

Research article

A COMPARISON OF THE EFFECTS OF FATIGUE ON SUBJECTIVE AND OBJECTIVE ASSESSMENT OF SITUATION AWARENESS IN CYCLING

Wade L. Knez^{1,2} ✉ and Daniel J. Ham¹

¹The University of Ballarat, School of Human Movement and Sport Sciences, Mt. Helen, Victoria, Australia.

²James Cook University, Institute of Sport and Exercise Science, Cairns, Queensland, Australia.

Received: 20 July 2005 / Accepted: 25 January 2006 / Published (online): 01 March 2006

ABSTRACT

Maximal effort on a 30 km Time Trial (TT₃₀) was examined to assess whether it would elicit changes in objective and subjective tests of the participants' perception of the environment and their ability to anticipate future occurrences (situation awareness; SA) and to determine the effect of post-exercise recovery on SA. Nine experienced (5.22 ± 2.77 years) road cyclists had their objective and subjective levels of SA assessed prior to and at the completion of two TT₃₀. The participants' results were compared to measurements of maximal oxygen uptake (VO₂max), peak power output (PPO), age and years of competitive cycle racing experience. Fatigue resulting from maximal effort on a TT₃₀ produced significant changes in both the objective and subjective test of SA. Effect sizes of 0.93 and 0.99 indicated that the first and second TT₃₀ were likely or almost certain to have a beneficial effect on the objective assessment of SA. However, the effect sizes of 0.97 and 0.95 relating to the subjective assessment of cognitive performance on the first and second TT₃₀ showed that it was very likely the participants' had an increased difficulty in maintaining SA. A recovery period of up to three minutes post TT₃₀ had no effect on SA. Changes in SA had no relationship with measurements of VO₂max, peak power output (PPO), age and years of competitive cycle racing experience. The findings suggest that within a laboratory environment, participants consistently underestimate their ability to make accurate assessments of their cycling environment compared to objective measures of their SA.

KEY WORDS: Endurance, cognition, psychophysiology, exhaustive exercise.

INTRODUCTION

One day cycling classics or multi-stage cycling races can be won and lost by correct and timely decisions made in a fatigued state. Indeed, the Tour de France has been described as a three week long chess game and has been won by margins as small as eight seconds. The ability to make accurate and decisive assessments of the environment in order to make a decision about a future occurrence is fundamental in road cycling for both performance and safety. Research has shown that fatigue can impair

cognition (Aks, 1998; Allard et al., 1989; Cian et al., 2001; Isaacs and Pohlman, 1991; Wrisberg and Herbert, 1976) and it is important that individuals minimize the potential for injuries whilst maintaining optimal awareness and performance. This study sought to use both psychology and physiology to investigate whether cycling-induced fatigue has an affect on both objective and subjective situation awareness (SA).

Situation awareness

Endsley (1988) defines SA as the "perception of elements in the environment within a volume of time

and space, the comprehension of their meaning and projection of their status in the near future". SA encompasses three formal processing components. Level one relates to the individual's perception of the importance and the characteristics of elements within the environment. Level two requires the individual to process the information from level one in order to develop a picture of the current situation in the present environment. Level three requires the individual to anticipate the actions of those components in level two. The third level of the SA appears to be the most crucial in the development of SA as it requires prior knowledge or experience of those elements in the environment in order to project an accurate future status (Endsley and Jones, 1997). Indeed, human beings have a limited capacity for taking in and processing environmental information (Cowan, 2001). Therefore, it is logical to expect that factors reducing our ability to process and retain information will affect SA.

Factors affecting SA

Research has identified a number of factors that can limit or disrupt the chain of events leading to a decrease in SA. These include both physiological and psychological elements such as fatigue, boredom, time pressure and anxiety (Hockey, 1986; Sharit and Salvendy, 1982). Indeed, small amounts of stress can actually have a beneficial effect but further increases can limit an individual's SA (Hockey, 1986; Janelle et al., 1999; Williams and Elliot, 1999). Easterbrooks' (1959) cue utilisation hypothesis explains this situation by suggesting that at low levels of arousal the athlete will notice both relevant and irrelevant cues but as arousal increases, the athlete will narrow his/her focus so that irrelevant information will be excluded while maintaining focus on relevant cues. If arousal levels increase above the athlete's optimum level, attention can narrow further, excluding even relevant information or it may result in distractibility with the athlete shifting their focus randomly between relevant and irrelevant cues. Consistent with this are the somatic and cognitive components of the Multi-dimensional anxiety theory that has shown a negative linear relationship between cognitive anxiety and performance and an inverted-U shape relationship with somatic anxiety and performance.

