Mitigation of the Impact of Cognitive Fatigue on Simple Motor Performance by Phytochemicals: The Effect of a Blackcurrant Supplement

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Abstract

Cognitive fatigue can be brought on by prolonged periods of demanding cognitive activity which has been found to impair both cognitive and physical performance. Phytochemical supplementation can result in improvements in both cognitive and physical performance. However, the ability for phytochemical supplementation to reduce the effects cognitive fatigue has on subsequent physical performance has not been investigated. Therefore, the present study examined the effects that phytochemicals from a blackcurrant supplement had in reducing the effects of cognitive fatigue on simple motor performance. Sixty healthy participants completed 75 minutes of a vigilance task (cognitive fatigue) or 75 minutes of watching an emotionally neutral documentary (control). Half of the participants in each condition also received a blackcurrant supplement (3.2mg/kg) 1 hour before beginning the experimental session. Following the 75 minutes of time-on-task participants completed mood and motivation questionnaires as well as four motor tasks. Analyses revealed the vigilance task was successful in inducing cognitive fatigue, but this had little effect on subsequent motor performance compared to controls. Further analyses revealed the blackcurrant supplement had little influence on either cognitive or motor performance, although the lack of an effect of cognitive fatigue on motor performance made this finding difficult to interpret. Effect size calculations indicated that a larger sample would have likely resulted in statistically significant findings for the majority of the motor tasks. It is concluded that for the specific tasks used in the present study, cognitive fatigue did not impair subsequent motor performance. Nor did the blackcurrant supplement, at the dose used, enhance motor performance following cognitive fatigue. Possible explanations for these findings are discussed and some potentially useful future studies outlined.

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Chapter 1: Background

The relationship between nutrition and human health and functioning has been of interest for a long time. Recently, attention has turned to the effects that specific nutrients have on both physical and mental performance (Maggini & Spitzer, 2013; Morin, 2011). Despite the complexities in studying these effects, the ability of specific foods to influence different aspects of cognitive and physical performance has been increasingly recognised (Chung et al., 2012; Dye, Lluch, & Blundell, 2000). The mechanisms through which these effects take place are slowly becoming understood. The majority of the research that has looked at the relationship between specific foods and performance has to date focussed on aging populations with a large proportion of the studies looking at the effects on neurodegenerative decline commonly seen in aging, and the influence of specific foods in reducing or even reversing such declines (Cantuti-Castelvetri, Shukitt-Hale, & Joseph, 2000; Shukitt-Hale, Carey, Simon, Mark, & Joseph, 2006; Shukitt-Hale, Cheng, & Joseph, 2009). The paucity of research on the effects that food supplementation may have on younger populations highlights the need for further research.

Foods that have been found to have properties that provide a positive impact on health, mental state, and physical performance are defined as functional foods (Rincón-León, 2003). Functional foods provide benefits to human functioning beyond the nutrients necessary for survival (Rincón-Leon, 2003). Importantly, the impact functional foods have on humans appear to be dose-dependent; therefore, more research is needed to determine the specific dose rates and the length of time of the supplementation necessary for different foods to have an effect (Rincón-León, 2003).

What functional foods, and specifically which properties of these foods, are beneficial in improving human functioning is at present unclear due to poor understanding of the biological mechanisms through which they act. The research that exists in the field has thus far only made links to potential mechanisms (Nozaki et al., 2009). Westenhoefer and colleagues (2004) suggest that functional foods may act by helping to maintain an optimal level of performance, by enhancing function, or by reducing the factors that lead to deficits in performance. The vast range of cognitive and motor domains to be tested under conditions of supplementation mean that the research is spread thin across the domains, with little research following up claims of earlier research (Macready et al., 2010).

Cognition and mental alertness are necessary for everyday functioning, and both have been shown to be influenced by nutritional factors, both positively and negatively. A number of food groups have been studied in relation to their effects on cognitive performance, with the effects of macronutrients being one of the most studied. Macronutrients can be divided into three groups: carbohydrates, proteins, and fats. When consumed they produce glucose, amino acids, and fatty acids, respectively (Dye et al., 2000). The results of these studies are mixed, but it is generally found that supplementation that increases blood glucose improves performance on cognitive tasks, particularly memory and reaction-time tasks, while a decline in blood glucose impairs performance. Also, carbohydrate-rich diets tend to result in performance decrements whereas protein-rich diets generally enhance cognitive performance (Dye & Blundell, 2002; Dye et al., 2000). Caffeine is another nutrient that has been widely studied in relation to its ability to improve cognitive performance (Lieberman, 2001). Caffeine is consistently found to improve mental alertness and therefore improve other aspects of cognition such as reaction time and vigilance as well as being found to enhance mood (Lieberman, 2001). It has been suggested that the effects nutrition has on cognitive performance are at least in part mediated by changes in mood and arousal (Gibson & Green, 2002). Therefore, when examining the effects of nutrition on cognitive performance, it is important to take mood into consideration.

Just as nutrition can influence cognitive performance, physical performance can also be affected. The energy required to perform physical activities comes from energy sources in the diet, such as carbohydrates and protein (Maggini & Spitzer, 2013). Therefore, reducing the intake of foods that are known to produce cellular energy is likely to result in the impairment of subsequent physical performance. It has been found that there are noticeable impairments in physical performance, particularly in endurance exercise and work capacity, when intake of vitamins and minerals is limited (Lukaski, 2004). Research has implicated deficiencies in numerous vitamins and minerals, such as magnesium, iron, and B12, in impairing physical performance by acting on muscle mechanisms and increasing the amount of oxygen needed to perform, thereby decreasing muscle endurance and capacity (Lukaski, 2004). Impairments in performance can be affected not just by long-term deficiencies but also by short-term dietary deficiencies with Chung et al. (2012) highlighting the positive effects of supplementation on late morning performance in children who miss breakfast. Lukaski (2004) suggests that while supplementation of the deficient nutrients can result in improvements in performance, supplementation will not have an effect on performance if there is no deficiency in the given nutrient. However, there are groups of micronutrients, such as phytochemicals, that are not needed for healthy human functioning. Therefore, supplementation of phytochemicals can have added benefits and improve functioning and performance beyond that of supplementing nutrients that are necessary for healthy functioning (Rincón-León, 2003).

This current research project is a small part of a larger research project being conducted by the New Zealand Institute of Plant and Food Research (PFR). The overall project is aimed at finding if phytochemical supplementation can affect physical performance and recovery. The purpose of the present research is to examine whether the phytochemical supplementation can ameliorate the effects that cognitive fatigue have on simple motor performance. The next phase of the project will be to look at the effects that a phytochemical supplement can have in improving cognitive performance following a physically fatiguing task. By looking at the effect phytochemical supplementation could have on both directions of the relationship between cognitive and physical performance will help to determine more specifically how the phytochemical is influencing performance and which elements of performance are more susceptible to being enhanced by the supplement.

This chapter has provided a brief background to the issues surrounding research in the area of nutrition and human function and has highlighted the effects that functional foods can have on both cognitive and physical performance. Before examining the effects that phytochemicals have been shown to have on cognition and performance, an understanding of the way cognitive fatigue impairs performance first needs to be established. For this reason Chapter 2 presents a review of the literature that focuses on the effect that cognitive fatigue has on both cognitive and motor performance, and some of the potential mechanisms through which this effect takes place. Chapter 3 then provides a review of phytochemicals and research that has implicated them in having an effect on both cognitive and physical performance. Lastly, Chapter 4 discusses how the present study fits into the literature, and presents the research hypotheses to be investigated.

Chapter 2: Cognitive Fatigue and Performance

Fatigue acts as an important biological alarm that indicates the need for rest. However, it is not always possible to stop working on a fatigue-inducing task. In such situations task engagement and performance begin to decline. There is a tendency for periods of adequate performance to be interrupted more and more frequently with lapses in task engagement, as opposed to a complete and sudden collapse in performance (Nozaki et al., 2009; van der Linden, Frese, & Sonnentag, 2003). Cognitive fatigue is a common phenomenon, not just in illness but also in the daily lives of healthy individuals. The state of cognitive fatigue is caused by prolonged periods of cognitively demanding activity and generally involves a decrease in the level of performance on the task over time, resistance to continuing with the task, and subjective feelings of tiredness (Boksem & Tops, 2008).

Fatigue is a predominantly subjective state, making it difficult to quantify and therefore measure. Typically, fatigue is assessed using a range of self-report questionnaires; however, the lack of a universal definition of fatigue reduces the reliability of the data collected from these measures (DeLuca, Genova, Hillary, & Wylie, 2008). Objectively, cognitive fatigue can be measured by changes in performance over a period of time, such as increases in reaction time or an increase in errors (Schwid et al., 2003; van der Linden & Parasuraman, 2013). However, Deluca et al. (2008) report that an important consideration in fatigue research is that there has been shown to be no relationship between objective and self-report measures of cognitive fatigue.

The consequences of cognitive fatigue are varied and can include decreases in concentration and increased errors in driving, decreased productivity at work, resulting from impaired task performance whilst fatigued. This chapter provides a review of the literature to date that focuses on the effects that cognitive fatigue produces. First, there is a discussion on how cognitive fatigue is induced and how cognitive fatigue can be distinguished from boredom. This is followed by a discussion of the two competing theories that attempt to explain the performance decrements seen in cognitive fatigue. Next, the effects that cognitive fatigue have been found to have on specific areas of cognition and physical performance are reviewed. Finally, the potential neurocognitive mechanisms through which these effects are suspected to act are discussed.

Inducing Cognitive Fatigue

Time-on-task has consistently been shown to be an effective method of inducing cognitive fatigue; as the time spent on the task increases, performance begins to deteriorate. However, it is important to note that for the task to be effective in inducing fatigue it needs to be mentally demanding and requiring constant attention. As well, the time needed to be spent on the task depends on the type of task. For example, research has indicated that reading performance remains relatively stable over a 6 hour period, whereas performance on a mental manipulation task deteriorates as time-on-task increases (Ackerman & Kanfer, 2009). The time-on-task effect results from the mental resources being consumed and not being replenished fast enough due to the continuous nature of the high workload (Lim et al., 2010). A common pattern of time-on-task effects tends to show an initial improvement in performance, reflecting learning. However, following this initial improvement there is a continued deterioration (that may fluctuate slightly) of performance overtime (Csathó, van der Linden, Hernádi, Buzás, & Kalmár, 2012).

Research using brain imaging techniques, such as the electroencephalogram (EEG), further supports the assertion that time-on-task induces cognitive fatigue. For example, Boksem, Meijman, and Lorist (2005) assert that as participants become cognitively fatigued the EEG would be expected to show increases in alpha and theta power, reflecting a drop in arousal. As time-on-task increased they found that these powers did in fact increase, supporting the claim that time-on-task leads to cognitive fatigue.

The effects that time-on-task has on performance are particularly evident in vigilance tasks (Van Dongen, Belenky, & Krueger, 2011). Vigilance tasks require the participant to remain focused and alert to task-specific stimuli for a prolonged period of time (Warm, Parasuraman, & Matthews, 2008). Participants are often required to distinguish between correct and incorrect stimuli and make the appropriate response assigned to each stimulus. Depending on the learning curve involved for performance on the task, vigilance decrement may become evident about 20 to 35 minutes into the vigilance task (Krueger, 1989; Pattyn, Neyt, Henderickx, & Soetens, 2008). However, if the task is completely novel to the participant some learning is expected to take place in the early stages of the task, and as mentioned earlier, this leads to an initial improvement in performance before a decrement is observed. Interestingly, it has been suggested that the vigilance decrement induced by prolonged and continuous mental effort is still evident after the task has finished (Smit, Eling, & Coenen, 2004). This suggestion has important implications for research in the cognitive fatigue field, as it indicates that performance on tasks presented following the mentally fatiguing vigilance task are also likely to be impaired. However, the length of time the vigilance decrements are still present after the task has finished is yet to be determined.

It has been suggested that the time-on-task effect is increased by boredom and monotony (Van Dongen et al., 2011). However, a distinction between fatigue and boredom is yet to be established to everyone's satisfaction. Several researchers have attempted to make such a distinction; for example, Krueger (1989) suggested that while cognitive fatigue is generally the result of continuous task engagement, boredom can result from participating in a monotonous task for just a few minutes. Myers (1937) attempted to distinguish the two by stating that to overcome fatigue, rest from any form of work is needed, whereas to overcome boredom a change of task is all that is needed. Despite the attempts to separate the two constructs, many researchers find that they are intrinsically intertwined and therefore each influences the other (Lal & Craig, 2001). The fact that the symptoms of both cognitive fatigue and boredom are very similar and that there is a paucity of research distinguishing the two (Scerbo, 1998), means that there is little agreement regarding the role that boredom plays in cognitive fatigue.

Mindlessness versus Resource Depletion

The cause of the performance decrements seen in long monotonous tasks requiring sustained attention are currently being debated in the literature, focusing on two competing theories: the mindlessness theory and the resource depletion theory

(Helton & Russell, 2011). The mindlessness, or boredom, theory is based on suggestions by Robertson and colleagues (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) that performance decrements are the result of understimulation in vigilance tasks. Vigilance tasks typically involve the respondent repeatedly identifying and responding to critical stimuli. During the time between such stimuli, however, respondents tend to become distracted and begin to respond to the task in a thoughtless, mindless and automated style (Helton & Russell, 2011). This disengagement from the task increases task-unrelated thoughts (TUTs), thereby resulting in performance decrements (Helton & Warm, 2008; Langner, Willmes, Chatterjee, Eickhoff, & Sturm, 2010).

In regard to signal detection, Helton and Warm (2008) argue that the easier the signal is to detect the more errors the respondent is likely to make. This is caused by the responses becoming more automated due to ease of detection, thus resulting in mindlessness. This reasoning is supported by research in which participants performing vigilance tasks using easily detectable signals report higher levels of TUTs compared to more difficult vigilance tasks (Smallwood et al., 2004; Helton & Warm, 2008). Therefore, if the mindlessness model is correct, an increase in TUTs should lead to further performance decrement (Helton & Warm, 2008).

In order to induce higher levels of routinisation and therefore mindlessness, Robertson and colleagues (Manly et al., 1999; Robertson et al., 1997) used a modified vigilance task in which participants were to respond to the more frequent non-signals and ignore the critical signals. Participants in these studies were also asked to complete the Cognitive Failures Questionnaire (CFQ) to determine their level of absentmindedness. Results from the CFQ indicated that participants scoring higher on absentmindedness also made more detection errors on the modified vigilance task than those who scored low on absentmindedness (Grier et al., 2003). This result supports the theory that mindlessness causes the detection errors seen in vigilance and other long, repetitive tasks.

Opposing the theory that declines in performance are the result of mindlessness, is the resource depletion theory. Proponents of this theory argue that the performance decrements seen over time are the result of a decline in the attentional resources readily available (Helton & Warm, 2008; Lagner et al., 2010). Viewed from this perspective, resources are "reservoirs of mental energy" (Helton & Warm, 2008, p.19) assigned to performance on the task. These reservoirs or pools of energy cannot be maintained over the course of long tasks as they need time to replenish their resources. The continuous nature of vigilance tasks means there is little time for replenishment. Therefore, as the time spent on the task increases, with no chance for rest, the energy pool is depleted of resources, resulting in a decline of performance (Helton & Russell, 2011; Helton & Warm, 2008; Langner et al., 2010).

Unlike mindlessness theory, in which ease of signal detection is proposed to ultimately lead to declined performance, supporters of resource depletion theory purport that the decline in performance is the result of harder to detect signals. The decrement occurs due to the respondent needing to focus more attention on the task to detect those signals (Helton & Warm, 2008), and therefore attentional resources are depleted as time on task increases.

