐	☐
Do you suffer or have you in the past suffered from any skin condition?	☐	☐
Do you suffer from any neurologic disease (other than epilepsy) or other medical condition?	☐	☐
Have you ever had a fainting spell or syncope? If yes, please describe on which occasion(s)? ……..	☐	☐

Do you suffer from daily or severe headaches? ☐ ☐

Have you ever had a stroke? ☐ ☐

Have you ever had a serious head injury (/had neurosurgery)? ☐ ☐

Have you had an illness that caused brain injury? ☐ ☐

Have you had any brain related condition? ☐ ☐

This is now then end of the questionnaire

If you answered NO to all of the questions above, you are cleared for physical activity.

If you answered YES to one or more of the above questions, please speak to a supervisor regarding your participation within this study.

Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this electrical stimulation clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

Date: … … / … … / … …

Name: …… Witness: ……

Signature: …….. Signature: ……

Appendix A1. Transcranial direct current stimulation screening questionnaire.

People often see some risk in situations that contain uncertainty about what the outcome or consequences will be and for which there is the possibility of negative consequences. However, riskiness is a very personal and intuitive notion, and we are interested in **your gut level assessment of how risky** each situation or behaviour is. For each of the following statements, please indicate how risky **you perceive** each situation. Provide a **tick** using the scale to the left:

Not at all Risky	Slightly Risky	Somewhat Risky	Moderately Risky	Risky	Very Risky	Extremely Risky	
							Admitting that your tastes are different from those of a friend. (S)
							Going camping in the wilderness. (R)
							Betting a day's income at the horse races. (F)
							Investing 10% of your annual income in a moderate growth mutual fund. (F)
							Drinking heavily at a social function. (H/S)
							Taking some questionable deductions on your income tax return. (E)
							Disagreeing with an authority figure on a major issue. (S)
							Betting a day's income at a high-stake poker game. (F)
							Having an affair with a married man/woman. (E)
							Passing off somebody else's work as your own. (E)
							Going down a ski run that is beyond your ability. (R)
							Investing 5% of your annual income in a very speculative stock. (F)
							Going whitewater rafting at high water in the spring. (R)
							Betting a day's income on the outcome of a sporting event (F)
							Engaging in unprotected sex. (H/S)

Not at all Risky	Slightly Risky	Somewhat Risky	Moderately Risky	Risky	Very Risky	Extremely Risky	
							Revealing a friend's secret to someone else. (E)
							Driving a car without wearing a seat belt. (H/S)
							Investing 10% of your annual income in a new business venture. (F)
							Taking a skydiving class. (R)
							Riding a motorcycle without a helmet. (H/S)
							Choosing a career that you truly enjoy over a more secure one. (S)
							Speaking your mind about an unpopular issue in a meeting at work. (S)
							Sunbathing without sunscreen. (H/S)
							Bungee jumping off a tall bridge. (R)
							Piloting a small plane. (R)
							Walking home alone at night in an unsafe area of town. (H/S)
							Moving to a city far away from your extended family. (S)
							Starting a new career in your mid-thirties. (S)
							Leaving your young children alone at home while running an errand. (E)
							Not returning a wallet you found that contains $200. (E)

