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Attentional differences as a function of rock climbing performance

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ABSTRACT

The purpose of this study was to investigate the relationship between attention (using two different attention task) and self-reported climbing ability whilst considering potential confounding factors [sex, age, climbing experience and cardiorespiratory fitness (CRF)] in a group of experienced climbers. Accuracy of response (AC) and reaction time (RT) from two different attention tasks using the Vienna Test System, along with self-reported on-sight and red-point climbing ability, were assessed in thirty-five climbers. Linear regression revealed that climbers with the highest self-reported on-sight grade had better AC during the attention task. Linear regression models revealed, after controlling for potential confounders, that AC, measured using two attention tasks, was positively related to climbers' highest self-reported on-sight climbing ability (β : 0.388; p : 0.031). No significant differences were found between AC and self-reported red-point climbing ability (β : 0.286; p : 0.064). No significant relationship was found between RT and climbing ability (β : -0.102 to 0.020; p : 0.064). In conclusion, higher level rock climbers appear to have an enhanced attention which is related to on-sight lead climbing style, and thus it may be an important component of climbing performance. Coaches should consider incorporating techniques to train attention based on on-sight climbing style in climbers.

INTRODUCTION

Attention is a central feature of all perceptual and cognitive functioning (Chun et al., 2011), which allows for the selection and processing of information (Kahneman, 1973; Lavie, 2005). Attention is comprised of three distinct networks which are responsible for controlling different attentional functions, they are: orienting, alerting, and executive control (Posner, 2017). Orienting is primarily responsible for the ability to prioritize sensory input by selecting a modality. Alerting serves to produce and maintain optimal levels of arousal and performance, a necessary pre-requisite for other attention functions (Peterson & Posner, 2012). Finally, executive control is responsible for directing attention to relevant and useful information, away from irrelevant information, and also for inhibiting extraneous stimuli (Roderer, Krebs, Schmid, & Roebers, 2012).

Collectively these systems can be overloaded when individuals attempt to multitask and divide their attentional capacity between information selection and deciding on action strategies. Consequently it is unsurprising that in sport, attention appears to be related to sport practice (Heppe, Kohler, Fleddermann, & Zentgraf, 2016; Kioumourtzoglou, Kourtessis, Michalopoulou, & Derri, 1998; Meng, Yao, Chang, & Chen, 2019; Qiu et al., 2018; Sanchez-Lopez, Silva-Pereyra, & Fernandez, 2016; Williams & Davids, 1998). This has been shown to be the case in sports such as martial arts (Sanchez-Lopez et al., 2016), basketball (Qiu et al., 2018), soccer (Heppe et al., 2016) and volleyball (Kioumourtzoglou et al., 1998). However, the differences in attention responses seem to depend on the influence of a variety of information processing demands associated with each sport's modality (Singer, 2000; Voss et al., 2010).

Specifically in climbing, several authors have studied attention and climbing performance (Bourdin et al., 1998; Green & Helton, 2011; Nieuwenhuys et al., 2008; Young, 2011; Green et al., 2014). It has been suggested that climbing performance could be associated to attentional control (Young, 2011) which is associated with postural control and the climbing route difficulty (Bourdin et al., 1998). Young (2011) demonstrated that whilst ascending, climbers who were distracted (via cognitive interference) by a task that necessitated a heightened degree of attention, performed significantly worse (i.e., in terms of increased climbing time) than non-distracted climbers. Similarly, the effect of attentional interference on climbing performance was demonstrated by Green & Helton, (2011). The authors suggested that when climbers use their attentional resources in a task other than climbing (i.e. a memory task), climbing efficiency and distance ascended decreased. It has also been shown that attentional demands increase with the difficulty of a climbing task, which further affects climbing efficiency (Bourdin et al., 1998). Despite the literature describing the influence of attention on different aspects of climbing performance, to date, data investigating the relationship between attention and climbing performance, remains limited. Given the psychophysiological demands of rock climbing ability (Giles et al., 2014) which encompass physical and tactical elements combined with complex psychological traits such as a high self-confidence and low trait anxiety (Aras & Ewert, 2016), this lack of research seems unusual.