The decrements seen in vigilance performance have widely been explained by the resource depletion theory (Helton & Warm, 2008; Warm et al., 2008). The resource depletion theory is further supported by findings that cerebral blood flow velocity declines with reductions in signal detection (Warm et al., 2008). The specifics of this and other physiological mechanisms of cognitive fatigue will be discussed in a later section.

The resource depletion perspective is further supported by researchers who have actively compared the two competing theories (Grier et al., 2003; Helton & Russell, 2011; Helton & Warm, 2008; Langner et al., 2010) by testing whether tasks that promote routinisation or tasks that require a higher mental load lead to greater declines in performance over time. Such studies consistently produce results that corroborate the claims from the resource depletion perspective while finding no support for the mindlessness theory (Langner et al., 2010). Therefore, research is in support of the notion that it is a depletion of attentional resources, and cognitive fatigue, that result in performance decrements, as opposed to boredom or mindlessness (Helton et al., 2005; Helton & Warm, 2008). Helton and Russell (2011) make clear, however, that while the performance decrements seen in vigilance tasks are the result of resource depletion, it does not mean that the tasks are not subjectively boring. This boredom, where it occurs, is just not the cause of the decrements.

Cognitive Fatigue and Cognition

Understanding the effects that cognitive fatigue has on particular areas of cognition is an important step to understanding how cognitive fatigue may influence motor performance. There is evidence, for example, that the production of muscle movement arises in the prefrontal areas of the brain associated with cognition before stimulating the pre-motor cortex (Bray, Graham, Martin Ginis, & Hicks, 2012). The literature is consistent in showing that the three major areas of cognition affected by cognitive fatigue are (1) difficulties in sustaining attention and ignoring distractions, (2) impaired ability to monitor actions effectively, and (3) difficulty planning and preparing responses (Boksem & Tops, 2008).

Attention. The literature shows that attention is impaired under cognitive fatigue in a variety of ways (Csathó et al., 2012). Whether it be increased difficulty in sustaining attention (Boksem et al., 2005), or difficulty in ignoring irrelevant distractions (van der Linden et al., 2003), studies consistently provide evidence of attention being most severely affected by cognitive fatigue (Yang, Xiao, Liu, Wu, & Miao, 2013). A decline in attention has been known to be a result of cognitive fatigue from early fatigue research. Both Bartlett (1943) and Brown (1944) have demonstrated the influence of prolonged mental activity on attention in pilots and drivers, respectively. Both researchers reported that as the time spent on the task went on, participants became distracted by task-irrelevant features more frequently as attention to the task at hand waned. However, explanation of these changes is required; it is not known whether the withdrawal of attention to the task is the result of a subconscious change in arousal or if the withdrawal is a strategic change in performance to overcome the fatigue. That is, as someone becomes fatigued they may actively decide to change where their focus lies and begin thinking of task irrelevant information, thereby impairing their performance on the assigned task.

More recent research has lent further support to these early findings by using physiological measures to monitor the brain during fatiguing tasks, examining the changes that occur in the brain during fatigue and attention. Boksem et al. (2005), for example, used event-related potentials (ERPs) to measure selective attention, a form of attention necessary for ignoring irrelevant information. By measuring ERP amplitudes within the brain, the authors were able to identify a shift in the attentional processes of the participants. In the early stages of the continuous task being performed, it was evident that participants were more able to allocate their attention to the target stimuli and ignore task-irrelevant stimuli compared to the later stages of the task, when their attention appeared to be focused more on the irrelevant stimuli (Boksem et al., 2005).

The effects that cognitive fatigue has on attention and distractor stimuli may be dependent on the frequency with which the target stimuli are presented (Csathó et al., 2012). This idea is based on Lavie's (1995) theory of perceptual load, which suggests that attentional capacity is affected by perceptual load; that is, if the irrelevant stimuli presented in the task are congruent with the target stimulus (for example, they are both letters) the result is a high perceptual load, which generally leads to a decline in performance. The higher the perceptual load the more difficult the target stimulus is to identify, and therefore the greater the impact on attention. Csathó et al. (2012) suggest that as cognitive fatigue increases, with increasing time-on-task, the effects of a high perceptual load on attention will become more prominent. The idea that a higher perceptual load is what results in the decreases in attention seen in cognitive fatigue lends further support to the resource depletion theory over the mindlessness theory. Because the mindlessness theory implicates routinisation as being the cause of fatigue, it would therefore be expected that a low perceptual load would result in higher levels of fatigue as this would lead to higher levels of routinisation than a high perceptual load.

The mechanism thought to underlie the impairments to attention in cognitive fatigue is top-down control. Top-down control refers to the voluntary allocation of attention driven by knowledge of the specific task. Attention is focused on target stimuli thus inhibiting the influence of task distractors (Boksem, Meijman, & Lorist, 2006; Langner, Seinborn, Chatterjee, Sturm, & Willmes, 2010; Sarter, Givens, & Bruno, 2001). Under normal conditions top-down control processes maintain optimal performance by ensuring continuous task engagement. However, the voluntary, and therefore effortful, nature of these processes makes them vulnerable under conditions of cognitive fatigue (Langner et al., 2010). Boksem et al. (2005) demonstrated this effect of cognitive fatigue on top-down control of attention in their research using ERP amplitudes. As was discussed earlier, they found that as cognitive fatigue increased participants had more trouble ignoring task-irrelevant stimuli. Participants also showed an aversion to continued performance. These results suggest that the top-down control processes were jeopardised by the onset cognitive fatigue; attention became increasingly focused on the irrelevant stimuli as opposed to the target stimuli leading to a decrement in performance. The fatigue-related effects on attention appear to be similar to the effects seen in other populations in which top-down control is known to be compromised, for example, the elderly and patients with neurological conditions (van der Linden & Eling, 2006).

While much of the literature surrounding impaired attention in cognitive fatigue focuses on sustained attention, Yang et al. (2013) have proposed that the effects may actually arise from impairment to the pre-attentive processing. Pre-attention is the process by which all information in the surrounding environment is filtered to determine what is important. The information deemed important to the task at hand is then consciously processed (Atienza, Cantero, & Escera, 2001). In this sense, the processing of information is unconscious during the pre-attentive stage and conscious during the attentive stage. Yang et al. (2013) demonstrated an effect of cognitive fatigue on pre-attentive processing in an electrophysiological study. They looked at the MMN (mismatch negativity) component of ERPs, which has proven valuable in detecting changes in pre-attentive processing (Yang et al., 2013). The authors found that the MMN amplitudes in the fronto-central area of the brain were decreased significantly in cognitive fatigue; meanwhile the temporal MMN amplitudes were not affected. This finding led the authors to conclude that pre-attentive processing is impaired under cognitive fatigue. If it is the pre-attentive processing that is affected under cognitive fatigue, then this could provide valuable insight into the way in which cognitive fatigue impairs motor performance, particularly motor tasks that are more novel. This is because when pre-attentive functioning is impaired it reduces the ability of the individual to transfer their attention to a given task (Yang et al., 2013).

Novel tasks require conscious attention for successful completion, thus are more likely to be affected because the pre-attentive processes are unlikely to transfer the required attention to the attentive stage. Tasks that are more automated are often able to be completed without conscious attention.

Action monitoring. The literature on the effects of cognitive fatigue on action monitoring consistently find that cognitive fatigue results in a decline in error awareness and correction of erroneous responses (Boksem et al., 2006; Boksem & Tops, 2008; Bonnefond, Doignon-Camus, Hoeft, & Dufour, 2011; van der Linden et al., 2003). Many of the problems that people suffering from cognitive fatigue experience are largely the consequence of failing to monitor their actions effectively (Boksem et al., 2006). Action monitoring allows people to strategically adjust their ongoing behaviour to optimise performance; this is a particularly important process for the correction of erroneous responses (Boksem et al., 2006).

The neurological underpinnings of the effect of cognitive fatigue on action monitoring have been demonstrated using ERP components by both Boksem et al. (2006) and Bonnefond et al. (2011). The two indices of the ERP that are of importance in action monitoring are the error related negativity (ERN/Ne), which measures error detection, and the error positivity (Pe), which measures error awareness (Bonnefond et al., 2011). Boksem et al. (2006) also report that the ERN/Ne is necessary to initiate strategic changes after erroneous responses. The authors from both studies report that when participants become cognitively fatigued, ERPs show marked deflections in both the ERN/Ne and Pe indices. These changes are believed to indicate cognitive fatigue resulting in impairment of strategic action monitoring processes (Boksem et al., 2006).

van der Linden et al. (2003) found that the effects of fatigue on action monitoring are more prominent in people who are unfamiliar with the task. In becoming familiar with the task, people are likely to come up with a number of successful strategies that when fatigued they can switch between. Whereas, those unfamiliar with a task are less likely to have a variety or strategic options and therefore are likely to continue with unsuccessful strategies or change back to strategies that are unsuccessful because they worked earlier (van der Linden, Frese, & Meijman, 2003; van der

Linden et al., 2003). This idea has important implications for cognitive fatigue in a number of settings, and could be tested in future research by comparing groups who have either been given multiple sets of strategies to utilise during a long task or have only been given one strategy.

Interestingly, Boksem and colleagues (Boksem et al., 2006; Boksem & Tops, 2008) have found that even participants who are cognitively fatigued can improve their performance when motivated to do so. This suggests that if the reward is great enough, that is, it outweighs the cost of continued performance, people can overcome feelings of fatigue and once again monitor their actions. However, this monitoring may not be as effective as before cognitive fatigue set in. Boksem et al. (2006) found that, in general, their participants could not improve both their speed and accuracy in the task. This led them to suggest that while it appears there is a motivational component involved in action monitoring and cognitive fatigue, the relationship between the two is more than a simple imbalance between cost and benefit.

Planning, preparation, and response readiness. The effects that cognitive fatigue has in planning, preparation and response readiness are particularly important to understanding the effects of cognitive fatigue on motor performance. This is evident in research that has traced the time course of the activation of motor responses and found that activation is preceded by preparatory processes that seem to precede even the conscious thought to move (Müller-Gethmann, Rinkenauer, Stahl, & Ulrich, 2000; Kato, Endo, & Kizuka, 2009; Kutas & Donchin, 1980; Trevena & Miller, 2002).

The decision to make a movement starts before consciously deciding to act. Müller-Gethmann et al. (2000) report that this is evident from research that uses a modified reaction time task, in which participants are prompted to make a specific movement as quickly as possible. When given a pre-cue for what the movement to come will entail, reaction times are found to be much shorter than when no cue is given. This suggests that the preparatory processes use this information and are ready for action when prompted to act. When no pre-cue is given the preparatory processes do not begin until the prompted to act, resulting in longer reaction times (Müller-Gethmann et al., 2000). The crucial role of preparatory processes in initiating a response to stimuli is further supported by physiological measures. For example, Kutas and

Donchin (1980) used EEG and electromyogram (EMG) recordings to determine activation of preparatory processes well before the initiation of movement when the participant was cued to timing of the response. More recently Kato et al. (2009), using an ERP study, measured lateralised readiness potential (LRP) and determined that the activation of a response occurs well before the motor cortex initiates a movement.

It has been shown that the preparation processes required for response activation are largely mediated by cognitive fatigue (Kato et al., 2009; Lorist et al., 2000). Lorist et al. (2000) manipulated the time between the response to the previous stimulus and the presentation of the next stimulus. They reported that even when their participants were given sufficient time for response preparation, participants who were fatigued did not utilise the time to prepare their response. Therefore, even with ample preparation time, cognitively fatigued participants were unable to execute correct responses to the stimuli presented (Lorist et al., 2000).

Planning was also determined to be impaired under conditions of cognitive fatigue in a study by van der Linden, Frese, and Meijman (2003). The authors reported that when their participants were completing the Tower of London task, those who were fatigued took significantly longer to begin the task than participants who were not fatigued. The authors used the time to begin the task to determine the initial planning time needed to respond to the task. Therefore, the longer the participant took to begin the task, the longer that participant needed to plan their response. It was found that even though fatigued participants had longer planning times, their performance on the rest of the task (based on task errors) did not differ from participants who were not fatigued (van der Linden, Frese, & Meijman, 2003). This suggests that taking longer to plan out actions may help to eliminate the effects that cognitive fatigue has on performance. Although it is likely that this will be task dependent, only improving performance on a specific set of tasks. Future research examining the effect of planning time on a variety of tasks would be beneficial to the field of research.

Cognitive Fatigue and Physical Performance

There has been an abundance of research that has focused on the effects of cognitive fatigue on cognitive performance and the effects of physical performance on mental performance. There is growing support in the literature for the idea that depletion of resources in one domain from effortful task adherence has considerable consequences for effortful performance in subsequent tasks, even if the subsequent task draws from a different domain of resources (Bray et al., 2012; Hagger, Wood, Stiff, & Chatzisarantis, 2010). Lieberman (2001) suggests that mental and physical fatigue are not independent states, with an element of cognitive fatigue often being present in physical exhaustion. This indicates that inducing cognitive fatigue may then go on to impair physical performance. It has been suggested that the additional mental demand placed on participants in cognitive fatigue research results in a decline in the attentional resources available to the participant (Mehta & Agnew, 2012). These attentional resources are required to maintain the necessary output for motor performance by increasing the drive to motor neurons (Mehta & Agnew, 2012). As was discussed previously, attentional resources are diminished during cognitive fatigue, thereby providing a possible mechanism through which cognitive fatigue may impair motor performance.

Despite this, relatively few studies have focused on the effects that cognitive fatigue has on subsequent physical performance and fewer yet on specific motor task performance (Bray et al., 2012; Marcora, Staiano, & Manning, 2009). Marcora et al. (2009) report that the first observations of an effect of cognitive fatigue on motor performance date back to 1891 when Angelo Mosso observed a reduction in muscle endurance in his colleagues after delivering long lectures and running oral examinations. Until recently, however, research following up these claims has been neglected. Of the research that does exist in this area, much of it focuses on the effects on physical performance while simultaneously working on mentally demanding activities. However, research focusing on such simultaneous performance can still provide valuable insight into the potential after effects that mentally demanding tasks can have on physical performance.

In their study looking at the interactive effects of concurrent mental and physical workload, Mehta and Agnew (2012) found that participants showed a substantial decrease in muscular endurance when they worked on a multiplication arithmetic task while simultaneously performing maximum muscle contractions of the shoulder. An earlier study by Mehta and Agnew (2011) found that the decrease in muscle endurance from concurrent mental and physical performance is much more evident when the muscle contractions were performed at a higher workload. Using an effortful handgrip task, Bray et al. (2012) demonstrated the effect that simultaneous mental and physical work can have on muscle endurance on a more executive group of muscles in the hand. They found that physical performance continued to deteriorate as the time spent on the simultaneous cognitive task went on.

Impaired muscle endurance has also been found to occur as an after effect of mentally demanding activities. Using the executive muscle group used in hand grip, Bray, Martin Ginis, Hicks, and Woodgate (2008) found that when participants first completed a mentally demanding task (the Stroop test) their performance on a subsequent grip strength task had significantly decreased from their baseline performance. Moreover, the researchers report that, using EMG, they not only found declines in muscular endurance but also in neuromuscular activity. This result suggests that when already cognitively fatigued, participants then showed greater levels of fatigue at the beginning of the physical task than controls, and the fatigue increased at a greater rate throughout the task (Bray et al., 2008).