Research gives an insight into the extent to which fatigue producing acute exercise bouts can affect an individual's SA. Aks (1998) using a visual search task whereby participants were required to make a rapid response as to the presence or absence of a target with a specific size, or size and colour to measure cognition and SA, reported an improvement in response time and accuracy following 10 minutes

of exercise. However, no information was provided on the participants' initial level of fitness or the participants' level of fatigue. Consequently, there is no reference point to which a magnitude of fatigue can be compared. In a similar study investigating the influence of exercise on visual attention, Allard et al. (1989) reported cycling for four minutes at a workload equivalent to 60% of the participants' VO_{2max} improved performance on timed visual search tasks requiring participants to identify single or conjoined features within a display containing varying numbers of items. However, VO_{2max} derived from heart rate on submaximal tests can result in a significant overestimation (Greive et al., 1995).

Others have shown that performance on visual search tasks is optimal when in a rested state (Meyers et al., 1969). Furthermore, a number of authors have reported no change in performance on visual cognition tasks requiring participants to locate the position of a target number or shape within a field (Bard and Fleury, 1978), or asked to report a single letter within a sequence of letters (Fleury et al., 1981). This ambiguity may be explained by the intensity/duration of the task itself and the level of fatigue produced by the task. Tomporowski (2003) reported that exercising up to 60 minutes facilitated information processing; however, exercising for longer periods compromised both information processing and memory. The author suggested that this decrease in cognition may have been due to dehydration. It is questionable whether duration and dehydration alone are the crucial determinants in the relationship between exercise and cognition, as a number of the aforementioned articles showed different cognitive effects depending on the intensity of exercise. Supporting this contention is research reporting an increase in the speed of vertical line matching task with increasing treadmill running speed (McGlynn et al., 1977). Therefore, in conducting SA research it is important to describe the acute bout of exercise and the degree to which it physically fatigues the individual.

Collectively considered, it appears that the effect of acute exercise on visual search tasks is ambiguous. Three possible explanations for the disparity in results are the intensity/duration of the exercise bout, the methodology used to assess SA and finally a failure to include an appropriate control conditions that permit the isolation of the effects of physical activity on cognition.

Unfortunately, no published study was located that had attempted to consider the effect of fatigue on subjective feelings of SA. If SA is affected both by physiological and psychological stressors, then we hypothesise that both subjective and objective SA

will be similarly affected by fatigue. It is important to assess both subjective and objective elements to obtain an understanding of the athlete's sense of control. This may enable athletes to become more aware of their level of arousal and how it can negatively affect his or her performance. Furthermore, as a prerequisite for further research was to see whether this type of assessment tool could be used as a reliable tool to measure SA.

METHODS

Participants

Nine healthy male moderately-trained individuals were recruited for the present study. Participants were local A-grade cyclists, 26 ± 7 years of age (mean \pm SD), had a cycling VO_2max of 51.4 ± 5.4 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, a peak power output (PPO) of 327.5 ± 30.5 W and were cycling competitively for 5.22 ± 2.77 years. Each participant completed a medical and training history and a lifestyle evaluation questionnaire, and was excluded if they had been told they had any type of cardiovascular illness. All risks and benefits of participation in the study were thoroughly explained to the volunteers; each participant provided informed consent and the investigation was approved by the Medical Research Ethics Committee of The University of Ballarat.

Experimental overview

Upon reporting to the laboratory for testing (22°C , 40% RH and 720-730 mmHg) participants completed a progressive exercise test that allowed the determination of VO_2max and PPO. No less than 48 hours after completing the progressive exercise test, participants completed a TT_{30} . Participants also completed the subjective and objective assessments of SA prior to and after the TT_{30} ; this TT_{30} and the associated SA assessments were considered a familiarisation. The TT_{30} and SA assessments were then repeated twice (performed one week apart) in the following two weeks: each test was performed at the same time of day.