As rock climbing ability has previously been associated with a high cardiorespiratory fitness (CRF) (Aras & Ewert, 2016) and this is known to be related to attention

(Colcombe & Kramer, 2003; Kramer & Colcombe, 2018), it may be that CRF also has some influence on climbers attentional performance. Greater CRF appears to be associated with a better cognitive function which is related to an increased ability of the heart to deliver oxygenated blood to cerebral structures (Colcombe & Kramer, 2003), cerebral blood flow (Brown et al., 2010), and a brain-derived neurotrophic factor (Vaynman, Ying, & Gomez-Pinilla, 2003). Luque-Casado et al., (2016) suggested that there is likely to be a relationship between CRF and sustained attention in sports performance. Those authors observed that cyclists and triathletes with higher CRF had shorter reaction times (RT) than those with a lower CRF during a sustained attention task. Further, it has also been proposed that non-athletes with a high CRF may have a better ability to allocate attentional resources over time compared to non-athletes with a low CRF during a sustained attention task (Ciria, Perakakis, Luque-Casado, Morato, & Sanabria, 2017). Further, Sanabria et al., (2019) speculated that the relationship between CRF and sustained attention may be dependent on the type of sport being conducted. Given that rock climbing has been shown to independently have both a high CRF (Fryer et al, 2017), and a high attention demand (Green & Helton, 2011; Bourdin et al., 1998), CRF may be a physiological mediator that could at least in-part explain on-sight and red-point ability. To our knowledge, the relationship between ability level (on-sight and red-point), CRF and attention in rock climbers has not yet been studied. Therefore, the main purpose of the present study was to investigate the relationship between attention (using two different attention task) and self-reported climbing ability taking into account potential confounding factors (sex, age, climbing experience and CRF) in a group of experienced climbers.

MATERIALS AND METHODS

Participants

Thirty-five sports climbers (10 women), mean aged 34.7 ± 6.2 years, volunteered to take part in the study. All participants were healthy, non-smokers, and were not taking any vascular acting medication. Participants were asked not to consume food for 4 hours prior to testing and to avoid caffeine and exercise for a minimum of 12 hours. All testing sessions were conducted in the same week, in an environmentally controlled exercise laboratory. Participants read and signed the informed consent prior to participation in the study. The study protocol was approved by the Institutional Review Committee for Research Involving Human Subjects prior to recruitment; data collection was performed in accordance with the ethical standards set by the journal and the Declaration of Helsinki. Data from this study comes from the High-Performance International Rock-Climbing Research Group (C-HIPPER).

Procedure, Apparatus and Materials

Participants visited the laboratory once. During the visit, each participant completed forms for the determination of informed consent, health history, and demographic data. Detailed information on climbing experience (years), frequency (days per week) and self-reported rock climbing ability were recorded. Two attention tasks (Signal Detection and Determination Tasks) were administered (counterbalanced) with a 30-minute break

between each, using a laptop (15-inch; 1366x768 colour screen) running the Vienna Test System software version 26.04 (Schuhfried, Austria). In addition, participants completed an incremental treadmill cardiorespiratory exercise test to determine CRF.

Self-Reported Climbing Ability

Rock climbing ability is most commonly expressed in terms of the best ascent of a route within the last 6-12 months. Routes are ascended as either on-sight (no prior knowledge or visual route inspection requiring a screening to find new holds) or red-point (pre-practiced where the athlete remember the location of each holds and the movement required). Climbing ability was reported as the best grade achieved 6 months prior to the study. Self-report has been used for on-sight and red-point performance extensively within the literature (Baláš et al., 2017; Fryer et al., 2017; Zarattini et al., 2018). It is been shown to be a valid assessment of on-sight ability level (Draper et al., 2011). Climbers had a best 6-month on-sight ability ranging from 6a+ to 8a+ and from 6b to 8b+ for the best 6-month red-point ability based on the French grading system. In brief, this system is based on a scale of integers ranging from 4 (very easy) upward to 9 (very difficult) with letter subdivision of a, a+, b, b+, and c, c+ from 6a to upwards. In accordance with the Position Statement by the International Rock Climbing Research Association (IRCRA) (Draper et al., 2016), performance grades were converted from French Sport to specific numerical values (IRCRA grades) to enable calculations and statistical analyses. IRCRA scale range between 1(very easy) to 32 (very difficult), for reporting climber ability (Draper et al., 2011, 2016). Climbers had a best 6-month on-sight ability ranging from 12 to 24 and red-point from 13 to 26 based on the IRCRA scale (see Table 1).