Not all research has provided evidence for a decrease in physical performance under conditions of mental demand. Mehta and Parasuraman (2013) found no effect on handgrip endurance in the presence of a mental arithmetic task. However, the mentally demanding task in this study was only presented for three minutes, whereas other research has presented the demanding tasks for anywhere from 15 minutes to 90 minutes. Some studies have even had participants perform mentally demanding tasks for 8 hours (comparable to an average working day). This suggests that time-on-task in Mehta and Parasuraman's (2013) study was not long enough to induce a state of cognitive fatigue, or to interfere with the attentional resources needed for the physical task.

As well as muscular endurance, muscle activation has also been implicated in the effects of cognitive fatigue on physical performance. This is thought to be due to the smallest functional units of the muscle, the motor units. These motor units have very low firing thresholds resulting in near continuous activation. The end result is muscle exhaustion, likely because of the lack of time for recovery and repair of damaged muscle fibres (Lundberg et al., 2002). It has been suggested that mentally demanding activities can contribute to motor unit activation (Lundberg et al., 2002). Furthermore, Lundberg et al. (2002) found that the same motor units are activated under both mentally and physically demanding tasks. This finding suggests that even in the absence of physical muscle recruitment, mentally demanding tasks can keep motor units activated. It therefore seems plausible that the continuous nature of mentally fatiguing tasks will contribute to motor unit activation, thereby impairing muscle capability and resulting in impairment in subsequent, or simultaneous, physical performance.

As well as the effects of cognitive fatigue on muscle endurance and activation, research also supports the idea that cognitive fatigue impairs subsequent high intensity physical performance. Marcora and colleagues (Marcora et al., 2009; Pageaux, Lepers, Dietz, & Marcora, 2014) have found that when participants first completed a cognitively demanding task their performance on a subsequent endurance exercise was significantly worse compared to controls. Marcora et al. (2009) demonstrated this effect using 90 minutes of cognitive demand followed by an endurance cycling exercise in which time-to-exhaustion was measured; time-to-exhaustion was significantly less in fatigued subjects. Meanwhile, Pageaux et al. (2014) demonstrated the effect using 30 minutes of cognitive demand followed by a running exercise in which performance was measured by the participants' chosen pace; those who were fatigued chose a significantly slower pace compared to non-fatigued controls. Interestingly, the findings of these studies were not explained by the effect cognitive fatigue has on subsequent performance, as is the case in the majority of other research. Instead, the authors suggest that the impairments in physical performance were the result of an increase in the perception of effort required by the participant to perform the task. Marcora and colleagues argue that when cognitively fatigued the effort required to perform a given task is perceived to be much higher than when presented with the same task when not fatigued. In this sense, it is expected that when the effort required to perform a task is too high, participants will withdraw any further effort, thereby completing the task to a lesser level than participants who are not fatigued.

Given the potential consequences of impaired motor performance under conditions of cognitive fatigue, further research is necessary in order to gain a greater understanding of the exact functions that are affected by cognitive fatigue and the mechanisms that influence these effects.

Neurocognitive Mechanisms of Cognitive Fatigue

The mechanisms involved in fatigue are not well understood (Holtzer & Foley, 2009; Okada, Tanaka, Kuratsune, Watanabe, & Sadato, 2004). However, researchers have proposed a number of possible theories that underlie and contribute to the understanding of the phenomenon known as cognitive fatigue. Neuroimaging techniques have helped researchers to locate the areas of the brain that are affected by prolonged cognitive performance, and which may play a part in the development of cognitive fatigue (Ishii et al., 2013; Lim et al., 2010; Lorist et al., 2009).

The purpose of the present research is to investigate the effects that cognitive fatigue have on simple motor performance. Thus, the focus is on the potential mechanisms of cognitive fatigue that may also play a part in influencing motor performance. An in-depth investigation of the neurocognitive mechanisms of fatigue is beyond the scope of the present investigation. However, it is necessary to provide a brief discussion of those mechanisms that are most commonly thought to be implicated as this will help in understanding how phytochemical supplementation may influence the effects that cognitive fatigue have on motor performance.

Brain regions. The areas of the brain suspected to be involved in cognitive fatigue have been identified through brain imaging studies. Many of these studies use models based on diseases in which fatigue is a prominent symptom such as Multiple Sclerosis (MS) and Cognitive Fatigue Syndrome (CFS). While fatigue as a daily phenomenon among otherwise healthy people is unlikely to be the result of damage to these structures, the findings from research using these models suggest that a level of temporary impairment to the structures involved in clinical fatigue also plays a role in subsequent impairments seen in people experiencing temporary, nonclinical cognitive fatigue (Boksem & Tops, 2008).

Anterior Cingulate Cortex (ACC). Neuroimaging studies have shown that the ACC is actively involved in both cognitive control and motor control tasks (Bray et al., 2012). It has been suggested that the ACC is the structure where cognition and motor control interact (Paus, 2001). The command signals that initiate and control movement, which originate from the prefrontal cortex, are suspected to send information to the primary motor cortex through the motor output system in the ACC (Kato et al., 2009). Therefore, the ACC is thought to play a major role in the influence that cognitive fatigue has on subsequent motor performance (Bonnefond et al., 2011; Bray et al., 2012; Paus, 2001).

The ACC is known to be involved in sustained attention as well as being linked to the amount of effort that people perceive themselves to be making (Marcora et al., 2009; Pageaux, Marcora, & Lepers, 2013; Paus, 2001). The fatigue-related changes induced from continuous involvement in a mentally demanding task are likely the result of changes and impairment in the ACC. These changes in the ACC may result in a higher perception of the effort required to perform a subsequent physical task (Marcora et al., 2009; Pageaux et al., 2013). As was discussed earlier, a higher perception of effort required for a task results in impaired performance.

The ACC has also been shown through ERP research to be an essential structure involved in action monitoring (Bonnefond et al., 2011; Kato et al., 2009; Tanaka et al., 2013). Such research has shown that the amplitude of the ERN/Ne recorded from the ACC increases when erroneous responses are made, suggesting that the structure is actively involved in the processes of identifying and correcting erroneous responses (Bonnefond et al., 2011). However, as time-on-task increases and cognitive fatigue sets in the amplitude of the ERN/Ne generated by the ACC is significantly reduced (Lorist, Boksem, & Ridderinkhof, 2005; Tanaka et al., 2013), and therefore the ability to monitor and adjust performance is impaired.

Basal Ganglia. Research that has looked at patients with known damage to the basal ganglia has identified this structure as being involved in motivation, drive, and initiation, all of which are inhibited under conditions of cognitive fatigue (Chaudhuri & Behan, 2000; Fellus & Rashidzada, 2005). The effect that cognitive fatigue has on performance in subsequent cognitive and motor tasks has therefore been proposed to result from impairment to functional circuits of the basal ganglia (Chaudhuri & Behan, 2000). The basal ganglia circuits provide feedback loops to the prefrontal cortex as well as to the primary motor cortex, areas critical for maintaining and executing both cognitive and motor control (Fellus & Rashidzada, 2005). The basal ganglia initiates responses by preparing motor and sensory cues that are then sent via the feedback loops to the primary motor cortex and the prefrontal cortex resulting in the subsequent set of responses (Chaudhuri & Behan, 2000). However, cognitive fatigue has been shown to disrupt these processes leading to delayed initiation of responses as well as inhibiting the execution of the responses needed for the task (Chaudhuri & Behan, 2000; Fellus & Rashidzada, 2005).

The fact that the basal ganglia partially control voluntary movement further implicates it in the effects that cognitive fatigue has on motor performance. The basal ganglia enable the motor mechanisms that are required for a task and inhibit mechanisms that will be unbeneficial (Macready et al., 2010). As cognitive fatigue sets in and the basal ganglia become impaired, mechanisms that are unbeneficial to the task are activated more frequently reducing the efficiency of task performance. However, as the skills required to complete a given task become more automatic, motor function initiation shifts to other brain regions such as the premotor cortex (Macready et al., 2010). Therefore, the effects that fatigue has on the basal ganglia may only carry over to motor performance when the skills required to complete are task are relatively novel.

Neurotransmitters. As well as specific brain regions and structures being implicated in cognitive fatigue, disturbances to neurotransmitter systems also are thought to play a role.

Dopamine. Changes in the dopamine system may affect a number of cognitive fatigue outcomes, mainly due to the fact that large regions of the brain s are innervated by dopaminergic systems (Lorist et al., 2009). Boksem et al. (2006) have suggested that a reduction in the activity of the dopamine system may underlie cognitive fatigue. This idea of dopamine involvement comes from research that identifies dopamine as being closely linked to alertness, energy, and cognitive control processes (van der Linden et al., 2006). Furthermore, van der Linden et al. report that when participants are given supplements or medication known to increase dopamine levels in the brain, the effects of cognitive fatigue are significantly reduced.

The effects of cognitive fatigue may be the result of reduced dopamine activity in the ACC (Lorist et al., 2009; van der Linden et al., 2006). Specifically, action monitoring and information processing, both of which have been discussed as being affected in cognitive fatigue, are believed to be influenced by dopamine levels (Boksem et al., 2006; Lorist et al., 2009). The process by which these functions are thought to be affected possibly result from the reduced input of dopamine to the ACC by the basal ganglia (Boksem et al., 2006).

It has also been suggested that the reduction in dopamine activity during cognitive fatigue may be caused by the declining benefits of continued effort as time-on-task increases (Csathó et al., 2012). This theory has developed from research in which participants' strategies for task completion change to less demanding and low cost alternatives as dopamine activity reduces (Lorist et al., 2009; Lorist & Faber, 2011).

It is important to note that while a reduction in dopamine activity may impair performance it does not result in a complete inability to perform assigned tasks. Rather, it results in performance difficulties due to a reduction in flexibility, inhibition and attention (Lorist et al., 2009), therefore making it difficult to make necessary behavioural changes.

Dopamine clearly affects motor performance. For example, research on the degenerative disease known as Parkinson's disease is caused by a reduction in dopaminergic neurons in the substantia nigra, a structure of the basal ganglia. The resulting loss of dopamine input into other areas of the basal ganglia leads to impaired motor control (Miller & Shukitt-Hale, 2012).

Glutamate. Research on the glutamate network has indicated a potential role for it in initiating cognitive fatigue. This network is critical for aiding in the processing of information, a function that is affected during cognitive fatigue. Lorist and Faber (2011) suggest that disturbances to the glutamate network can result in a failure to remove the excess glutamate once it has produced its intended effects. This leads to an increase in excitability and the energy required to process the extra glutamate in the brain. The authors also mention that such a disturbance may result in compensatory efforts by other brain networks, leading to increased activation across the brain. This is corroborated with findings from Lorist et al. (2009) who demonstrated through EEG that as time-on-task increased more neural circuits became activated. As the time-on-task and brain activation increased, task errors and reaction time also increased. These findings support the suggestion that the glutamate network plays a role in cognitive fatigue.

Summary

Cognitive fatigue is a state which results in declines in performance and task engagement. While it is a common symptom in numerous illnesses, it is also common in healthy individuals and is brought on by continuous engagement in cognitively demanding tasks which allow little opportunity for rest or recovery (Nozaki et al., 2009; van der Linden, Frese, & Sonnentag, 2003). This chapter has highlighted the influence cognitive fatigue can have on simultaneous and subsequent performance in both cognitive and physical functioning. The effects had on physical performance have been shown to largely stem from the impairments to cognitive functioning, emphasising the importance of research enhancing the understanding of this relationship. There was a brief discussion of the neurocognitive mechanisms suspected to be involved in cognitive fatigue and how it affects performance. However, research is only beginning to determine which brain structures are involved and the processes that are implicated in cognitive fatigue. While research on the effects of cognitive fatigue has come a long way in recent times, continuing research is needed in order to replicate findings and pinpoint the mechanisms, tasks, and processes that are most affected in cognitive fatigue.

Chapter 3: The Effect of Phytochemicals on Cognitive Fatigue and Motor Performance

A number of food properties have been found to influence cognitive and physical performance. The focus of this chapter, however, will be on the influence of phytochemicals, specifically those found in berry fruits, on cognitive and motor performance, and how they may play a part in reducing the effects of fatigue. Previous research has produced mixed results for phytochemical supplementation on performance and little research has been done on the effects in healthy adult samples. Before discussing these effects, a brief overview of what phytochemicals are and the ones that are of specific interest to this research is provided.

What are Phytochemicals?

Phytochemicals, found in fruit and vegetable plants, are secondary polyphenol molecules that are produced as a defence mechanism against disease, helping improve the survivability of the plant (Hurst & Hurst, 2013; Shukitt-Hale et al., 2005). Shukitt-Hale et al. (2009) suggest that it is the very same mechanisms that protect the plant that could trigger adaptive cellular pathways that protect cells when exposed to adverse conditions when consumed by animals and humans. Of the phytochemicals found in plants, it is a subgroup of flavonoids that has received the most attention, the anthocyanins. Anthocyanins have been found to produce strong anti-inflammatory and antioxidant activities which is why they have been cited as having beneficial effects in cognition, motor performance, and age-related declines (Shukit-Hale et al., 2005). Anthocyanins are pigments that create the colours within the skin, flesh and flowers of the plants (Shukitt-Hale et al., 2005) and are particularly abundant in fruits that have deep pigmentation, such as berries.

The beneficial effects that anthocyanins may have on cognition and motor performance are at least partly due to their ability to cross the blood-brain barrier. Animal studies have reported that post supplementation-detectable amounts of anthocyanins have been found to be present in the brain (Papandreou et al., 2009; Shukitt-Hale et al., 2005; Spencer, Vauzour, & Rendeiro, 2009). In fact, Spencer et al. (2009) suggest that the properties of anthocyanins act through "an ability to protect vulnerable neurons, enhance existing neuronal function, stimulate neuronal regeneration and induce neurogenesis" (p.1), thereby providing an opportunity to improve the processing of cognitive and motor activities (Papandreou et al., 2009; Shukitt-Hale et al., 2009; Spencer et al., 2009).

Phytochemicals and Cognition

A large number of the studies examining the effects of phytochemicals on cognition have used aged samples, aiming to find out if phytochemical supplementation can reduce the cognitive declines typically seen in aging.

Many recent studies have described the effects that foods high in phytochemical properties have on cognition. Shukitt-Hale and colleagues (Joseph et al., 1999; Miller & Shukitt-Hale, 2012; Shukitt-Hale et al., 2006; Shukitt-Hale et al., 2009; Shukitt-Hale et al., 2005) have conducted a number of laboratory experiments on aged rats demonstrating the effects that a number of fruit and vegetable supplements high in phytochemicals have on cognitive performance. Miller and Shukitt-Hale (2012) report that in the earlier of these studies, rats that were fed either a blueberry or strawberry supplemented diet showed improved spatial working memory compared to controls. More recently, the group have demonstrated the same effects with a wider range of phytochemical supplemented diets including, spinach, grape juice, blackberries, blackcurrants and cranberries. However, Shukitt-Hale et al. (2006) note that when given different concentrations of the grape juice the outcomes were mixed. The grape juice had the greatest effect on cognitive performance when it was given at 10% concentration, whereas in rats that were supplemented with 50% concentrated grape juice there was no significant difference in cognitive performance compared to controls. The authors could not explain this finding, highlighting the importance for future research to examine dose-dependent effects on performance.

Other research looking at the effects of phytochemicals on cognitive performance have also found positive results in other areas of cognition from berry supplementation. For instance, Papandreou et al. (2009) report that following seven days of wild blueberry extract supplementation to healthy adult mice, there was a significant improvement in long-term memory. Barros et al. (2006) found blueberry supplementation lead to enhancements in both memory and learning in young mice. Furthermore, blueberry supplementation has also been shown to enhance memory retention and recognition for novel objects in mice (Barros et al., 2006; Goyarzu et al., 2004).