Maximal tests

Progressive exercise test (VO_2max)

VO_2max and PPO were determined on an electronically braked cycle ergometer (Veletron, Elite, RacerMate Inc, USA) modified with participants' own clip-in pedals. Handle bar and saddle positions of the cycling ergometer were altered to replicate participant's own cycling position for the test. The participants warmed-up for five minutes at a self selected workload and cadence. The incremental test began with an initial workload 100 watts that increased by 30 watts every three

minutes until volitional exhaustion or the participant was unable to maintain a cadence of ≥ 60 rpm. Although power on an electronically braked cycle ergometer is maintained independent of cadence, participants were asked to cycle their typical cadence (approximately $90 \text{ rev}\cdot\text{min}^{-1}$ during maximal testing in an effort to minimise variations in mechanical efficiency. VO_2max was recorded as a mean of the two highest VO_2 values attained during the incremental test. PPO was defined as the final completed work load the participant achieved. Inspired volume was calibrated and verified prior to each test using a three-liter syringe in accordance with the manufacturer's instructions. Expired O_2 and CO_2 concentrations were measured using electronic gas analysers (SensorMedics, Vmax series 29), that were calibrated prior to each test with known gas concentrations.

Laboratory simulated 30 km time-trial (TT_{30})

The laboratory simulated $\text{TT}_{30\text{s}}$ were completed (Veletron, Elite, RacerMate Inc, USA) at a freely selected wattage and cadence. Participants were asked to refrain from any high-intensity or long duration training for 48 prior to each test. Participants were also asked to consume a high carbohydrate meal the night before testing, and to arrive in a euhydrated state. During the TT_{30} , feedback on distance was provided to participant; speed and time were blinded to the participant. Rating of perceived exhaustion (RPE, Borg, 1973) was assessed every five km of the $\text{TT}_{30\text{s}}$ and immediately upon completion of the test to obtain an appreciation of the level of exertion experienced at the conclusion of TT_{30} .

Situation awareness

Cognition Self Assessment tool (CSAT)

Two complementary approaches/tests were used to assess SA. The first was a Cognition Self Assessment tool (CSAT) comprising of direct subjective self-assessment questions about cognitive capacity, framed in contextual terms, which have face validity for the participants, with a response in the form of a mark drawn on a vertical scale of perceived cognitive capacity. This is conceptually related to the Participant Subjective Awareness Questionnaire (PSAQ). There are a number of advantages of using this type of assessment tool as it allows specific subjective information to be gathered in a controlled real world environment as well as during laboratory based assessments (Endsley, 1996). It also allows the assessment of the individual's own degree of self-confidence in SA (Endsley, 2000) subsequently, it can be used to identify a cyclist's specific areas of perceived

weakness. Moreover, it is inexpensive, easy to administer and minimises the level of intrusiveness (Endsley, 1996; Fracker and Vidulich, 1991; Taylor and Selcon, 1991). In the CSAT, the participant is asked: "In your current physical state, how difficult would it be for you to carry out the following: Judge distances between bikes; plan racing lines in and out of corners; anticipate breaks; develop race strategy; awareness of key competitors?" and instructed to place a horizontal mark indicating their perceived level of difficulty on a vertical line 150 mm long, ranging from "very easy" at the bottom to "very difficult" at the top. The recorded score is the distance from the top (very difficult), measured to the nearest 0.5 mm, and expressed as a percentage of the total length of the line (150mm). A high/low score thus represents high/low perceived cognitive function. The disadvantage of using subjective measures of SA is that the participants may not know what information they are unaware of. Moreover, participants can also be influenced by self-assessments of their performance (Endsley, 2000). However, in the present study participants were unaware of their performance outcome.