Table 1 Mean (SD) of the anthropometric, demographic, physical fitness and performance data in the care tasks of the participants of this study.

	All (n=35)	Male (n=25)	Female (n=10)
Age (yrs)	34.7 (6.2)	33.5 (6.5)	37.9 (4.2)*
Mass (kg)	64.5 (8.6)	68.3 (6.7)	55.2 (5)+
Height (cm)	171.5 (8)	173.7 (8)	166 (4.9)+
Experience (years)	11.1 (7)	11.5 (7.6)	10.1 (5.7)
Self-reported climbing ability			
Best 6-month on-sight grade (French)	7a (3)	7a+ (2.9)	6b+ (1.6)*
Best 6-month red-point grade (French)	7a+ (3.6)	7b (3.7)	6c+ (1.6)*
Treadmill measures			
Cardiorespiratory fitness (mL·kg·min ⁻¹)	48.6 (5.3)	50.7 (4.9)	45.1 (4.6)*
Heart rate (bpm)	186.4 (10.5)	188.0 (10.9)	182.6 (8.9)

*P<0.05; +P<0.001

Attention Tasks

Signal Detection Task

The Signal Detection Task (SIGNAL, 26.04 versions, Vienna Test System) was used to evaluate the accuracy of participants response (AC) to a visual scanning and selective attention (Chong & Ong, 2015). This task was characterised by the presentation of an infrequent and unexpected target among frequent non-target stimuli (distractors) for a relatively long period of time, requiring participants to be precise in order to detect the objective stimulus between the distractors. Specifically, during the SIGNAL task, white dots pseudo-randomly disappear and appear on a black background. Participants were instructed to press the indicated key with the index finger of their dominant hand each time they detected a programmed stimulus constellation, created by four points that formed a square (see Figure 1 for illustration of technical terms). Climbers used headphones while performing the tasks to reduce distraction because of background noise.

The SIGNAL task had a total duration of 840 sec (including the instruction and practice phases). The main practice phase had 1000 points changes with a total of 60 stimuli constellations being this task just an only trial. The number of correct responses on time

as a measure of AC in the execution of the task was collected in percentage for the final analysis.