The effects that phytochemical supplementation has on human cognition has been studied much less extensively. Like in animal studies, the majority of the research that does exist has been done with older adult samples. In one study, when given a blueberry supplement daily for 12 weeks, memory was significantly improved (Krikorian, Shilder et al., 2010). Specifically, memory improvements were made in word recall and paired associate learning. Similarly, it was found that older adults who were given a grape juice supplement for 12 weeks showed improvements in spatial memory, delayed recall, and learning when compared to participants who were given a placebo (Krikorian, Nash, Shidler, Shukitt-Hale, & Joseph, 2010). Miller and Shukitt-Hale (2012) highlight the need for further research on the effects that phytochemicals have on cognition in humans in order to determine which sources provide the most benefits and also what intake level is the most effective.

It has been suggested by a number of authors that a potential mechanism through which phytochemicals influence cognitive functioning is by inducing an increase in the release of dopamine (Papandreou et al., 2009; Shukitt-Hale et al., 2009). As was discussed in the previous chapter, dopamine plays a crucial role in cognitive fatigue and the effects it has on cognitive performance.

While phytochemicals from berry fruits have been shown to influence areas of cognition, there has not yet been any research to demonstrate the effects that they may have on cognitive fatigue. However, research on phytochemicals from other plant sources has identified the potential for a reduction in feelings of cognitive fatigue by phytochemicals. For example, Kennedy et al. (2010) found that when participants were given two single doses of a sage extract, not only did performance on memory and attention tasks improve, but the level of cognitive fatigue was also reduced. Also, Lindheimer, Loy, and O'Connor (2013) found rosemary extract to induce small reductions in cognitive fatigue. Therefore, research examining whether the benefits of berry fruit-supplemented diets may extend to improving cognitive fatigue as well as the other cognitive domains identified is necessary.

Phytochemicals and Motor Performance

As well as the benefits seen for cognitive functioning, research has also demonstrated positive effects on motor functioning. Again, these findings are largely based on studies in aging populations. A reduction of dopaminergic neurons in the substantia nigra has been implicated as a potential mechanism for a reduction in motor control (Miller & Shukitt-Hale, 2012). Recently, research has demonstrated that phytochemical supplementation in mice can prevent motor control impairment when dopaminergic neurons have been destroyed (Kim et al., 2010). In this study the researchers injected the mice with a neurotoxin to destroy dopaminergic neurons, resulting in motor control impairment in mice given a control diet. However, when mice were given diets supplemented with an anthocyanin-rich mulberry extract for 15 days prior to being given the neurotoxin, the extract prevented the deficits to motor functioning seen in the controls.

The motor functions that have most frequently been reported as showing improvements following phytochemical supplementation are balance and fine motor coordination (Shukitt-Hale et al., 2009). In their research examining the effects of blackberry supplementation on age-related deficits in rats, Shukitt-Hale et al. (2009) found that rats that were given the supplement performed significantly better than controls on tasks which required balance and fine motor coordination, including walking across a suspension wire (muscle strength and coordination), a rod walk (coordination), and a plank walk (balance and coordination).

While an effect of grape juice supplementation on cognition was only seen at 10% concentration, for an effect to be observed on motor performance, a 50% concentration of the grape juice was necessary (Shukitt-Hale et al., 2006). This suggests that for phytochemicals to be able to induce changes in motor functioning, they may need to be administered in higher doses compared to what may be adequate to enhance cognitive functioning (Shukitt-Hale et al., 2006). This could explain why many of the sources of phytochemicals that have been shown to benefit cognition are yet to demonstrate effects in improving motor performance.

While there is little research demonstrating effects of phytochemical supplementation on tasks requiring fine motor control, Hurst and Hurst (2013) report that there have been findings of an effect on exercise endurance. They argue that the mechanism through which this effect is likely to occur is through an influence on muscle capacity and performance, which can be improved through supplements high in antioxidants, such as fruit and vegetables. The mechanisms through which fine motor control are governed are suspected to involve motor areas of the brain rather than direct muscle involvement; however, such findings highlight the potential for phytochemical supplementation, at the right dose rates, to improve motor control in humans.

Summary

The benefits of nutritional properties in enhancing human performance and functioning are increasingly being cited. Of interest in this chapter was the benefit of phytochemicals in improving performance. The chapter highlights the influence of phytochemicals from a number of sources in improving both cognitive and physical performance. For the most part the literature focuses on the benefits to cognitive and physical performance individually and has failed to take into consideration the relationship between the two. This has highlighted a large gap in the literature, emphasising the need for future research to look at the effects phytochemical supplementation may have on the interaction between cognition and physical performance.

Chapter 4: The Present Study

The previous chapters demonstrate that cognitive fatigue can influence both cognitive and physical performance, as well as showing the ability of specific foods to enhance performance in both cognitive and physical domains. While the effects that both fatigue and nutrition can have on different aspects of performance have been known for a long time, research has only relatively recently become interested in the specific areas of these domains. Despite the increasing interest in the effects of food supplementation on both cognitive and motor fatigue, these two domains have generally been studied independently of one another. There is little research on the interaction between cognitive fatigue, motor performance and dietary supplementation.

The present study appears to be the first to examine whether phytochemicals can act to ameliorate the effects that cognitive fatigue has on motor performance. Therefore, the current study is conducted not only to provide some insight into effects on simple motor performance by cognitive fatigue, but also to understand if phytochemical supplementation has the potential to influence both mental and physical performance.

Hypothesis 1

Based on research that has identified cognitive fatigue as leading to reduced performance capability in physical tasks (Marcora et al. 2009), it was hypothesised that *participants who are cognitively fatigued will show a decline in performance on subsequent motor tasks compared to those participants who are not fatigued.*

To test this hypothesis, the procedures were based on those employed by Marcora et al. (2009). However, the focus in the present research is on simple motor task performance as opposed to endurance exercise. In the Marcora et al. study, fatigue was successfully induced by participants completing a vigilance task, the AX-CPT (see the Method section for a description of this task), for 90 minutes. Based on other research which has identified time-on-task effects from working on demanding tasks for a much shorter time, anywhere from 20 to 30 minutes (Pattyn et al., 2008), the present study had participants complete the AX-CPT task for 75 minutes. The expectation that cognitive fatigue would be induced after 75 minutes of time-on-task is further supported by the claims of the resource depletion theory. Based on this theory, it was expected that performance on the AX-CPT task would decline and fatigue would be induced by the end of the 75 minutes as the attentional resources were depleted without time for replenishment (Helton & Warm, 2008; Lagner et al., 2010). The effects that fatigue has on attentional resources, action monitoring, and response planning and preparation are expected to carryover to performance on subsequent motor tasks, resulting in a decline in performance relative to baseline.

A limitation of the previous research that has examined the effects of fatigue on motor performance is that much of it has only assessed performance on one area of motor functioning, for example, grip strength. When looking at the effects on motor performance it is necessary to examine the effects on a range of motor tasks (Macready et al., 2010). The present study examined the effects of cognitive fatigue on four motor tasks, each assessing different domains of motor control: motor speed (finger tapping), grip strength (dynamometer), psychomotor functioning (simple reaction time), and accuracy (grooved pegboard). As suggested by (Lagner et al., 2010) the more automated the task the less effect cognitive fatigue will have on it; therefore, the biggest effects in the current study were expected to be seen when participants used their non-preferred hand to complete the motor tasks.

Hypothesis 2

The main research question of this thesis was whether phytochemical supplementation can ameliorate the effects that cognitive fatigue has on motor performance. To answer this question this study investigated the effects of a single dose blackcurrant supplement for its ability to relieve the effects that cognitive fatigue were expected to have on motor performance. It was hypothesised *that the participants given a blackcurrant extract supplement would not show as greater declines in motor performance after the fatigue task compared to participants not given the supplement.*

Blackcurrants are a rich source of phytochemicals, particularly flavanols and anthocyanins, which have been found to reduce age-related deficits, improving coordination and balance (Shukitt-Hale et al., 2009). While there appear to be no published studies examining the effects of blackcurrant supplementation on cognitive fatigue and the related changes in physical performance, research has demonstrated the ability for other phytochemical-rich foods to reduce levels of cognitive fatigue and improve cognitive functioning (Lindheimer et al., 2013; Miller & Shukitt-Hale, 2012).

That the blackcurrant supplement would reduce the effects of cognitive fatigue on motor performance could come about in one of two ways. First, the supplement may prevent the onset of cognitive fatigue by acting on the cognitive system during the mentally fatiguing vigilance task, and therefore reducing the level of fatigue compared to controls. This would be demonstrated by participants' level of accuracy on the task remaining relatively stable, or improving, as the time-on-task increases compared to controls, whose accuracy could be expected to decline. Second, the blackcurrant supplement could act on the motor control functions, and, therefore, while the supplement condition may show signs of fatigue in the fatiguing task, subsequent performance on the motor tasks would not be affected. That is, performance on the motor tasks was expected to remain stable or possibly improve compared to baseline performance.

Chapter 5: Method

Participants

Sixty healthy people aged between 18 and 40 years (*M* = 23.03, *SD* = 4.83) volunteered to participate in the study. Participants had no known neurological or psychological conditions, and their motor function was not impaired in any way. All participants had normal or corrected to normal vision. Of these 60 participants, 39 were female (age *M* = 22.41, *SD* = 4.39) and 21 were male (age *M* = 24.19, *SD* = 5.50). Participants were recruited through advertisement, from undergraduate classes at Massey University, and by word of mouth. They were given a $30 voucher to compensate for the time given to the research. All procedures and materials used in the present study were approved by the Massey University Human Ethics Committee (protocol 13/20).

Group Assignment

Participants were randomly assigned to one of four conditions; blackcurrant/fatigue, blackcurrant/no fatigue, no blackcurrant/fatigue, and no blackcurrant/no fatigue (Figure 1). There were 15 participants assigned to each condition and randomisation of the participants was conditional on maintaining an equal gender ratio in each group.

	Blackcurrant		No Blackcurrant	
Fatigue	Males	5	Males	5
	Females	10	Females	10
	Total	15	Total	15
No Fatigue	Males	5	Males	6
	Females	10	Females	9
	Total	15	Total	15

Figure 1. Visual representation of the group assignment.

Apparatus and Measures

Motor tasks. The primary aim of the present study was to investigate whether a phytochemical supplement could ameliorate the effect of cognitive fatigue on simple motor performance. The following four motor tasks were considered to be tasks that involved only minimal cognitive input while testing a range of motor domains.

Finger tapping. Participants were asked to tap as fast as they could on the 'B' key of the computer keyboard for 30 seconds, first with their preferred hand, followed by their non-preferred hand. The hand was held in a consistently used fixed position with the arm and hand held raised and parallel to the table; holding the arm in this position differentiated the position from that held in the fatiguing task, ensuring a different muscle group was utilised. Participants were prompted to start tapping when the computer displayed the word "TAP", and were told to continue tapping until prompted by the computer to stop. The number of taps and were recorded by the computer, and the mean number of taps was used for analyses.

Absolute reaction time. A yellow disc (diameter: 108pixels) was presented in the centre of the computer screen at random intervals, ranging from 0.5 to 2 seconds. Participants were asked to respond to the yellow disc as quickly as possible by pressing the "B' key on the keyboard with their index finger. Participants completed 20 trials first with their preferred hand followed by a further 20 trials with their non-preferred hand. Reaction time (± 1 ms) was recorded by the computer. The median reaction time from the 20 trials was recorded and used for the analyses. The mean median reaction time was used in preference to the mean because reaction time response distributions frequently exhibit a positive skew (Whelan, 2008).

The grooved pegboard. The Lafayette Instrument Company Grooved Pegboard Model 32025 (Lafayette Instrument Company, 2002) was used for the present study (Figure 2). Participants were required to insert pegs into holes on a pegboard as quickly as they could. To be inserted, a peg had to be rotated until the ridge on the peg aligned with the groove on the pegboard. Participants first used their preferred hand to fill the pegboard from top to bottom; for the right hand the board was filled from left to right and for the left hand from right to left. They then changed hands and filled the board in the opposite direction. Participants could only pick up one peg at a time and could only use one hand to manoeuvre the peg to make it fit. The time taken to fill the board (in seconds) was recorded manually by the researcher.

Figure 2: Lafayette grooved pegboard.
Source: http://www.wisdomking.com/product/lafayette-grooved-pegboard-test.

Dynamometer. A handheld dynamometer (Lafayette Instrument Company, 2004) was used to measure of grip strength (Figure 3). It required participants to squeeze the dynamometer as hard as they could. The task was alternated between hands until three trials per hand were manually recorded, a total of six trials. The average grip strength for each hand was used in all analyses.

Figure 3: Lafayette dynamometer.
Source: https://www.chponline.com/store/cart.php?m=product_detail&p=382

Subjective measures. In addition to the motor tasks, participants were requested to complete brief questionnaires relating to their level of motivation and mood both before and after completing the fatigue or control task.

Motivation questionnaire. The items used in the motivation questionnaire in this study were based on those developed and validated by Matthews, Campbell, and Falconer (2001). The questionnaire items covered two dimensions, success motivation and task interest motivation. Participants were asked to rate how each of 8 statements applied to them. Ratings for each item were recorded on a 5-point Likert-type scale ranging from 0 to 4, where 0 represented ‘not at all’ and 4 represented ‘extremely’. The questionnaire given before the task was phrased to be pre-tense while the questionnaire given after the task was phrased to be post-tense (see Appendix A). Appendix A also shows that items 2, 4, and 6 were worded in reverse to the other items; that is, they represented the level of boredom. The items that were worded in reverse were recoded for scoring so that the highest possible score always represented the highest level of motivation; for example, where in the normal items the score given correlated to the rating number (e.g. 1=1), the reverse items scale was flipped (0=4, 1=3, 2=2, 1=4 points), and then the scores were added (score range = 0-32).

POMS-Brief. The Profile of Moods Survey Brief Form (POMS-Brief; McNair, Lorr, Heuchert, & Droppleman, 2003) is a 30-item checklist used to measure current mood states. For this task participants were asked to rate the 30 mood states on a 5-point scale from 0 to 4, where 0 represented 'not at all' and 4 represented 'extremely'. The total mood disturbance scores and the fatigue subscale scores were used for analyses. O'Connor (2004) reports the reliability of the overall POMS and the fatigue subscale to be acceptable and consistent with the expectations of the nature of mood. O'Connor also reports the measure to be consistent with other measures of fatigue as well as being able to discriminate between healthy populations and patient groups that should differ in fatigue and mood.

Treatments

Fatigue manipulation

Vigilance Task. To induce cognitive fatigue an "AX" task was completed by participants in the fatigue conditions for 75 minutes. The AX task used was based on the one used by Marcora et al. (2009). The task consisted of 750 trials; each trial began by displaying the letter 'a' in red, followed by two consecutive distractor letters displayed in white. Finally a second red letter was displayed on the screen; this letter was either an 'x' or a 'y'. All letters were presented centre screen on a black background in helvetica font size 100 for 400 ms with 1100 ms between letters. When the final letter was an 'x' participants responded by pressing the key marked with a 'Y' using their middle finger. When the letter shown was a 'y' participants were required to press the key marked with an 'N' using their index finger. Participants had only 400 ms to respond; thus, a high degree of concentration was required from trial to trial. When an incorrect response was made or the response was too slow, a short sharp beep alerted participants to their error. The next trial began as soon as the participant made a response, or missed the response time of the previous trial. Participants were given two sets of practice trials, each consisting of 50 trials before beginning the main task. Because decrements in performance accuracy over time are established effects of cognitive fatigue, performance accuracy for the first 15 minutes and the last 15 minutes were compared. A decline in performance accuracy from the beginning to end of the task would be indicative of cognitive fatigue.