Random number cognition test (RANCT)

The second test (RANCT) was a quick, easy-to-administer test which directly measured cognitive performance of a more general non-specific nature and variants of this test are used quite extensively in sporting literature to objectively assess cognitive function. It involves the use of visual perception and detection tasks (Aks, 1998; Allard et al., 1989; Bard and Fleury, 1978; Fleury et al., 1981). These require the participant to rapidly scan word, letter or number patterns to successfully carry out search tasks. The advantage of this type of assessment is that it is objective in nature and therefore is not influenced by participants' perceived success in a performance test. Furthermore, like the CSAT this can be administered in a controlled real world environment or in a laboratory simulation, and could be used over time to systematically assess improvements in SA. Performance on visual search tasks such as these is based on the Feature Integration Theory (FIT) (Treisman and Gelade, 1980), which affirmed that in order to locate specific features within a field; attention is required in the scanning process in order to glue the sequence together. Using the RANCT participants are presented with a 6×6 square array containing the integers 1 to 36 in a random order. The aim is to cross out as many numbers as possible, in sequential order, starting at 1, 2, 3 etc., in a fixed time of 30 seconds. The score is the maximum number reached. *The scoring protocol is actually "the number reached minus one for every missing*

number in the sequence". This was designed to compensate for any advantage to be gained by crossing out numbers ahead of the point reached in the strict. Although not task specific, this test is easily and inexpensively administered.

Each test was administered once immediately before the commencement of the task, and three times immediately after completion, with a nominal 30 seconds being allowed for each. In practice, the CSAT test takes only a few seconds, whilst the RANCT takes the full 30 seconds. The remainder of each 60 second cycle was taken up with the mechanics of co-coordinating the activity.

Reliability

Prior knowledge is the crucial component in SA (Endsley and Jones, 1997), therefore as a necessary component of this investigation a reliability study of the CSAT and the RANCT was carried out on the participants to ascertain if indeed there was a learning effect. This reliability testing was conducted in a rested condition over six separate occasions/days separated by at least two days. Each participant was administered the three CSAT and RANCT tests on each occasion and these scores were compared with each other to ascertain test-retest reliability.

Statistical analysis

Paired t-tests and effect size calculations were used to examine changes in objective (RANCT) and subjective (CSAT) tests of SA pre to post the first and second TT₃₀. Time sequence effects for each measure (CSAT and RANCT) were analysed using a separate repeated measures analysis of variance (RMANOVA). Pearson's product moment correlation coefficients were used to examine possible relationships between resting CSAT and RANCT, as well as percentage changes in CSAT and RANCT with performance variables (VO₂max and PPO), age and years of cycling experience. Significance was set at the 0.05 level of confidence and all statistical analyses was completed on SPSS (version 12) software. The stability reliability of the Random Number Cognition test (RANCT) and Cognitive Self Assessment Tool (CSAT) were assessed to determine the consistency of the test scores across days, on the basis of the Cronbach's alpha coefficients and intra-class correlations (ICCs).

RESULTS

The first aim of this study was to compare changes in subjective and objective assessments of SA in

Table 1. Changes in SA scores pre- and post-exercise for each trial. Data are means (\pm SD).

		PRE	POST	Effect size	Chances (% and qualitative) of substantial improvement
RANCT	TT ₁	13.31 (2.96)	15.33 (3.54) *	.62	93.3; likely, probable
	TT ₂	12.25 (4.71)	17.25 (2.76) †	1.34	99.9; almost certain
CSAT (%)	TT ₁	21.62 (15.51)	41.67 (27.18) *	.94	97.3; very likely
	TT ₂	20.28 (14.40)	42.48 (31.28) *	.97	95.0; very likely

* and † $p < 0.05$ and $p < 0.001$ respectively, between pre- and post-time trail.

TT₁ = 30 km time trial 1; TT₂ = 30 km time trial 2.

response to TT₃₀. Analysis showed that the TT₃₀'s resulted in a significant increase in the objective assessments of SA. The effect sizes of 0.62 and 1.34 respectively showed that there was a 93.3% chance that TT₁ was beneficial and a 99.9% chance that TT₂ was almost certain to have a beneficial effect on SA. However, the subjective assessment indicated a significant increase in the participants' perceived difficulty to maintain SA and the effect sizes of 0.94 and 0.97 respectively indicated that there was a 97.3% and a 95.3% chance that the first and second TT₃₀'s were very likely to have an increase in the participants' perceived difficulty to maintain SA (Table 1). Despite these changes, there was no significant effect of time on either the RANCT or CSAT over the three post-TT₃₀ assessments of SA. Furthermore, there was no significant relation between the percentage change in the RANCT and CSAT and the years in competitive cycle racing, VO₂max, age or peak power output.