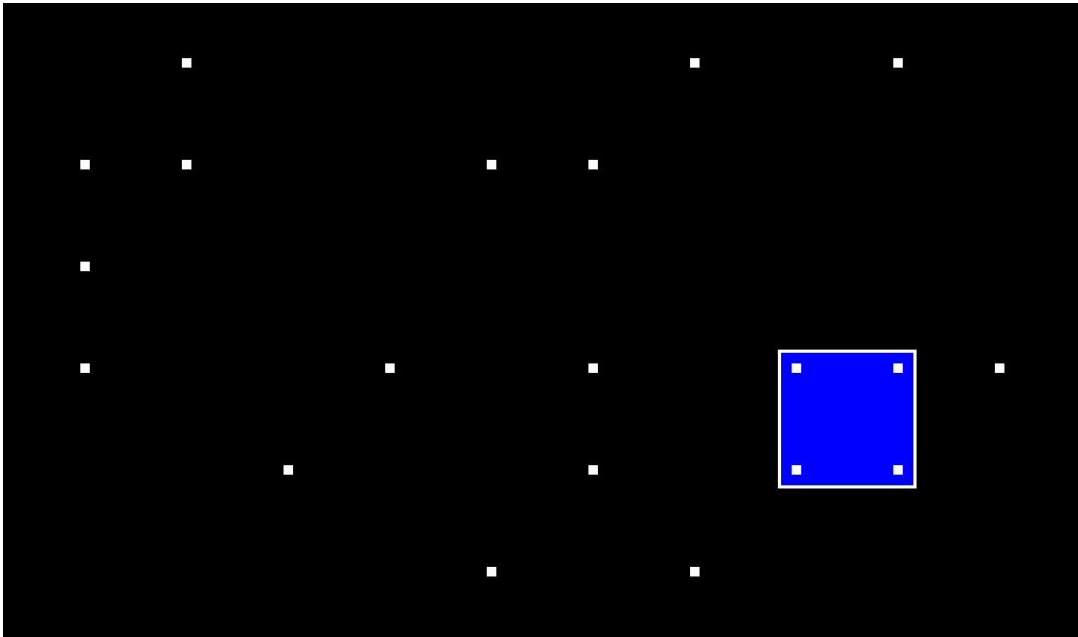


Figure 1 Form S1: Standard (white dots on black background) from Vienna Test System.

Determination Task

A modified version of the S12 Determination Task (DT, 32.00 version, Vienna Test Systems) was used to measure the speed of motor response, also called reaction time (RT) (Schuhfried, 2004)(Chong & Ong, 2015). This task was characterised by different temporal uncertainty of stimuli presentations. Specifically, the DT task displayed ten black-bordered white squares on a white background, arrayed in two horizontal rows of five. Each trial consisted of a square being temporarily filled with one of five different colours: namely black, blue, green, yellow, or red; which appeared in one of ten different locations (five in an upper row and five in a lower row). Participants were required to quickly press the corresponding coloured button, using the dominant hand, to score a correct answer (see Figure 2 for illustration of appearance terms).

Regardless of the speed of participant response, the coloured square would remain constant for 1250 ms before being superseded by the next trial, with a different random square now coloured and another participant response required. The DT task had a total duration of 950 sec (including the familiarization and instruction phases).

Familiarisation phases were 300 sec long and consisted of 20 stimuli. The instruction phase with a duration of 650 sec consisted of three different trials with a total of 540 stimuli (79 white, 74 yellow, 78 red, 78 green, 74 blue). Each trial had 180 stimuli with a durations of 1582 msec, 948 msec and 1078 msec for the first, second and third trial respectively. The same random sequence of stimulus presentation was used for all

participants (see Appendix 1). Speed response as a measure of RT in the execution of the task (msec) was collected from each condition for final data analysis.