Control task. The control task consisted of participants watching *March of the Penguins* (Darondeau, Lioud, & Priou, 2005) for 75 minutes on the same computer screen used for the AX-CPT. This movie was chosen based on the theme being considered as emotionally neutral by the researchers. Phytochemical manipulation

Phytochemical manipulation

Supplement. Participants in this condition were given a single dose blackcurrant extract in capsule form. The capsules were made up by PFR into 5 kg weight bands (e.g., 60 – 65 kgs) so that participants received roughly 3.2 mg per kg of body weight. The supplement was administered 1 hour before the session began; this was based on research by Nielsen, Dragsted, Ravn-Haren, Freese, and Rasmussen (2003) who report observable levels of blackcurrant anthocyanins to be present in humans around 45 minutes after ingestion. The dose of the supplement was deemed appropriate by past research conducted by PFR identifying the level to be near the cut off point for any further benefit (Hurst, 2014).

Control. The present study did not use a placebo-controlled group; therefore the control group for the phytochemical manipulation received no form of placebo.

Design and Analysis

The study was designed as a 2 x 2 x 2 factorial design, where the factors were: Time (baseline vs. post task), Fatigue condition (fatigue vs. no fatigue), and Blackcurrant condition (blackcurrant vs. no blackcurrant). However, there are potential carryover effects caused by taking the blackcurrant supplement an hour before baseline measures were taken. The blackcurrant supplement can continue to have its effects for up to 10 hours. Therefore, in the condition where participants took the supplement and completed the vigilance task, both of these interventions could be affecting performance. Thus, the 3-way factorial design could not be used for analyses. Therefore, a series of 2-way ANOVAs were used to test each hypothesis individually and a series of *t*-tests were run as manipulation checks. For the first hypothesis (cognitive fatigue will impair subsequent motor performance) a series of 2-way ANOVAs were conducted for each motor task and each hand as well as for mood and motivation, a total of 10 analyses. The factors were Time (baseline vs. post-task) and Condition (fatigue vs. no fatigue, neither of which received a supplement). To test the second hypothesis (a blackcurrant supplement will ameliorate the effects of cognitive fatigue on motor performance) the same process was used; however, the factors were Time (baseline vs. post-task) and Condition (blackcurrant vs. no blackcurrant; both of which were fatigued).

As well as reporting the standard statistical outcomes of these analyses, the effect size is also reported; Cohen's *d* (Cohen, 1988) for *t*-tests and partial eta squared (η_p^2) for ANOVAs. Reporting of the effect sizes allows for further interpretation of the results and indicates the probability of a null result being a true null result or being due to the sample being too small. Cohen's (1988) conventions for effect size are used: $d = .20$ or $\eta_p^2 = .01$ is a small effect; $d = .50$ or $\eta_p^2 = .06$ is medium; and, $d = .80$ or $\eta_p^2 = .14$ is large.

All statistical analyses were completed using the statistical software package IBM SPSS for Windows, version 21 (IBM Corp, 2012).

Procedure

Participants were tested in separate rooms between 0900 hours and 1230 hours, to help minimise any time-of-day effects. Each session ran for 2 hours. When they agreed to take part in the study, participants were asked not to consume any caffeine, fruit or fruit by-products during the morning leading up to their session.

Participants in the conditions receiving blackcurrant supplement came in an hour before the main session was to begin. At this time, they were given an information sheet describing the study. They then gave informed consent and completed a health screen (see Appendix B for each of these forms). Participants were then weighed, wearing normal indoor clothing and given the appropriate dose of the supplement (3.2mg/kg). Participants who were not in the conditions receiving blackcurrant supplement gave informed consent and completed their health screen when they came in to begin the session.

Sessions began by taking baseline measurements of participants' performance on each of the motor tasks; the order of these tasks was randomly assigned. Participants then completed the POMS-Brief and motivation questionnaires, and were then asked to give a 3 ml saliva[1] sample. Following this, participants in the cognitive fatigue condition spent 75 minutes completing the vigilance task, to induce fatigue. Participants who were not in the conditions to be fatigued spent the same length of time watching an emotionally neutral documentary movie about the yearly journey of Emperor Penguins (Darondeau et al., 2005). After completing this stage of the session, participants gave another (1ml) saliva sample. They were then given the POMS-Brief and motivation questionnaires to complete again. Participants then repeated the motor tasks; again, these tasks were presented in a random order. Finally, participants were once again asked to give another 3 ml saliva sample.

Participants were then debriefed and any questions they had were answered, they were then given their voucher and were free to leave.

[1] Saliva samples were collected as a part of the larger research project for analysis of cortisol levels, the analyses are not used in the present study.

Chapter 6: Results

Fatigue Manipulation

Accuracy over time was used to assess whether the AX-CPT task was sufficient in inducing mental fatigue. Looking at Figure 4 below it can be seen that performance accuracy declined as a function of time regardless of whether the blackcurrant extract was taken or not. The small interaction between Time and Condition seen in Figure 4 was not significant, F (1, 28) = .37, p = .55, η_p^2 = .01. There was a significant main effect for Time, F (1, 28) = 20.04, p <.001, η_p^2 = .42, with both conditions showing a decline in performance accuracy from the beginning to the end of the task.

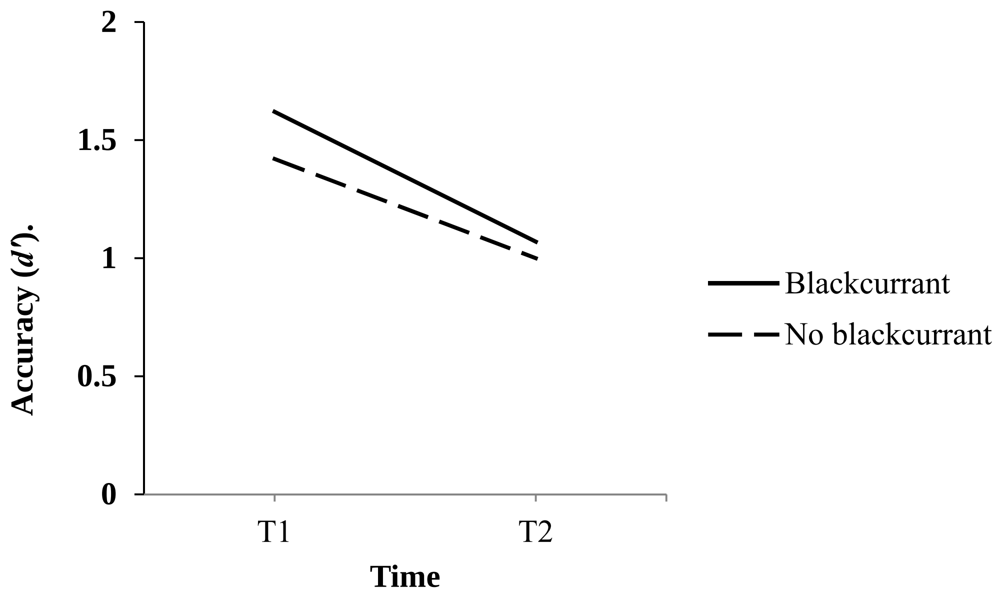

Figure 4. Interaction between condition and time for performance accuracy (*d'*).

Figure 4 reveals that while the difference in performance accuracy at each time point between the two conditions was not significant, those who were supplemented with blackcurrant extract showed slightly better performance accuracy throughout the task than those who were not, though this main effect for Condition was not significant, F (1, 28) = .25, p = .62, η_p^2 = .01.

As a manipulation check, a series of *t*-tests were run to assess whether the significant declines found in performance accuracy over time were associated with increased subjective feelings of fatigue. To make this analysis, subjective fatigue scores were collapsed into two conditions, those who completed the fatiguing task and those who completed the control task, regardless of whether they received the blackcurrant supplement. Paired *t*-tests revealed that for the fatigued condition there was a significant increase in subjective fatigue scores from baseline (M = 4.07, SD = 2.66) to post-task performance (M = 8.07, SD = 4.33), t (29) = 5.64, p <.001, d = 1.11. The control condition (watching DVD) also produced a significant increase in subject fatigue scores from baseline (M =3.77, SD = 3.58) to post-task (M = 5.27, SD = 4.53), t (29) = 2.80, p = .009, d = .37. An independent *t*-test was then run to assess the differences in subjective fatigue scores between the conditions at each time point. There was no significant difference between the conditions at baseline, t (58) = .37, p = .71, d = .10. Subjective fatigue scores post-task revealed that participants who completed the fatiguing task reported significantly higher levels of fatigue compared to participants who completed the control task, t (28) = 2.45, p = .02, d = .63.

In summary, the AX-CPT task successfully reduced performance accuracy over time. This decline in performance accuracy was accompanied by an increase in subjective levels of fatigue. While the control task also appears to have increased levels of subjective fatigue, the AX-CPT task increased these levels at a significantly greater rate. Together these findings suggest the task was sufficient in inducing mental fatigue.

Mood and Motivation

To assess the impact that participants' mood and motivation may have had on performance two sets of mixed between-within ANOVAs were run. The first set was used to analyse the effect fatigue had on mood and motivation. For this, one condition completed the fatigue task and the other the control task; neither received blackcurrant supplementation. A 2 Time (baseline, post-task) x 2 Fatigue (no fatigue, fatigue) ANOVA showed that there was a significant main effect for motivation scores over time, F (1, 28) = 44.89, p <.001, η_p^2 = .62, with both the fatigue and no fatigue conditions showing a decline in motivation. However, motivation for the fatigued condition declined at a greater rate than the control condition, resulting in a significant interaction between Time and Fatigue, F (1, 28) = 5.64, p = .03, η_p^2 = .17, qualifying the main effect. The main effect comparing the fatigue and no fatigue conditions approached statistical significance, F (1, 28) = 3.68, p = .07, η_p^2 = .12, and with a medium effect size of .12, it is likely that a larger sample would have resulted in a significant difference between the fatigue and no fatigue conditions.

Mood disturbance was found to increase significantly over time for both fatigue and no fatigue conditions, F (1, 28) = 24.14, p <.001, η_p^2 = .46. As with motivation, there was a significant interaction between Time and Fatigue, F (1, 28) = 6.69, p = .02, η_p^2 = .19, qualifying this main effect. A greater increase in mood disturbance was seen in those who were fatigued compared to controls. There was no main effect for Fatigue, F (1, 28) = .16, p = .69, η_p^2 = .01.

The second set of analyses was used to examine whether blackcurrant supplementation had any effect on reducing the falloff in mood and motivation in fatigued participants; both of these conditions were fatigued, one received a blackcurrant supplement and the other did not. A 2 Supplement (Blackcurrant, no blackcurrant) x 2 Time (baseline and post-task) ANOVA demonstrated that motivation decreased significantly over time for both supplement and no supplement conditions, F (1, 28) = 52.62, p <.001, η_p^2 = .65. There was no interaction between Time and Supplement, F (1, 28) = .42, p = .52, η_p^2 = .02, with motivation for both conditions decreasing over time at similar rates. No main effect for Supplement was found, F (1, 28) = .50, p = .48, η_p^2 = .02.

Mood disturbance for both the supplement and no supplement conditions increased significantly over time, F (1, 28) = 40.94, p <.001, η_p^2 = .59; however, this increase was shown to be similar for both conditions resulting in no significant interaction between Time and Supplement, F (1, 28) = .56, p = .46, η_p^2 = .02. The main effect comparing the supplement and no supplement conditions was not significant, F (1, 28) = .15, p = .70, η_p^2 = .01.

In summary, mood and motivation did not vary between the Fatigue and Supplement conditions for either analysis. The fatigue task, however, induced greater declines in both mood and motivation than the control task. These declines were not reduced by the blackcurrant supplement, with both those who received the supplement and those who did not showing a similar rate of decline.

Hypothesis 1: Cognitive Fatigue Impairs Subsequent Motor Performance

To test the hypothesis that mental fatigue impairs subsequent motor performance mixed between-within ANOVAs were run for each motor task. A 2 Condition (fatigue vs. no fatigue) x 2 Time (baseline vs. post-task) where Time was the within-subject factor was conducted. Table 1 presents the means and standard deviations for performance on all of the motor tasks for each condition.

Table 1

Means and standard deviations (in parentheses) for motor task performance as a function of Time and Condition.

	Fatigue		Control	
Motor task	T1	T2	T1	T2
Dynamometer				
PH	30.27(10.53)	29.47(8.50)	32.93(9.90)	32.87(9.07)
NPH	30.15(8.95)	28.20(8.34)	31.73(10.44)	30.73(10.18)
Pegboard				
PH	60.99(5.57)	61.96(8.16)	62.12(7.84)	63.48(7.69)
NPH	71.31(7.80)	68.56(7.16)	70.55(9.62)	67.17(7.88)
Reaction time				
PH	.29(.03)	.30(.03)	.29(.03)	.29(.03)
NPH	.30(.03)	.29(.02)	.29(.04)	.28(.02)
Finger tapping				
PH	176.40(34.90)	176.93(25.92)	190.53(25.63)	182.07(23.99)
NPH	157.80(26.79)	158.93(17.79)	168.13(27.90)	159.27(27.75)

Note. T1 = baseline performance; T2 = post intervention (fatigue task or control task); PH = preferred hand; NPH = non-preferred hand.

Units of measurement: dynamometer = kgs; pegboard = seconds; reaction time = milliseconds; finger tapping = number of taps.

Dynamometer

Looking first at the dynamometer values for preferred hand performance, it can be seen that there was slight decrease in performance for the fatigue condition while the control condition remained stable. However, this difference did not result in a significant interaction between Time and Condition, F (1, 28) = .492, p = .49, η_p^2 = .02. There were no main effects for either Time, F (1, 28) = .688, p = .41, η_p^2 = .02, or Condition, F (1, 28) = .777, p = .39, η_p^2 = .03.

In contrast to preferred hand performance, there was a significant main effect for Time, F (1, 28) = 7.93, p = .01, η_p^2 = .22, for non-preferred hand performance. Grip strength at baseline was significantly higher than post task for both conditions (see Table 1). There was no interaction between Time and Condition, F (1, 28) = .826, p = .37, η_p^2 = .03, and no main effect for Condition, F (1, 28) = .358, p = .55, η_p^2 = .01.

Grooved pegboard

Looking at the performance means for the preferred hand in Table 1 it can be seen that over time performance worsened for both the fatigue and no fatigue conditions. There was no interaction between Time and Condition, F (1, 28) = .038, p = .85, η_p^2 = .001. While there was an increase in time taken to complete the task, it was insufficient to produce a significant main effect for Time, F (1, 28) = 1.31, p = .26, η_p^2 = .05. However, given the effect size of .05, it is likely that had there been a larger sample the difference between baseline and post task performance would have been significant. There was no main effect for Condition, F (1, 28) = .280, p = .60, η_p^2 = .01.

Non-preferred hand performance resulted in a significant main effect for Time, F (1, 28) = 7.39, p = .01, η_p^2 = .21, with the time taken to complete the task being slower at post task than baseline (see Table 1). A main effect for Condition was not found, F

(1, 28) = .193, p = .664, η_p^2 = .01, and there was no interaction between Time and Condition, F (1, 28) = .188, p= .668, η_p^2 = .01.