Table 2. Reliability scores for the RANCT and CSAT .

Test	Intraclass correlation coefficient	95% confidence limits for ICC
RANCT	.897	(.751, .976)
CSAT	.987	(.969, .996)

A secondary aim of this study was to assess the reliability of the RANCT and the CSAT used to measure SA. The results of the reliability testing showed that both the CSAT and the RANCT to have an extremely high reliability (Table 2). The high reliability of the CSAT indicates that, using this tool, the participants were able to give consistent and reliable reports of their perceived ability to carry out tasks indicative of their SA. The high reliability score of the RANCT indicates that this tool can achieve a consistent measure of the participant's visual perception and detection skills and cognitive function. Furthermore, participants reported no awareness of the similarity between the four variants of the RANCT, and no conscious recognition of

patterns. There was no evidence in the scores of individuals of any learning effect.

DISCUSSION

The principal aim of the present study was to examine whether a maximal effort on a TT₃₀ elicited changes in objective and subjective tests of SA and to assess whether changes in SA were related to cycling experience, VO₂max, PPO or age. A secondary aim was to determine whether there was a recovery effect on SA. A necessary component of this study was the evaluation of the reliability of the two tools chosen and used to assess SA in this modality and this sample group. Both the RANCT and CSAT were reliable tests that provided consistent measures of the participant's SA and perceived SA.

The major findings of the present study showed that a TT₃₀ does produce significant changes in both the objective and subjective test of SA. However, the subjective assessment of cognitive performance on the first and second TT₃₀ showed a significant increase in the self assessment of their difficulty to maintain SA, whilst the objective assessment showed a significant increase in their SA.

Situation awareness

The objective assessment of SA, the RANCT increased significantly from pre- to post- the first and second TT₃₀ ($p < 0.05$ and $p < 0.001$ respectively). This finding is consistent with previous research that showed an increase in visual search scores in a high-exertion exercise (Aks, 1998). However, it is inconsistent with those who reported performance on visual search tasks to be optimal when in a rested state (Meyers et al., 1969). The difference may be explained by the work completed by Yerkes and Dodson (1908), suggesting an inverted-U shaped relationship existed between arousal and cognition. Moreover, it was shown that the range over which performance improves with increasing arousal varies with task complexity. A

simple task needs a higher level of arousal than a more complex task to reach a maximal quality of performance. Increasing exertion during exercise is associated with increasing arousal and consequent changes in the central nervous system. Indeed, using Easterbrook's (1959) cue utilisation hypothesis, it would seem reasonable that although the participants' level of arousal or stress was high and perhaps not at an optimal level when they had completed the TT_{30's}, it must have still been at a level whereby the efficiency of cognition was higher than when they were at a resting level.

Interestingly, the present study showed an increase in the participant's perception of difficulty to maintain SA from pre- to post-TT₃₀ ($p < 0.05$) as measured by the CSAT, which is inconsistent with results from the objective assessment of SA. These researchers could not find any research that had investigated subjective self assessments of cognitive function in addition to objective assessments in a sporting setting, although self-assessment of exertion (RPE) is routinely used. However, tools such as the PSAQ have been used regularly in a military context (Matthews et al., 2000) to assess soldiers awareness of their surroundings but often the result of this type of research is difficult to obtain in a public domain and certainly little effort is made to define the level of physiological fatigue the soldiers experience.

The findings of the present study are interesting because it shows that under the conditions of this study, there was incongruence between what the participants perceived their ability would be and indeed what their ability was to maintain SA. This is important because maintaining awareness allows athletes to gain control of pressure situations and control can be a key issue as anxiety levels decrease with an increased sense of control (Ravizza, 2001). Although, the participants' perception of their fatigue/arousal did not negatively affect the objective assessment of SA, these types of tools can be important instruments in enabling athletes to become more aware of their arousal level, the contributing factors and how their appraisal of them can affect their perceptions of their ability to recognize key elements of their environment and make correct and timely decisions. Whilst it is difficult to transfer these findings to performance in a competitive environment, it provides an example of how the disciplines of psychology and physiology can be used in a complimentary way that is purposeful and in the future can be adapted to performance in a competitive environment.