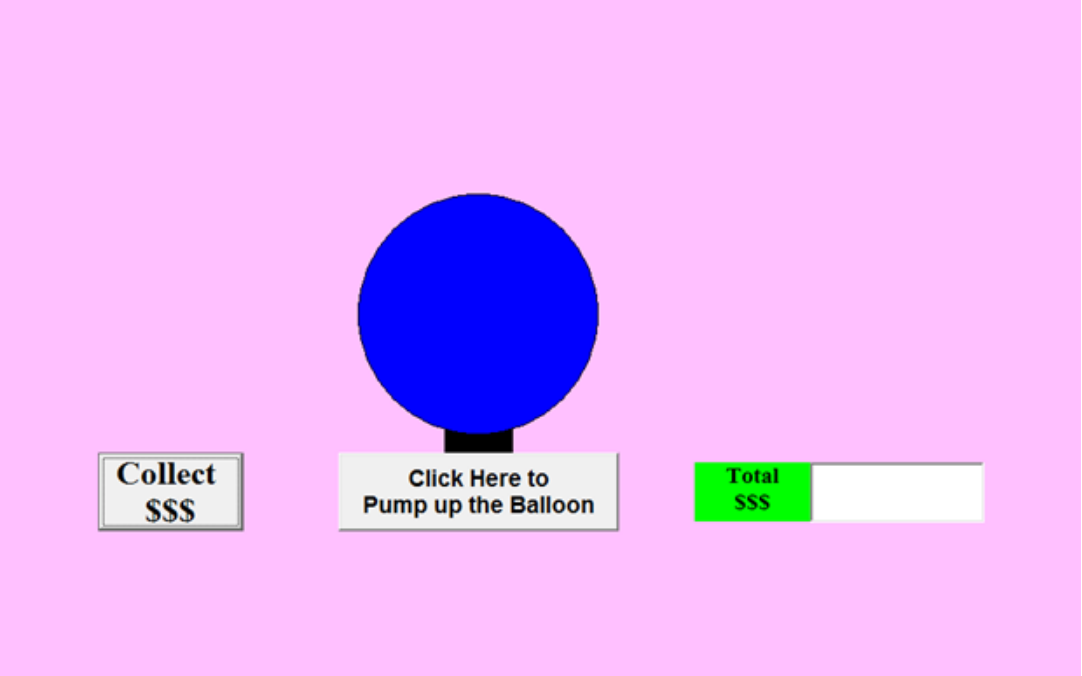
Appendix A2. **Domain specific risk taking (DOSPERT) perception questionnaire.**

For each of the following statements, please indicate your **likelihood** of engaging in each activity or behavior. Provide **tick** the appropriate box, using the scale to the left:

Extremely Unlikely	Moderately Unlikely	Somewhat Unlikely	Not Sure	Somewhat Likely	Moderately Likely	Extremely Likely	
							Admitting that your tastes are different from those of a friend. (S)
							Going camping in the wilderness. (R)
							Betting a day's income at the horse races. (F)
							Investing 10% of your annual income in a moderate growth mutual fund. (F)
							Drinking heavily at a social function. (H/S)
							Taking some questionable deductions on your income tax return. (E)
							Disagreeing with an authority figure on a major issue. (S)
							Betting a day's income at a high-stake poker game. (F)
							Having an affair with a married man/woman. (E)
							Passing off somebody else's work as your own. (E)
							Going down a ski run that is beyond your ability. (R)
							Investing 5% of your annual income in a very speculative stock. (F)
							Going white-water rafting at high water in the spring. (R)
							Betting a day's income on the outcome of a sporting event (F)
							Engaging in unprotected sex. (H/S)

Extremely Unlikely	Moderately Unlikely	Somewhat Unlikely	Not Sure	Somewhat Likely	Moderately Likely	Extremely Likely	
							Revealing a friend's secret to someone else. (E)
							Driving a car without wearing a seat belt. (H/S)
							Investing 10% of your annual income in a new business venture. (F)
							Taking a skydiving class. (R)
							Riding a motorcycle without a helmet. (H/S)
							Choosing a career that you truly enjoy over a more secure one. (S)
							Speaking your mind about an unpopular issue in a meeting at work. (S)
							Sunbathing without sunscreen. (H/S)
							Bungee jumping off a tall bridge. (R)
							Piloting a small plane. (R)
							Walking home alone at night in an unsafe area of town. (H/S)
							Moving to a city far away from your extended family. (S)
							Starting a new career in your mid-thirties. (S)
							Leaving your young children alone at home while running an errand. (E)
							Not returning a wallet you found that contains $200. (E)

Appendix A3. Domain specific risk taking (DOSPERT) propensity questionnaire.



Appendix A4. Screenshot of balloon analogue risk task (BART) interface.

rating	description
6	NO EXERTION AT ALL
7	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

Appendix A5. Ratings of perceived exertion (RPE) scale

Feeling Scale (FS)
(Hardy & Rejeski, 1989)

While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed this scale to measure such responses.

+5 Very good

+4

+3 Good

+2

+1 Fairly good

0 Neutral

-1 Fairly bad

-2

-3 Bad

-4

-5 Very bad

Appendix A6. Feeling scale.