Simple reaction time

Reaction time for the preferred hand showed no main effects for Time, F (1, 28) = 3.24, p = .08, η_p^2 = .10, or Condition, F (1, 28) = .228, p = .64, η_p^2 = .10. The effect size of .10 for an effect over time, however, suggests that a larger sample would have resulted in a significant main effect for Time. There was not interaction between Time and Condition for simple reaction time, F (1, 28) = .299, p = .589, η_p^2 = .01.

Reaction time for the non-preferred hand also showed no interaction between Time and Condition, F (1, 28) = .301, p = .59, η_p^2 = .01. Further, there were no main effects for Time, F (1, 28) = 2.72, p = .11, η_p^2 = .09, or Condition, F (1, 28) = 1.66, p = .21, η_p^2 = .06, although there were moderate to small effect sizes of .09 and .06, respectively.

Finger tapping

Interestingly, the means in Table 1 for finger tapping performance with the preferred hand show that performance remained stable for the fatigue condition yet decreased for the controls, with the controls showing better overall performance. Despite this, the interaction between Time and Condition was not significant, F (1, 28) = 1.10, p = .303, η_p^2 = .04, nor were there significant main effects for these two factors, F (1, 28) = 1.08, p = .307, η_p^2 = .04, and F (1, 28) = .86, p = .363, η_p^2 = .03, respectively.

In contrast, performance with the non-preferred hand revealed a significant interaction between Time and Condition, F (1, 28) = 4.82, p = .04, η_p^2 = .15, with performance remaining relatively stable over time for the fatigue condition and declining over time for the controls (see means in Table 1). The main effect for Time did not reach significance, F (1, 28) = 2.88, p = .101, η_p^2 = .09. The effect size was medium but qualified by the interaction. . There was no main effect for condition, F (1, 28) = .35, p = .31, η_p^2 = .04.

Summary

In summary, the results suggest that the fatigue induced appears to have little influence on subsequent motor performance in comparison to controls. With the exception of finger tapping with the preferred hand, both the fatigue and no fatigue conditions changed in similar ways following the manipulation task. While motor performance did decline significantly from baseline to post-task on the dynamometer and pegboard tasks, the decline was seen equally in the control condition, suggesting it was not the fatiguing task that resulted in this decline. The effects that were seen were more prominent in performance with the non-preferred hand compared to the preferred hand, suggesting non-preferred hand performance may be more susceptible to the effects of cognitive fatigue.

Hypothesis 2: Blackcurrant Supplement Ameliorates the Effects of Cognitive Fatigue on Motor Performance

To test the hypothesis that blackcurrant supplement reduces the effects of mental fatigue on motor performance, mixed between-within ANOVAs were run for each motor task, in which, Condition (supplement vs. no supplement) was the between-subject factor and Time (baseline vs. post-task) was the within-subject factor. Both groups associated with the two levels of Condition were fatigued. Table 2 presents the means and standard deviations for performance on all of the motor tasks for each condition.

Manipulation check

Due to the blackcurrant supplement being administered before baseline performance was measured, independent *t*-tests were run to ensure that baseline performance was not affected by the supplement. These tests revealed no significant (all *p*s >.05) differences in baseline performance between participants who received the supplement and controls for any of the motor tasks

Table 2

Means and standard deviations (in parentheses) for motor task performance as a function of Time and Condition.

	Blackcurrant		Control	
Motor task	T1	T2	T1	T2
Dynamometer				
PH	30.93(9.02)	29.93(8.18)	30.27(10.53)	29.47(8.50)
NPH	29.53(9.56)	27.53(8.44)	30.15(8.95)	28.20(8.34)
Pegboard				
PH	62.02(6.32)	63.29(7.90)	60.99(5.57)	61.96(8.16)
NPH	70.56(5.90)	70.51(7.89)	71.31(7.80)	68.86(7.16)
Reaction time				
PH	.30(.03)	.29(.03)	.29(.03)	.30(.03)
NPH	.31(.03)	.30(.02)	.30(.03)	.29(.02)
Finger tapping				
PH	181.00(18.82)	177.47(19.19)	176.40(34.90)	176.93(25.92)
NPH	160.80(18.41)	162.00(22.04)	157.80(26.79)	158.93(17.79)

Note. T1 = baseline performance; T2 = post fatigue task performance; PH = preferred hand; NPH = non-preferred hand.

Units of measurement: dynamometer = kgs; pegboard = seconds; reaction time = milliseconds; finger tapping = number of taps.

Dynamometer

The means for grip strength with the preferred hand (see Table 2) show that performance was effectively the same for both conditions at each time of measurement, resulting in there being no significant interaction between Time and Condition, F (1, 28) = .036, p = .85, η_p^2 = .001, and no main effect for Condition, F (1, 28) = .030, p = .86, η_p^2 = .001. The main effect for time did not reach statistical significance, F (1, 28) = 2.88, p .101, η_p^2 = .09, but with an effect size of .09

(medium) it is likely that a larger sample would have resulted in a statistically significant main effect, with performance declining as a function of time.

Similarly, performance with the non-preferred hand also resulted in there being no interaction between Time and Condition, F (1, 28) = .003, p = .956, η_p^2 = <.001, nor was there a main effect for Condition, F (1, 28) = .04, p .842, η_p^2 = .001. There was a main effect for Time, F (1, 28) = 22.63, p <.001, η_p^2 = .45, with performance decreasing from baseline to post fatigue measurement (see Table 2).

Grooved pegboard

Mean speed for completing the pegboard with the preferred hand increased slightly for both conditions (Table 2). However, this increase was not large enough to produce a significant main effect for Time, F (1, 28) = .76, p = .39, η_p^2 = .03. With both conditions increasing by the same margin there was no interaction between Time and Condition, F (1, 28) = .02, p = .91, η_p^2 = .001, and no main effect for Condition, F (1, 28) = .28, p = .39, η_p^2 = .03.

Non-preferred hand performance on this task showed no main effect for Time, F (1, 28) = 1.11, p = .30, η_p^2 = .04. Looking at Table 2 it can be seen that performance for the condition that received the blackcurrant supplement remained stable over time while the control condition slightly improved; however, this did not result in a significant interaction, F (1, 28) = 1.01, p = .32, η_p^2 = .04. Finally, there was no main effect for Condition, F (1, 28) = .04, p = .849, η_p^2 = .001.

Simple reaction time

Examination of the means for preferred hand performance (Table 2) shows that there was an improvement in performance for the condition supplemented with blackcurrant, while those who were not supplemented demonstrated a decline in performance. This interaction was significant, F (1, 28) = 4.05, p = .05, η_p^2 = .13, producing a large effect size. There were no main effects for either Time, F (1, 28) = .007, p = .93, η_p^2 = <.001, or Condition, F (1, 28) = .01, p = .92, η_p^2 = <.001.

For non-preferred hand performance there was no significant interaction between Time and Condition, F (1, 28) = .36, p = .55, η_p^2 = .01. Nor was the main effect for Time statistically significant, F (1, 28) = 3.17, p .09, η_p^2 = .10, although the effect size of .10 suggests there was a change between pre- and post-testing. There was no main effect for condition, F (1, 28) = .54, p = .47, η_p^2 = .02.

Finger tapping

Performance with the preferred hand produced no significant interaction between Time and Condition, F (1, 28) = .21, p = .65, η_p^2 = .007. There were also no significant main effects for Time, F (1, 28) = .11, p = .74, η_p^2 = .004, or Condition, F (1, 28) = .10, p = .76, η_p^2 = .003. The same was found for performance with the non-preferred hand, with there being no interaction, F (1, 28) = <.001, p = .988, η_p^2 = <.001, and no main effects, both *F*s <1.

Summary

In summary, the results for this hypothesis suggest that blackcurrant extract had little effect on motor performance following cognitive fatigue. Preferred hand reaction time performance was the only motor task to show an interaction between Time and Condition, with the blackcurrant condition becoming quicker while the control condition became slower. Performance on all other motor tasks appeared to remain stable between the conditions with any changes in performance being evident in both conditions.

Chapter 7: Discussion

The present study aimed to find out if the cognitive fatigue-related declines in motor performance can be ameliorated by supplementation with a blackcurrant extract. In order to achieve this, two questions needed answering: does cognitive fatigue impair motor performance? And does a blackcurrant supplement ameliorate the effects cognitive fatigue has on motor performance? Before answering these two main research questions, it was necessary to ensure the task chosen to induce fatigue successfully did so. The answers to these questions are summarised below.

Did the AX-CPT task successfully induce cognitive fatigue? As expected from previous research (Marcora et al., 20009; van der Linden et al., 2006), this task was sufficient in inducing cognitive fatigue. This was demonstrated by a decrease in the accuracy rates from beginning to the end of the task, as well as by an increase in levels of subjective fatigue that was greater than the increase seen in the control group.

Does cognitive fatigue impair motor performance? There have been few studies investigating the effects of cognitive fatigue on simple motor performance, and those that have largely focused on simultaneous performance on mental and physical tasks. The present study was interested in finding out the effects of cognitive fatigue on subsequent simple motor performance. It was expected that motor task performance would be poorer following completion of a mentally demanding task than following a control task that did not require such a high degree of concentration. Non-preferred hand performance on all of the motor tasks did decline following the vigilance task, but performance declined at a similar rate following the control task. Thus, the control appears to have affected motor performance in the same way as the cognitively demanding task. As was predicted, non-preferred hand performance appears to have been affected to a slightly greater extent than preferred hand performance in both the fatigued and control conditions.

Does blackcurrant supplementation ameliorate the effects cognitive fatigue has on motor performance? It was expected that motor performance would be less affected by the vigilance task in participants who received a blackcurrant supplement compared to those who received no supplement. Taken together, the findings did not support this hypothesis. Although performance on a few of the motor tasks produced statistically significant differences there was no overall consistent pattern.

Inducing Cognitive Fatigue

There was a significant main effect for time when analysing performance accuracy for the AX-CPT task. This decline in performance accuracy occurred regardless of whether participants received a blackcurrant supplement. Using this decline in performance over time as a measure of cognitive fatigue is appropriate in the present study as previous research has identified such declines to be reflective of cognitive fatigue. For example, brain imaging studies have shown that the physiological changes that occur within the brain when a person is cognitively fatigued also occur as the time spent on a demanding task continues (Boksem et al., 2005). Therefore, it can be said that the AX-CPT task used in the present study was successful in inducing cognitive fatigue, represented by a decline in performance accuracy over time. This decline in performance accuracy has been suggested to be caused by a decrease in the ability to maintain selective attention and the inability to develop new strategies to improve performance as participants become fatigued (Tanaka, Mizuno, Tajima, Sasabe, & Watanabe, 2009).

As an additional check to ensure the declines in performance accuracy were indicative of cognitive fatigue, and to compare the fatigue levels in those who completed the fatiguing task and those who completed the control task, subjective levels of fatigue were analysed. From these analyses it was found that subjective levels of fatigue increased in those in the vigilance task condition. Subjective levels of fatigue also increased in the control condition. Whether this increase in subjective fatigue was the result of the control task actually inducing a state of cognitive fatigue is not known. However, given the difficulty in distinguishing between cognitive fatigue and boredom (Lal & Craig, 2001), it is possible that the movie used for the control condition did not fit the expected emotionally neutral criteria and was in fact boring rather than fatiguing. Establishing whether it was boredom or fatigue that was induced is difficult because as Scerbo (1988) highlights, they have very similar characteristics with both showing decreases in arousal and performance. Despite subjective fatigue increasing for both conditions, the levels of subjective fatigue increased at a significantly greater rate from baseline for the vigilance task condition compared to the control condition.

Hypothesis 1: Cognitive Fatigue Impairs Subsequent Motor Performance

The purpose of investigating Hypothesis 1 was to find out if a person's degree of mental alertness could impact on motor performance just as physical tiredness can impact mental performance (Dietrich & Sparling, 2004; Hogervorst, Riedel, Jeukendrup, & Jolles, 1996). It was expected that motor performance would decrease at a greater rate over time (relative to baseline) when participants were exposed to a mentally fatiguing task compared to a control task. It was also expected that performance with the non-preferred hand would be affected to a greater extent than preferred hand performance; this is because tasks that require skills that are automated are less likely to be affected by cognitive fatigue (Langner et al., 2010). Thus, it was reasonable to expect the non-preferred hand to be most affected by cognitive fatigue since it is less practised, and therefore less automated, in simple motor task skills.

Contrary to expectations, a significant Time x Condition interaction was only found for performance on one of the motor tasks: finger tapping with the non-preferred hand. On the whole, participants who completed the vigilance task did not show a greater decline in motor performance on any of the other motor tasks compared to the controls. Any declines that did occur in motor performance were just as likely to occur in the control condition. As shown by the effect size statistics, motor performance with the non-preferred hand was affected to a greater extent than with the preferred hand, as was expected. Declines in performance for the non-preferred hand often produced moderate to large effect sizes, emphasising the potential for non-preferred hand performance to be significantly impaired by cognitive fatigue. Declines in preferred hand performance did not reach significance for any of the motor tasks, and the effect sizes suggest that only two of the tasks (pegboard η_p^2 = .21; reaction time η_p^2 = .09) would potentially have reached significance if the sample contained more participants. The implications of these findings will be discussed shortly; first, a discussion of the methodological differences among previous research and the present study is warranted.

The lack of Time x Condition interactions in the present study is inconsistent with previous reports, in which motor performance was significantly affected by cognitive fatigue (e.g., Bray et al., 2012; Mehta & Agnew, 2012). There are a number of methodological differences among previous studies and the present study that could have, at least in part, contributed to the different outcomes obtained. . Firstly, the type of task used to induce a cognitive fatigue state differed among the studies, as did the tasks used in control conditions. In Bray and colleagues' (2008, 2012) studies, an incongruent Stroop task was used to induce fatigue. Participants were presented with a list which consisted of the names of colours, the colour of the ink the word was written in was different to the name of colour (e.g., the word "blue" may be written in red ink) Participants were required to say aloud the colour of the ink for each word, unless the ink was red; then they had to say the written word. Mehta and Agnew (2011) also used an incongruent Stroop task to induce cognitive fatigue. In a later study, Mehta and Agnew used a mental arithmetic task to induce cognitive fatigue, in which participant were required to multiply a given number by three and continue to multiply each answer by three for an unspecified period of time. This task was undoubtedly incredibly boring; therefore, the effects described by the authors could be the result of boredom as opposed to cognitive fatigue. The present study used the AX-CPT to induce cognitive fatigue, based on the vigilance task used by Marcora et al. (2009). The task required sustained attention, error monitoring, response inhibition and working memory, most likely resulting in activation of the anterior cingulate cortex (ACC), a brain structure that has been shown to be associated with both cognitive fatigue and motor performance (Bray et al., 2012; Marcora et al., 2009). Despite the differences in the cognitively demanding tasks used, all of the studies reported successfully inducing a level of cognitive fatigue.

As well as the differences in the tasks used to induce cognitive fatigue, previous studies also varied in the tasks used for the control conditions. Bray and colleagues (2008, 2012) used variations of the same task used to induce fatigue, but at a low cognitive demand level. The task was a congruent Stroop, in which the words were printed in the same colour as the word (e.g., the word "blue" in blue ink). In both of Mehta and Agnew's (2011, 2012) studies the control condition was defined by an absence of the fatigue-inducing task, with participants completing no task in its place. Both Marcora et al. (2009) and the present study used a presumed emotionally neutral documentary in place of the fatigue inducing task for the control conditions. However, different documentaries were used for the two studies. The difference in documentaries is an important consideration in understanding the different results found in the present study. While the present study found that subjective levels of cognitive fatigue increased significantly following the documentary, Marcora et al. reported no significant increase in cognitive fatigue following the documentary used in their study. Ideally, movies with standardised themes should always be used; this would help in reducing the influence movie content may have to states of fatigue and boredom. At present, however, there is no such standardised material. Further research looking into the effects different movie themes may have on mood, motivation, and cognition and establishing standardised material would be of benefit.