None of the changes in SA from pre- to post-TT₃₀ could be explained by correlations between the percentage change in the RANCT and CSAT and the

years in competitive cycle racing, VO₂max, age or peak power output. Indeed, this was not unexpected given the low variation in the variables from the sample. Future studies should include a larger number of participants providing a larger variation in key variables.

Recovery effect

To our knowledge no study has ever assessed the effect of recovery on SA. In the present study, there was no change in RANCT or CSAT scores up to three minutes after the first or second TT₃₀ and TT₃₀. It would appear that this amount of time is insufficient to have any effect on SA after an exhaustive bout of exercise. Indeed, future studies should include a longer assessment time in the recovery period and also attempt to more adequately quantify recovery both physiologically and psychologically.

CONCLUSIONS

In summary the present study has shown that a TT₃₀ does produce significant changes in both the objective and subjective test of SA. However, the data showed a substantial underestimation in participant's ability to subjectively assess their own level of situation awareness. Although participants perceived an increased difficulty to remain SA in response to the TT₃₀ they did not feel that the recovery time was sufficient to have a positive effect on their awareness. This was supported by the objective assessment of SA which showed no changes over the recovery time.

Despite these conflicting results it appears that both tests are a reliable assessment of SA, however, further research considering both physiological and psychological factors is necessary to enable greater generalisation to a competitive environment. This research could include environmentally relevant stimuli and therefore assist in understanding how subjective assessments of fatigue and anxiety contribute to performance and how we can manipulate this sense to improve decision making, performance and recovery.

REFERENCES

- Aks, D.J. (1998) Influence of exercise on visual search: implications for mediating cognitive mechanisms. *Perceptual and Motor Skills* **87**, 771-783.
- Allard, F., Brawley, L.R., Deakin, J. and Elliot, F. (1989) The effect of exercise on visual attention performance. *Human Performance* **2**, 131-145.
- Bard, C. and Fleury, M. (1978) Influence of imposed metabolic fatigue on visual capacity components. *Perceptual and Motor Skills* **47**, 1283-1287.