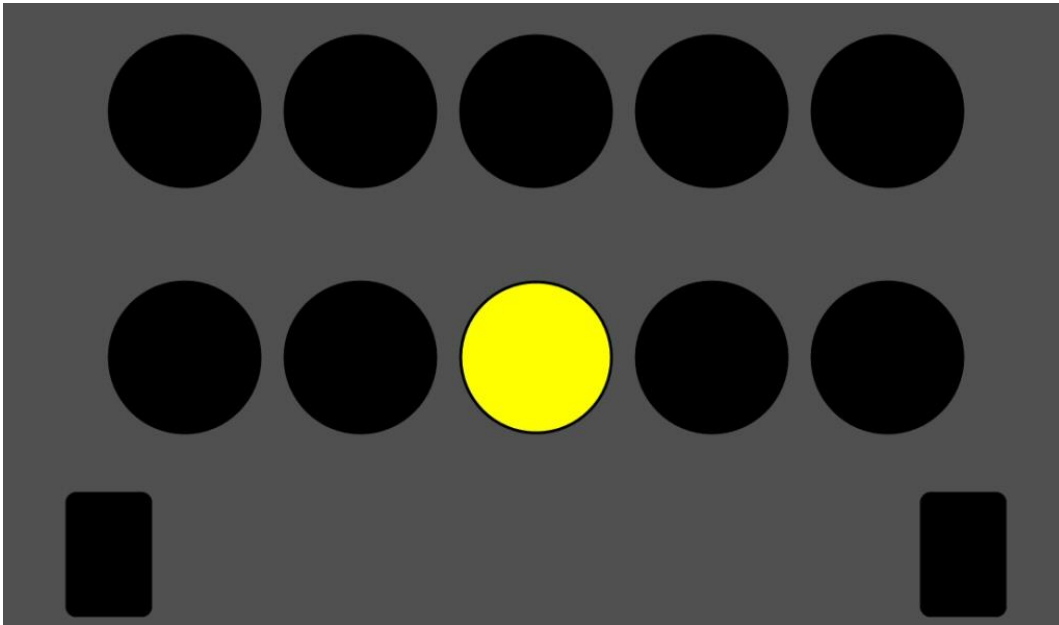


Figure 2 Form S12 with the presence of only one type of stimulus (colours) from Vienna Test System.

Cardiorespiratory Fitness

CRF was assessed by an incremental treadmill cardiorespiratory exercise test using the athlete led protocol (Draper & Marshall, 2014). Oxygen uptake was measured using a portable breath-by-breath expired air analyser (K4b²Cosmed, Rome, Italy) weighing 1.5kg. Data were transferred continuously via telemetry to a portable laptop. Breath-by-breath data were recorded continuously pre, during and post 5 minutes running. Breath-by-breath data were averaged over 10s intervals and exported to Excel and STATA for final data analysis. Heart rate and time to exhaustion were also collected.

Statistical analyses

All data were found to be normally distributed by Shapiro Wilk and had equal variances. Participant characteristics are presented as mean and standard deviation (SD) for continuous variables and frequencies for categorical variables. Potential sex differences for each dependent variable were analyzed by *t*-test for continuous variables and chi-square tests for categorical variables. Pearson correlations was used to examine relationship between attention tasks and descriptive climbing parameters. The Mallows Cp (Mallows, 1973) statistic regression model was used to find the optimum descriptive variables for the forecasting of attention tasks and climbing ability. Linear regression was performed to examine the association between climbing ability (on-sight or red-

point) and attention task (AC or RT). In addition to the performance, covariates were included in the regression analyses. Specifically, three levels of adjustment were used. Model 1 unadjusted, Model 2 adjusted for sex, age and climbing experience (years climbing) and Model 3 adjusted for sex, age, climbing experience (years climbing) and CRF (Cp Mallow: 3.38). Collinearity among the exposures was checked, and multicollinearity was not found in any of the models used. For all, the variance inflation factor was below 10 and averaged variance inflation factor was close to 1 (Myers, 1990). It is important to highlight that two of the participants (both male), were excluded from just the RT (not AC) analyses because they were colour blind. Statistical analyses were performed using STATA version 14.0 (Stata Corp, College Station, TX, USA). Statistical significance was set at $P < 0.05$.

RESULTS

Participant characteristics are shown in Table 1. Males were younger, heavier, and taller than females ($P < 0.05$). Moreover, males had a higher on-sight and red-point climbing ability with a greater CRF compared to females ($P < 0.001$ in all cases). Mean climbing experience was similar in both sexes.

Mean AC and RT measures in the attention tasks for all participants are presented in Table 2. No significant differences were found between male and female participants for any attention tasks, i.e., SIGNAL and DT.

The relationship between AC and self-reported on-sight climbing ability is shown in Table 3. Full linear regression model analysis revealed that AC (measured by SIGNAL detection task), was positively related with the highest self-reported on-sight ability (β : 0.388; p : 0.031). However, there was no significant relationship between AC and self-reported red-point ability (β : 0.286; p : 0.064) (See Table 4).

Table 2 Mean (SD) Attention tasks [accuracy of response (AC) and reaction time (RT)] for all participants and by sex.