Secondly, the presentation of the manipulation task in relation to the motor tasks differed across the studies. Mehta and Agnew (2011, 2012) looked at the effects on motor performance when a cognitively demanding task was completed simultaneously with the motor task. Bray et al. (2012) used performance blocks to determine the effects on motor performance; after completing baseline measures for the motor task, participants then completed seven 3 minute blocks, which consisted of performing the cognitive task followed by the motor task. The present study and those of Bray et al. (2008) and Marcora et al. (2009) looked at the effects that cognitive fatigue have on subsequent motor performance.

Thirdly, the length of time spent on the fatigue-inducing task varied substantially across these studies. Due to the simultaneous performance of tasks in Mehta and Agnew's (2011, 2012) studies, the time spent on the cognitive task was dependent on physical performance and therefore inconsistent across participants. For these studies participants were instructed to perform both the cognitive and motor tasks until physical exhaustion, that is, until the motor task could not be continued. Bray et al. (2012) administered the cognitive task in seven sets of 2.45 minutes with a 15 second break between trials, in which time the motor task was performed for a total of 22 minutes. In their earlier study, Bray et al. (2008) administered the cognitive task for 3.40 minutes before assessing subsequent motor performance. In Marcora et al.'s (2009) study the vigilance task was performed continuously for 90 minutes, whereas in the present study participants performed the vigilance task continuously for 75minutes. Despite the significant variations in time-on-task, all studies reported the task having significant effects on cognitive fatigue and motor performance. Interestingly, physical performance appears to have been affected to a greater extent in the studies that employed longer time-on-task. However, this effect is confounded by the fact that in some studies the cognitive and physical tasks were performed simultaneously while in others the physical task was subsequent to the cognitive task.

Fourthly, there were differences across all of the above studies in regard to the number of motor tasks assessed. The present study focussed on the effects that cognitive fatigue had on four different motor tasks; the dynamometer, the grooved pegboard, simple reaction time, and finger tapping. However, the majority of previous research used only a single task (Bray et al., 2008; Bray et al., 2012; Marcora et al., 2009; Mehta & Agnew, 2011, 2012). Not only were there differences in the number of motor tasks assessed but also in the type of motor tasks. The variety of motor tasks assessed in the present study allowed for the effects of cognitive fatigue in different functions of motor performance to be assessed; grip strength, motor speed, reaction time, and motor coordination. Previous research using only one motor task was only able to look at the effects in one domain of motor function. The domain that has been most prominent in previous research is endurance performance, both muscular endurance (Bray et al., 2008; Bray et al., 2012; Mehta & Agnew, 2011, 2012) and physical endurance (Marcora et al., 2009).

Given the number of differences in the methodologies of research in this area, caution needs to be exercised when comparing the results of the present study with the results of previous studies. Despite the differences, however, the findings of previous studies are still relevant and helpful in interpreting the findings of the present study. It is possible that the cognitively demanding task used to induce cognitive fatigue in the present study did not sufficiently deplete the resources required for further performance on a subsequent task. The resource depletion theory suggests that as time-on-task increases, cognitive resources become depleted and with little chance to replenish these resources performance on the task is affected (Helton & Russell, 2011; Helton & Warm, 2008; Langner et al., 2010). This depletion of resources is increasingly being recognised as having the potential to carry over into performance on subsequent tasks, even when the tasks draw from different domains of resources (Bray et al., 2012; Hagger, Wood, Stiff, & Chatzisarantis, 2010). However, research is yet to determine the level of resource depletion required for it to carry over into other domains.

The finding that the cognitively demanding task used in the present study successfully induced a level of cognitive fatigue, as indicated by a decrease in performance overtime, supports the resource depletion theory. The decrease in performance is the result of the cognitive resources required to successfully perform the task being depleted as the time-on-task continued with no chance for those resources to be replenished. However, the present results did not support the idea that resource depletion in one area of performance carries over to performance in another domain. Motor performance in the vast majority of tasks with preferred and non-preferred hands did not decline to a greater extent following performance on the cognitively fatiguing task compared to performance on the control task. There are two possible explanations for this; the first is that the level of resource depletion, or cognitive fatigue, induced by the cognitively demanding task was enough to impair performance in the current task but was not sufficient enough to carry over to subsequent tasks. The second possibility is that the decline in performance in the cognitive task was not the result of resource depletion, but of a state of mindlessness or boredom.

Robertson and colleagues (Manly, Robertson, Galloway & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) suggest that the declines seen in performance are the result of understimulation. This understimulation ultimately results in participants becoming distracted and disengaged from the task, leading to a mindless automated style of responding. Given the highly routinised nature of the cognitive task in the present study, it is possible that as time-on-task continued, participants began to mindlessly respond to the cues leading to declines in performance accuracy. This could explain the lack of effects the cognitively fatiguing task had on subsequent motor performance. A change in task is often all that is required to overcome the feelings of fatigue when the cause is boredom, or a decrease in arousal, as opposed to cognitive overload (Myers, 1937). In this sense, stopping the vigilance task and changing to the motor tasks may have been enough for the subjective feelings of fatigue to be overcome; thereby resulting in the lack of observed effects on the subsequent performance.

Alternatively, the control task may have induced too much fatigue, thereby masking the effects that cognitive fatigue had on subsequent motor performance. Given that previous research has successfully used the same cognitively demanding task to induce cognitive fatigue and demonstrate the effects on subsequent performance (Marcora et al., 2009; van der Linden et al., 2006), this is a plausible explanation. The present study also found that following the cognitive task, motor performance declines did occur. However, these declines were equally seen following the control task for the majority of motor tasks, resulting in there being no interaction between time and condition. Therefore, it is possible that motor performance declines were the result of cognitive fatigue, with both the experimental and control tasks inducing fatigue and leading to a decline in performance. Future research should therefore ensure that fatigued and control conditions are clearly distinguishable, with control participants showing minimal increases in subjective fatigue. To achieve this, future research must try to gain a better understanding of the relationship between fatigue and boredom.

As expected, performance declines were seen to a slightly greater extent in performance with the non-preferred hand compared to the preferred hand in the present study. This is an interesting result that highlights the importance of future research not only looking at performance with both preferred and non-preferred hands, but also looking at performance on a number of tasks that assess a range of motor functions. Performance with the non-preferred hand is much less automated and practised compared to the preferred hand, and therefore is much more sensitive to situations aversive to performance, such as a state of cognitive fatigue (Langer et al., 2010). To successfully complete tasks with the non-preferred hand requires constant effortful attention, which is known to be impaired under conditions of cognitive fatigue (Boksem et al., 2005; van der Linden et al., 2003). However, previous research appears not to have taken this into consideration, with the majority of studies either assessing performance with only the preferred hand or arm, or not specifying which was used (Bray et al., 2012; Malstrom, Wolinsky, Andresen, Miller, & Miller, 2005; Mehta & Agnew, 2011, 2012). The finding in the present study that non-preferred hand performance was impaired to a greater extent than preferred hand performance suggests that motor tasks used may not have been sensitive enough to detect performance changes following cognitive fatigue. That is, the more sensitive a task is to the effects of cognitive fatigue, then the more likely it would be that preferred hand performance on that task would also be affected.

Just as performance with the non-preferred hand requires constant effortful attention, so does performance on tasks that are novel. Performance on novel tasks requires an element of learning and skill acquisition. This involves brain structures used in planning, preparation and control of voluntary movements, such as the basal ganglia and ACC (Macready et al., 2010). These structures have been shown to be impaired under conditions of cognitive fatigue and influence the effects cognitive fatigue has on subsequent performance (Bonnefond et al., 2011; Bray et al., 2012; Chaudhuri & Behan, 2000; Fellus & Rashidzada, 2005; Paus, 2001). However, as tasks become better learned and more automated, there is a shift in the patterns of activity in the brain needed to perform the task (Macready et al., 2010). For this reason, motor tasks that are novel are more likely to be sensitive to conditions of cognitive fatigue than are those which are automatic and well learned.

Therefore, while the results in the present study suggest that simple motor performance was not generally affected by cognitive fatigue, it is important to consider the possibility that the motor tasks used were not sensitive enough to capture any fatigue-related changes; that is, the tasks required well learned and automated skills. The one significant interaction found in analyses testing this hypothesis indicated that finger tapping with non-preferred hand was affected to a greater extent under conditions of cognitive fatigue compared to control conditions. While finding a significant interaction for only one motor task may be due to chance, it also highlights the importance of examining the effects on a range of motor tasks that measure a range of motor functions. It could be that motor speed was the only motor task sensitive enough to show the effects of cognitive fatigue. Using a range of motor tasks can therefore prevent incorrect conclusions being drawn; suggesting task sensitivity plays a major role in the outcomes of such research. The exact element of task performance that needs to be novel is less clear; it could be that the task itself needs to be novel to produce effects, in which case all of the tasks used in the present study would be considered novel being that they are not tasks one performs on a regular basis. However, given that cognitive fatigue has been shown to impair brain structures involved in motor performance (Macready et al., 2010), it is more likely that it is the motor programmes within the brain required to complete the task that need to be novel. There would be great benefit from future research trying to establish whether it is task unfamiliarity or less developed motor programmes that are impaired in cognitive fatigue.

The majority of previous research has only examined the effects on single motor functions, and for the most part has been focused on the effects on muscle strength and endurance (Bray et al., 2008; Bray et al., 2012; Mehta & Agnew, 2011, 2012). These studies have established consistent results showing that motor performance in this domain is affected by cognitive fatigue. This suggests that tasks requiring muscle strength are sensitive to the effects of cognitive fatigue. This is likely due to the muscle motor units being extremely vulnerable to activation, with continuous performance on cognitively demanding tasks keeping these motor units activated (Lundberg et al., 2002). Interestingly, the present study did not find grip strength to be affected to a greater extent in fatigued participants compared to controls; however, it showed the largest decline in performance over time for both conditions. Therefore, the control task may have provided enough mental stimulation to keep the motor units activated enough to impair subsequent performance.

In summary, the results as a whole did not support the hypothesis that cognitive fatigue impairs subsequent motor performance. There are ultimately three possible explanations for the lack of findings in support of this hypothesis: first, the cognitively demanding task did not induce greater enough levels of fatigue, or resource depletion, to carry over into performance in subsequent tasks; second, the control task induced a level of cognitive fatigue that masked the effects the cognitively demanding task had on subsequent motor performance; and third, the motor tasks used were not sensitive enough to capture the effects of cognitive fatigue.

Hypothesis 2: Blackcurrant Supplement Ameliorates the Effects of Fatigue on Motor Performance

The main research question was whether blackcurrant supplementation has the ability to reduce the effects mental fatigue has on motor performance. The ability for phytochemicals to play a role in both cognitive and physical performance is increasingly being recognised (Chung et al., 2012). Some previous research has shown that different phytochemicals can reduce deficits in both cognitive and physical performance (e.g., Kim et al., 2010; Krikorian, Shilder et al., 2010; Miller & Shukitt-Hale, 2012; Papandreou et al., 2009) Typically these studies look at the effects on cognitive and physical performance independently of one another, with the present study appearing to be the first to examine the ability of a phytochemical to reduce the effects of cognitive fatigue on motor performance. Based on the findings of previous research it was expected that the present study would find that participants who were supplemented with a blackcurrant extract would show less impairment in motor performance following a cognitively fatiguing task compared to participants who were not given the supplement. It was anticipated that the blackcurrant supplement would act in one of two ways: first, by preventing the onset of cognitive fatigue, or by lessening the level of cognitive fatigue; or secondly, by acting as a barrier to the effect cognitive fatigue has on subsequent motor performance. That is, the vigilance task was still fatiguing, but motor performance was not impaired as a result of the fatigue. Neither of these predictions were found to be true; performance accuracy on the vigilance task declined at a similar rate in both those who received the supplement and those who did not, suggesting the blackcurrant supplement did not reduce impairment to cognitive functioning as time-on-task continued. With the exception of reaction time performance with the preferred hand, there were no significant interactions between Time and Condition. Neither did the blackcurrant extract influence motor performance following the onset of cognitive fatigue, with both those who received the supplement and those who did not showing similar changes in motor performance from baseline to post vigilance task. However, given the lack of effects cognitive fatigue had on motor performance, it is difficult to make generalisations about the findings for the effect of the blackcurrant supplement. Had motor performance been more impaired under cognitive fatigue then the effects of the blackcurrant supplement may have been bigger or more observable.

Despite the lack of significant findings for the first hypothesis, there are still a number of possible explanations as to why the blackcurrant supplement had no observable effects in the present study. Just as sensitivity was an issue in discussing the effects of cognitive fatigue on motor performance, it is equally important to mention here. Previous research has shown that phytochemicals have the potential to cross the blood-brain barrier, implying that a direct association with the brain is likely to be how phytochemicals influence performance (Papandreou et al., 2009; Shukitt-Hale et al., 2005; Spencer, Vauzour, & Rendeiro, 2009). However, the mechanisms within the brain by which phytochemicals act on cognitive and physical performance are not entirely understood. Therefore, the mechanisms that are influenced by phytochemicals may not have been utilised by the tasks used in the present study. Thus, the tasks were not sensitive to the changes in brain activity caused by phytochemical supplementation. Again, this demonstrates the importance of assessing multiple domains of functioning in order to avoid drawing incorrect conclusions about the potential influence phytochemicals may have in reducing the effects fatigue has on motor performance. This is highlighted in the present study by the finding that one motor task, reaction time with the preferred hand, resulted in a significant interaction between Time and Condition. This finding could be due to chance, or it could represent an area of functioning that is sensitive to phytochemical supplementation. In order to overcome the barrier that task sensitivity imposes on research of this nature, investigations are needed to determine the mechanisms through which phytochemicals influence both cognitive and physical performance as well as determining which tests are sensitive to these mechanisms.

The vigilance task used in the present study successfully induced mental fatigue as shown by the reduction in overall performance accuracy. Overall performance accuracy was deemed an appropriate measure in the present study as it has been shown to be indicative of the onset of cognitive fatigue (Csathó et al., 2012; van der Linden & Parasuraman, 2013). Because the purpose of the vigilance task was purely to induce cognitive fatigue it was not considered necessary to assess the individual components of performance accuracy (e.g., hit rate and false alarm rate). However, by looking only at the overall performance on this task, the chances of observing an effect on performance caused by the blackcurrant supplement may have been limited. Hoyland, Lawton, & Dye (2008) report that limiting analyses on a cognitive task to overall performance will not necessarily allow for changes in performance to be observed. They suggest that only a small element of task performance may be affected by food supplementation. Therefore, had the present study conducted separate analyses on the elements that made up the measure of overall performance accuracy, for example, hit rate and false alarm rate, there may have been observable changes in performance on the vigilance task caused by the blackcurrant supplement.

The dose of the blackcurrant supplement used in the present study may also have been a contributing factor in the lack of significant findings. Previous research has demonstrated that phytochemicals can have significant effects on performance in both cognitive and physical tasks. These studies, however, often involve long term supplementation with the large majority of studies providing supplementation for anywhere between 7 days to 4 months (Papandreou et al., 2009; Miller & Shukitt-Hale, 2012; Shukitt-Hale et al., 2006; Shukitt-Hale et al., 2009; Shukitt-Hale et al., 2005). A small amount of research has examined the effects of single doses of phytochemical supplements (Kennedy et al., 2010; Lindheimer, Loy, and O'Connor, 2013) but with inconsistent results. Due to time constraints and compliance issues, the present study opted for a single dose supplement. Had the supplement been administered over a longer of period of time, it is possible that the results would have been more consistent with previous research showing phytochemical supplementation to influence performance.