- Borg G. (1973) Perceived exertion: a note on history and methods. *Medicine and Science in Sports* **5**, 90-93.
- Cian, C., Barraud, P.A., Melin, B. and Raphel, C. (2001) Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. *International Journal of Psychophysiology* **42**, 243-251.
- Cowan, N. (2001) The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *The Behavioral and Brain Sciences* **24**, 87-185.
- Easterbrook, J.A. (1959) The effect of emotion on cue utilization and the organization of behavior. *Psychological Review* **66**, 183-201.
- Endsley, M.R. (1988) Design and evaluation for situation awareness enhancement. *Human Factors Society 32nd Annual Meeting*, 97-101, Santa Monica, CA.
- Endsley, M.R. (1996) Situation awareness measurement in test and evaluation. In: *Handbook of human factors testing and evaluation*. Eds: O'Brien, T.G. and Charlton, S.G. Lawrence Erlbaum., Mahwah, NJ.
- Endsley, M.R. (2000) Direct measurement of situation awareness: Validity and use of SAGAT. In: *Situation awareness analysis and measurement*. Eds: Endsley, M.R. and Garland, D.J. Lawrence Erlbaum Associates, Mahwah, NJ.
- Endsley, M.R. and Jones, W.M. (1997) Situation awareness, information dominance and information warfare. (Tech Report 97-01). Belmont, MA: Endsley Consulting.
- Fleury, M., Bard, C., Jobin, J. and Carriere, L. (1981) Influence of different types of physical fatigue on a visual detection task. *Perceptual and Motor Skills* **53**, 723-730.
- Fracker, M.L. and Vidulich, M.A. (1991) Measurement of situation awareness: a brief review. *Designing for Everyone, Proceedings of the 11th Congress of the International Ergonomics Association*. (pp. 795-797). London: Taylor and Francis.
- Greive, J.S., Kaminsky, L.A., Whaley, M.H. and Dwyer, G.B. (1995) Evaluation of the ACSM submaximal ergometer test for estimating VO_2max . *Medicine and Science in Sports and Exercise* **27**, 1315-1320.
- Hockey, G.R.J. (1986) Changes in operator efficiency as a function of environmental stress, fatigue and circadian rhythms. In: *Handbook of perception and performance*. Eds: Kaufman, K.B.L. and Thomas, J. John Wiley, New York.
- Isaacs, L.D. and Pohlman, E.L. (1991) Effects of exercise intensity on an accompanying timing task. *Journal of Human Movement Studies* **20**, 123-131.
- Janelle, C.M., Singer, R.N. and Williams, A.M. (1999) External distraction and attentional narrowing: visual search evidence. *Journal of Sport and Exercise Psychology* **21**, 70-91.
- Matthews, M.D., Pleban, R.J., Endsley, M.R. and Strater, L.D. (2000) Measures of Infantry situation awareness for virtual mout environment. *Human Performance, Situation Awareness and Automation: User Centred Design for the New Millennium Conference*, 262-267, Savannah, GA.
- McGlynn, G.H., Laughlin, N.T. and Bender, V.L. (1977) Effect of strenuous to exhaustive exercise on a discriminatin task. *Perceptual and Motor Skills* **44**, 1139-1147.
- Meyers, C.R., Zimmerli, W., Farr, S.D. and Baschnagel, N.A. (1969) Effect of strenuous physical activity upon reaction time. *Research Quarterly* **40**, 332-337.
- Ravizza, K. (2001) Increasing awareness for sport performance. In: *Applied sport psychology: Personal growth to peak performance*. Ed: Williams, J.M. Mayfield Publishing Company, California. 179-189.
- Sharit, J. and Salvendy, G. (1982) Occupational stress: Review and reappraisal. *Human Factors* **24**, 129-162.
- Taylor, R.W. and Selcon, S.J. (1991) Subjective measurement of situational awareness. In *Designing for Everyone, Proceedings of the 11th Congress of the International Ergonomics Association*. (pp. 789-791). London: Taylor and Francis.
- Tompsonowski, P.D. (2003) Effects of acute bouts of exercise on cognition. *Acta Psychologica* **112**, 297-324.
- Treisman, A.M. and Gelade, G. (1980) A feature-integration theory of attention. *Cognitive Psychology* **12**, 97-136.
- Williams, A.M. and Elliot, D. (1999) Anxiety, expertise, and visual search strategy in karate. *Journal of Sport and Exercise Psychology* **21**, 362-375.
- Wrisberg, C.A. and Herbert, W.G. (1976) Fatigue effects on the timing performance of well-practiced subjects. *Research Quarterly* **47**, 839-844.
- Yerkes, R.M. and Dodson, J.D. (1908) The relationship of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology* **18**, 459-482.

KEY POINTS

- Exhaustive exercise from a TT_{30} produces significant changes in both subjective and objective SA.
- This study indicates that fatigued participants underestimate their ability to maintain SA.
- A time period of three minutes is not enough to observe a recovery effect on subjective or objective SA.
- Both the objective and subjective tests proved to be reliable assessments of SA.

AUTHORS BIOGRAPHY

Wade L. KNEZ**Employment**

Lecturer, Institute of Sport and Exercise Science, James Cook University, Australia.

Degree

PhD

Research interests

Physiological and psychological fatigue, overtraining and maladaptation, alternative recovery methods, endurance and ultra-endurance exercise and the psychological influence of physiological recovery.

E-mail: wade.knez@jcu.edu.au

Daniel HAM**Employment**

Defence Scientist, Health and Human Performance, Defence Science and Technology Organisation, Fisherman's Bend, Victoria, Australia.

Degree

BSc

Research interests

Applied exercise physiology and cycling.

E-mail: daniel.ham@dsto.defence.gov.au

✉ Dr. Wade L. Knez

Institute of Sport and Exercise Science, James Cook University, Cairns, Queensland, 4870, Australia.