	All (N=35)	Male (N=25)	Female (N=10)
Accuracy of response (%)	87.6 (6.1)	88.8 (5.7)	84.8 (6.1)
Reaction time (msec) ^a			
Trial 1	673.03 (50.59)	669.13 (56.4)	682 (34.58)
Trial 2	657.88 (48.07)	650.87 (49.99)	674 (41.15)
Trial 3	665.15 (46.65)	660 (46.71)	677 (46.68)
Total	665.8 (43.6)	660 (46.8)	679 (33.5)

^aTwo daltonic participant were excluded from reaction time analyses, $n=33$ (23 males).

Table 3 Relationship between accuracy of response (AC; dependent variable) and self-reported on-sight climbing ability (independent variable) in 35 experienced climbers.

	β	P	R^2	$R^2 adj$
<i>Model 1</i>	0.371	0.028	0.134	0.112
<i>Model 2</i>	0.278	0.161	0.191	0.083
<i>Model 3</i>	0.388	0.031	0.343	0.225

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: sex, age, climbing experience (years) and $\bar{V}O_{2max}$. β = beta, regression equation; LCI= lower confidence interval (95%); UCI= upper confidence interval (95%).

Table 4 Relationship between accuracy of response (AC, dependent variable) and self-reported red-point climbing ability (independent variable) in 35 experienced climbers.

	β	P	R^2	$R^2 adj$
<i>Model 1</i>	0.308	0.072	0.095	0.067
<i>Model 2</i>	0.170	0.182	0.160	0.047
<i>Model 3</i>	0.286	0.064	0.298	0.172

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: sex, age, climbing experience (years) and $\bar{V}O_{2max}$. β = beta, regression equation.

The relationship between RT and self-reported on-sight and red-point ability is presented in Table 5 and 6. Linear regression analysis revealed that there were no significant relationships between RT and self-reported on-sight (β : -0.102 to 0.020; p: 0.304 to 0.680) or red-point ability (β : -0.089 to 0.007; p: 0.306 to 0.893).

Table 5 Relationship between reaction time (RT; dependent variable) and self-reported on-sight climbing ability (independent variable) in 33 experienced climbers.

RT	β	p	R^2	R^2_{adj}
Model 1				
Trial 1	-0.086	<i>0.632</i>	0.008	-0.025
Trial 2	-0.075	<i>0.680</i>	0.006	-0.027
Trial 3	-0.102	<i>0.570</i>	0.011	-0.021
Model 2				
Trial 1	-0.033	<i>0.304</i>	0.154	0.033
Trial 2	0.015	<i>0.388</i>	0.133	0.009
Trial 3	-0.033	<i>0.519</i>	0.106	-0.022
Model 3				
Trial 1	-0.029	<i>0.442</i>	0.155	-0.002
Trial 2	0.020	<i>0.535</i>	0.134	-0.026
Trial 3	-0.024	<i>0.645</i>	0.111	-0.053

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: age, climbing experience (years) and VO_{2max} ; β = beta, regression equation; RT: reaction time

Table 6 Relationship between reaction time (RT; dependent variable) and self-reported red-point climbing ability (independent variable) in 33 experienced climbers.

	β	p	R^2	R^2_{adj}
Model 1				
Trial 1	-0.024	0.893	0.001	-0.032
Trial 2	-0.051	0.780	0.003	-0.030
Trial 3	-0.089	0.621	0.008	-0.024
Model 2				
Trial 1	-0.017	0.306	0.153	0.032
Trial 2	0.007	0.389	0.133	0.009
Trial 3	-0.066	0.506	0.108	-0.019
Model 3				
Trial 1	-0.010	0.444	0.155	-0.003
Trial 2	0.014	0.536	0.134	-0.026
Trial 3	-0.052	0.637	0.113	-0.051

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: sex, age, climbing experience (years) and VO_{2max} ; β = beta, regression equation;

DISCUSSION

The current study is the first to assess the relationship between attention and self-reported climbing ability (on-sight and red-point) in rock climbers. Further, it is the first to assess how potential confounding factors may affect the predictive attention functioning. The results suggested that attention is significantly related to on-sight but not red-point climbing ability.

Greater levels of attention in higher ability climbers suggest two possibilities. Firstly, there is a degree of self-selection, with the higher ability climbers' performance occurring because of naturally greater level of attention. Secondly, and more likely, is that higher ability climbers' develop better attention, through repeated practice of the climbing task that requires them to detect the hand and footholds when they climb on-sight, as suggested by the "cognitive abilities hypothesis". This hypothesis focuses on the direct relationship between sport practice and the cognitive abilities which could be associated to the interaction between the athlete and their specialized environment (Mann, Williams, Ward, & Janelle, 2007; Singer, 2000). The hypothesis suggests that if volitional and repeated practice is the driving force behind mechanisms of brain plasticity (Debarnot, Sperduti, Di Rienzo, & Guillot, 2014), then sport type may be also a potential moderator of the sport-cognition relationship (Voss et al., 2010, Fetz, 2007).

As such, different sports appear to have different influences on cognitive functioning. For instance, Lum et al., (2002) observed that athletes from externally-paced sports (i.e. soccer) were better at voluntarily orienting attention to locations where useful information was. Whereas athletes from self-paced sports (i.e. Swimming) and/or non-athletes were not as good at voluntary orientating attention. This may in part explain why dynamic sports place a high premium on voluntary allocation of spatial attention. Kioumourtoglou et al., (1998) analysed perceptual speed, prediction, selective attention, decision-making, focused attention, estimation of speed and direction of a moving object, visual reaction time and spatial orientation between experts and novice basketball, volleyball, and water-polo players. The authors found that expert basketball players had better selective attention compared to novices. In addition, expert volleyball players had better focused attention, prediction, and estimation of speed and direction of a moving object compared to novices. Lastly, water-polo players had significantly better decision-making, visual reaction time, and spatial orientation than novices. As such, in the current study the "cognitive abilities hypothesis" may in part explain why a better attention in higher level climbers could be associated with the characteristics of a difficult routed (i.e. small holds are more difficult to find).

Analyses, shown in Tables 5 and 6, revealed that there was no relationship between RT and either on-sight or red-point ability. The absence of a relationship between RT and ability, together with the differences found in AC, is consistent with the findings of Wang et al., (2013). Here the authors suggest that differences in the execution of tasks and attention may be found depending on the nature of sport, i.e. whether it is self- or externally-paced. The absence of differences in RT measures between ability groups could indicate the type of perceptual-cognitive abilities required when climbing. The self-paced nature of climbing means that the athletes' performance is less influenced by temporal pressure and more by the accuracy of the response. However, it is also possible that an expert performance would be characterized by a more strategic and adapted allocation of the attentional resources (Bourdin et al., 1998). Future research should investigate this using a sample encompassing athletes with a range of different abilities from a variety of sports. This would help to clarify the potential differences between ability levels and types of sport (self-paced vs. externally-paced).

Previous research investigating the relationship between fitness and performance in attention tasks (Ciria et al., 2017; Luque-Casado et al., 2016) suggested that CRF was an important mediator. However, our results do not support such relationship. This divergent finding may be because previous research used different attention tasks and have compared sedentary participants with trained athletes, whereas the present study used only trained athletes albeit with different ability levels. In addition, the importance of CRF and attention has been investigated in sports where CFR is the primary factor for performance, such as triathlon and cycling. However, our data provides evidence in favour of the "hypothesis of cognitive abilities" associated with the interaction between the athlete and their specialized environment (Singer, 2000).

Climbing is a sport that demands attention to progress along the path without falls or failures and without attending to factors external to the task (e.g., risk to fall) which could affect performance. These performance advantages in AC on the attention task

could explain why better climbers are less affected by anxiety when on-sight climbing, as previously reported by Draper et al (2011). Particularly given that anxiety results in part from the failure of the attention network (Ghassemzadeh, Rothbart, & Posner, 2019). As such, the stronger relationship between attention and on-sight climbing ability could also be explained by the absence of anxiety seen in advanced climbers (Fryer et al., 2013), and thus they may have an enhanced ability to focus on the physical movements. One possible explanation for this difference in the AC in the attention task could be the general training of climbers, since during climbing, long periods of attention (i.e., monitoring) are required for good performance (Bourdin et al., 1998). As suggested by Pijpers et al., (2006) emotional state (anxiety) affects the attentional control and realization of affordances, but the inverse may be also possible. In this sense, we hypothesised that climbers with better attention would be less affected by the negative effect of anxiety, by focussing only on the relevant aspects of a climbing task such as the hold type, or foot placement.

The current study did not reveal any relationships between attention and red-point climbing ability. This finding is likely explained by the different characteristics between red-point and on-sight types of climbing. While on-sight climbing requires visual inspection of the route to look for the best/next hold to keep ascending, a red-point ascent is defined by a climber's previous knowledge of the route, its holds and the movement sequences required, thus the attentional demands of red-point style are likely lower. The current study supports the idea that on-sight climbing requires greater attentional demand compared to red-point climbing and this may contribute to the development of better attention. This is an important finding that may indicate on-sight climbing style could have a considerable positive learning effect on attention, which could be an important component of competitive climbing performance. However, further research is needed to assess if this learning effect exists and whether it can be trained. As such, coaches and trainers should consider including strategies based on practicing on-sight climbing styles instead of the red-point climbing style.

The findings of the current study may help explain why better climbers are less affected by anxiety during an on-sight ascent as seen in previous studies, e.g. Draper et al., (2011). Further, the greater the attention accuracy in better climbers, could imply a better climbing efficiency or perceptual motor-performance (efficient exploration and decrease in the number of typical exploratory movements) (Orth et al., 2017). This could be very important for competitive climbing, given that international competitions use on-sight climbing, and a grade of 0.4 (IRCRA) separated the top four competitors in the 2015 International Federation Sport Climbing World Cup (Fryer et al., 2016). We have reported a larger association than a grade between attention and on-sight climbing ability. This is another key finding that could suggest that attention or attentional demands may be an important aspect of competitive rock-climbing performance. However, the small R^2 (0.14 and 0.32) still supports the concept that climbing performance is a multi-factorial sport. As such there are likely to be other cognitive skills (working memory, inhibitory control, cognitive flexibility, reasoning, etc.) or attentional functions (alert, orienting or executive control) (Roca, García-Fernández, Castro, & Lupiáñez, 2018) that might explain large percentages of variance that we

have not measured in the current study. However, our finding is still important given that at the top level in climbing, marginal gains are key to success.

Whilst this research has presented important and unique findings, to fully contextualise the data, several limitations should be acknowledged. We performed power analyses on the multiple regression models presented in this study. For a level of significance of 0.05, with the current sample size, taking into account the R-squared of all the covariates in the model and the number of covariates, we observed a power of 64.9% to 84.8% for the main models. The experimental design allows us to reveal how the variables are related, but it does not allow us to detect possible cause-effect relationships. In addition, this study does not allow us to determine whether there are any differences between climbers and non-climbers. Given these points, future research should 1) increase the sample size, 2) conduct an intervention to confirm whether improving the ability of a climber actually improves execution in attention or even knowing whether climber with better attention is less affected by anxiety, and finally 4) to study possible differences in attention as consequence of climbing training between climbers and non-climbers.

CONCLUSION

In summary, our results suggest that after controlling for potential confounding factors (sex, age, climbing experience and cardiorespiratory fitness), attention measured objectively is positively related to on-sight, but not red-point climbing ability. This may be explained by the different ascent characteristics- in particular the greater attentional demands of on-sight lead climbing may be due to the lack of information regarding the route. The lack of association between reaction time and climbing performance may be due to the self-paced nature of the sport, as little external temporal demand placed on the athlete. Rock climbers and their coaches should consider attentional training for on-sight climbing performance in order to increase or maintain climbing ability.

AUTHOR CONTRIBUTIONS STATEMENT

IGP wrote the first draft of the manuscript. All authors conceived and designed the study and contributed to manuscript developing and writing until manuscript was submitted in its final version.

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