Previous research by Shukitt-Hale et al. (2006) has demonstrated the importance of the concentration of the phytochemical in influencing both cognitive and physical performance. In their study they found that grape juice supplemented diets with a concentration of 10% was effective in reducing declines on cognitive performance, while it took a concentration of 50% before an effect on motor performance could be seen. This suggests that dose of 3.2 mg/kg of body weight given in the present study may not have been sufficient in reducing performance changes resulting from cognitive fatigue, although the size of the dose was close to the level where increasing the supplement would have had no extra benefit (S. Hurst, personal communication, June 19, 2013). The dose given does not appear to have been large enough to influence cognitive performance let alone motor performance. Therefore, future research needs to look at determining the dose-response curve for different amounts of the blackcurrant supplement.

In summary, the results of the present study did not support the hypothesis that a blackcurrant supplement would reduce the effects mental fatigue has on subsequent motor performance. The blackcurrant extract was found to have no influence on cognitive performance, and as a whole was not found to prevent impairments to motor performance caused by cognitive fatigue. Interpreting these findings was made difficult by the lack of effect cognitive fatigue had on motor performance; however, aside from this there were a number of possible explanations that may have contributed to the blackcurrant supplement having no observable effects. First, the motor tasks assessed in this study may not have been sensitive to the effects of phytochemical supplementation, that is, the mechanisms that are influenced by phytochemicals entering the brain were not involved in the brain activity required to perform the motor tasks. Second, the way in which cognitive decline was assessed was not sensitive to the effects of phytochemicals. The supplement may have only induced changes in small elements in the task that were not observable in overall performance. Third, and possibly the most influential in the results of the present study being inconsistent with previous research, was the dose of the blackcurrant extract perhaps being too small, or not being administered over a long enough period, to have an effect on both cognitive and motor performance.

Limitations

The present study appears to be the first to examine whether phytochemical supplementation can ameliorate the effects had on motor performance by mental fatigue. Thus, the method used for the study was one of exploration to determine the potential for such a supplement to improve motor functioning in aversive circumstances, such as when cognitively fatigued. Given the explorative nature of the study, there are a number of limitations that need to be discussed that may have affected the findings, as well as the generalisability of the study.

The small sample size used in this study appears to have had a large impact on the results. For the majority of the analyses conducted to assess the effects of cognitive fatigue on motor performance there were effects. However, the effects were not large enough to produce statistically significant outcomes. A larger sample would likely have resulted in some significant interactions between Time and Condition, indicating that cognitive fatigue is capable of impairing performance on simple motor tasks. Had this been the case, any effects the blackcurrant supplement may have had would have been likely to be more observable.

The difficulty in distinguishing between cognitive fatigue and boredom is a long recognised issue in cognitive fatigue research (Krueger, 1989; Lal & Craig, 2001; Myers, 1937; Scerbo, 1998). While the present study sought to separate the two by using an emotionally neutral documentary style movie for the control task, further consideration of how boring the task was could have prevented the increase in levels of subjective fatigue in control participants. In saying that, the vigilance task used to induce cognitive fatigue may have induced symptoms more indicative of boredom or mindlessness as opposed to a depletion of resources due to the inherent routinisation involved in the task. This could be overcome in future research by using a different task, or modifying the current task so there is less of an element of routinisation. This could involve using a number of different cognitively demanding tasks that the participants complete for a set amount of time before moving to the next. Moreover, Scerbo (1998) suggests that vigilance tasks are less boring when you know you can quit, therefore, to overcome the boredom element of inducing cognitive fatigue participants could change between a number fatiguing tasks as they get bored. This does, however, raise a new concern; the changing of tasks may interfere with the level of fatigue induced.

The present study used no placebo for the control condition. The decision to follow this method was made because it was suspected that if the blackcurrant supplement resulted in any effects they would have been small and the use of a placebo could have masked those effects. However, participants were not blinded to the conditions; therefore, they knew whether or not they were receiving the supplement. It is suggested that future research uses a double blind procedure where neither the researchers nor the participants know what condition participants are in until after data collection is complete.

Participants who received the blackcurrant supplement had an hour of free time between taking the supplement and beginning the study. Allowing participants to leave the lab during this time may have created some problems. First, in that hour participants were free to do as they pleased and were only instructed not to consume any caffeinated beverages or fruit products. This likely resulted in participants returning to the lab having engaged in activities utilising different levels of cognitive demand. For example, some may have spent the time studying while others may have relaxed. This could have influenced the level of cognitive fatigue participants began the experiment with. Additionally, participants who received the blackcurrant supplement did not complete the baseline measures before taking the supplement, meaning there may have been carryover effects of the blackcurrant to baseline performance. While manipulation checks determined baseline performance was not influenced by the blackcurrant supplement, it is advisable that future research takes baseline measurements before the supplement is administered to avoid any potential carryover effects.

Conclusion

The present study investigated the influence that a blackcurrant supplement had on reducing the effect of cognitive fatigue on motor performance. Previous research has identified that cognitive fatigue can impair both simultaneous and subsequent motor performance (Bray et al., 2012; Marcora et al., 2009; Mehta & Agnew, 2011, 2012). As well, it is known that phytochemicals have the potential to influence both cognition and motor performance (Lindheimer et al., 2013; Papandreou et al., 2009; Miller & Shukitt-Hale, 2012; Shukitt-Hale et al., 2006; Shukitt-Hale et al., 2009; Shukitt-Hale et al., 2005). The present study appears to be the first to integrate the two and examine the association between phytochemicals and fatigue-related declines. Given the increasing mentally demanding lifestyles we are living and the potential consequences of cognitive fatigue, research examining this effect is timely.

The results of the present study are inconsistent with previous findings, with cognitive fatigue having little effect on subsequent motor performance. This finding made it difficult to interpret the influence of the blackcurrant supplement; however, it appeared that the supplement had little influence on either cognitive or motor performance. Despite the inconsistencies with previous research and the lack of significant findings, the present study highlighted some important issues to be considered in going forward with research of this nature. The results suggest that task sensitivity could play a major role in the outcome of such research. Tasks that are not sensitive to the effects of cognitive fatigue may mask any effects that may be occurring. Likewise, effects may be masked by using tasks that are not sensitive to the mechanisms influenced by phytochemicals. Additionally, the results suggest that research distinguishing between fatigue and boredom would be beneficial to future research to ensure that the state being induced is in fact cognitive fatigue.

Limitations of the study include the use of a small sample, difficulty distinguishing between fatigue and boredom, the potentially boring nature of the control task, not using a placebo or blinding participants to their condition, and not having a controlled environment for the participants to wait in between taking the supplement and beginning the trial. Finally, had time permitted, it would have been interesting to vary the size of the blackcurrant supplement dose. If by increasing the sample size and addressing the other limitations mentioned here future research was to find blackcurrant supplement to successfully ameliorate the effects cognitive fatigue has on motor performance, there could be far reaching implications. It could prove influential not just for understanding the influence phytochemical supplementation could have in reducing the effects of impairments in cognitive fatigue but also in other states of cognitive decline. This could result in improvements in performance in the workplace, reducing the number of driving errors caused by fatigue, and improving performance outcomes in medical conditions in which fatigue is a major inhibiting factor.

References

Ackerman, P. L., & Kanfer, R. (2009). Test length and cognitive fatigue: An empirical examination of effects on performance and test-taker reactions. *Journal of Experimental Psychology: Applied, 15*, 163-181. doi: 10.1037/a0015719

Atienza, M., Cantero, J. L., & Escera, C. (2001). Auditory information processing during human sleep as revealed by event-related brain potentials. *Clinical Neurophysiology, 112,* 2031-2045. doi: 10.1016/S1388-2457(01)00650-2

Barros, D., Amaral, O. B., Izquierdo, I., Geracitano, L., do Carmo Bassols Raseira, M., Henriques, A. T., & Ramirez, M. R. (2006). Behavioral and genoprotective effects of *Vaccinium* berries intake in mice. *Pharmacology Biochemistry and Behavior, 84,* 229-234. doi: 10.1016/j.pbb.2006.05.001

Boksem, M. A. A., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: An ERP study. *Cognitive Brain Research, 25*, 107-116. doi: 10.1016/j.cogbrainres.2005.04.011

Boksem, M. A. A., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological Psychology, 72*, 123-132. doi: 10.1016/j.biopsycho.2005.08.007

Boksem, M. A. S., & Tops, M. (2008). Mental fatigue: Costs and benefits. *Brain Research Reviews, 59,* 125-139. doi: 10.1016/j.brainresrev.2008.07.001

Bonnefond, A., Diognon-Camus, N., Hoeft, A., & Dufour, A. (2011). Impact of motivation on cognitive control in the context of vigilance lowering: An ERP study. *Brain and Cognition, 77,* 464-471. doi: 10.1016/j.bandc.2011.08.010

Bray, S. R., Graham, J. D., Martin Ginis, K. A., & Hicks, A. L. (2012). Cognitive task performance causes impaired maximum force production in human hand flexor muscles. *Biological Psychology, 89,* 195-200. doi: 10.1016/j.biopsycho.2011.10.008

Bray, S. R., Martin Ginis, K.A., Hicks, A. L., & Woodgate, J. (2008). Effects of self-regulatory strength depletion on muscular performance and EMG activation. *Psychophysiology, 45,* 337-343. doi: 10.1111/j.1469-8986.2007.00625.x

Brown, I. D. (1994). Driver fatigue. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 36,* 298-314. doi: 10.1177/001872089403600210

Cantuti-Castelvetri, I., Shukitt-Hale, B., & Joseph, J. A. (2000). Neurobehavioural aspects of antioxidants in aging. *International Journal of Developmental Neuroscience, 18,* 367-381. doi: 10.1016/S0736-5748(00)00008-3

Chaudhuri, A., & Behan, P. O. (2000). Fatigue and the basal ganglia. *Journal of the Neurological Sciences, 179,* 34-42. doi: 10.1016/j.brainres.2013.10.018

Chung, Y. C., Park, C. H., Kwon, H. K., Park, Y. M., Kim, Y. S., Doo, J. K., … Chae, S. W. (2012). Improved cognitive performance following supplementation with a mixed-grain diet in high school students: A randomised controlled trial. *Nutrition, 28,* 165-172. doi: 10.1016/j.nut.2011.05.017

Cohen, J. W. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Csathó, A., van der Linden, D., Hernadi, I., Buzás, P., & Kalmár, G. (2012). Effects of mental fatigue on the capacity limits of visual attention. *Journal of Cognitive Psychology, 24* 511-524. doi: 10.1080/20445911.2012.658039

Darondeau, Y., Lioud, C., & Priou, E. (Producers). (2005). *March of the penguins* [DVD]. NY: Warner Brothers.

DeLuca, J., Genova, H. M., Hillary, F. G., & Wylie, G. (2008). Neural correlates of cognitive fatigue in multiple sclerosis using functional MRI. *Journal of Neurological Sciences, 270,* 29-39. doi: 10.1016/j.jns.2008.01.018

Dietrich, A., & Sparling, P. B. (2004). Endurance exercise selectively impairs prefrontal-dependent cognition. *Brain and Cognition, 55,* 516-524. doi: 10.1016/j.bandc.2004.03.002

Dye, L., & Blundell, J. (2002). Functional foods: psychological and behavioural functions. *British Journal of Nutrition, 88*, 187-211. doi: 10.1079/BJN2002684

Dye, L., Lluch, A., & Blundell, J. E. (2000). Macronutrients and mental performance. *Nutrition, 16,* 1021-1034. doi: 10.1016/S0899-9007(00)00450-0

Fellus, J. L., & Rashidzada, W. (2008). Fatigue in other neurological conditions. In J. DeLuca (Ed.), *Fatigue as a window to the brain* (pp. 107-124). Cambridge, MA: MIT.

Goyarzu, P., Malin, D. H., Lau, F. C., Taglialatela, G., Moon, W. D., Jennings, R., ... & Joseph, J. A. (2004). Blueberry supplemented diet: effects on object recognition memory and nuclear factor-kappa B levels in aged rats. *Nutritional Neuroscience, 7,* 75-83. doi: 10.1080/10284150410001710410

Gibson, E. L., & Green, M. W. (2002). Nutritional influences on cognitive function: mechanisms of susceptibility. *Nutrition Research Reviews, 15,* 169-206. doi: 10.1079/NRR200131

Grier, R. A., Warm, J. S., Dember, W. N., Matthews, G., Galinsky, T. L., Szalma, J. L., & Parasuraman, R. (2003). The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 45*, 349-359. doi: 10.1518/hfes.45.3.349.27253

Hagger, M.S., Wood, C., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin, 136,* 495-525. doi: 10.1037/a0019486

Helton, W. S., & Russell, P. N. (2011). Feature absence-presence and two theories of lapses of sustained attention. *Psychological Research, 75*, 384-392. doi: 10.1007/s00426-010-0316-1

Helton, W. S., Hollander, T. D., Warm, J. S., Matthews, G., Dember, W. N., Wallaart, M., … Hancock, P. A. (2005). Signal regularity and the mindlessness model of vigilance. *British Journal of Psychology, 96,* 249-261. doi: 10.1348/000712605X38369

Helton, W. S., & Warm, J. S. (2008). Signal salience and the mindlessness theory of vigilance. *Acta Psychologica, 129,* 18-25. doi: 10.1016/j.actpsy.2008.04.002

Hogervorst, W., Riedel, W., Jeukendrup, A., & Jolles, J. (1996). Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills, 83,* 479-488. doi: 10.2466/pms.1996.83.2.479

Holtzer, R., & Foley, F. (2009). The relationship between subjective reports of fatigue and the executive control in Multiple Sclerosis. *Journal of the Neurological Sciences, 281,* 46-50. doi: 10.1016/j.jns.2009.02.360

Hoyland, A., Lawton, C. L., & Dye, L. (2008). Acute effects of macronutrient manipulations on cognitive test performance in healthy young adults: A systematic research review. *Neuroscience and Behavioral Reviews, 32*, 72-85. doi: 10.1016/j.neubiorev.2007.05.006

Hurst, R. D., & Hurst, S. M. (2013). Fruits and vegetables as functional foods for exercise and inflammation. In R. R. Watson, & V. R. Preedy (Eds.), *Bioactive Food as dietary interventions for arthritis and related inflammatory diseases* (pp. 319-336). doi: 10.1016/B978-0-12-397156-2.00022-3

IBM Corp. (2012). IBM SPSS Statistics for Windows (Version 21.0). Armonk, NY: IBM Corp.

Ishii, A., Tanaka, M., Shigihara, Y., Kanai, E., Funakura, M., & Watanabe, Y. (2013). Neural effects of prolonged mental fatigue: A magnetoencephalography study. *Brain Research, 1529,* 105-112. doi: 10.1016/j.brainres.2013.07.022

Joseph, J. A., Shukitt-Hale, B., Denisova, N. A., Bielinski, D., Martin, A., McEwen, J. J., & Bickford, P.C. (1999). Reversals of age-related declines in neuronal signal transduction, cognitive, and motor behavioural deficits with blueberry, spinach, or strawberry dietary supplementation. *The Journal of Neuroscience, 19,* 8114-8121. Retrieved from http://www.jneurosci.org/content/19/18/8114.short.

Kato, Y., Endo, H., & Kizuka, T. (2009). Mental fatigue and impaired response processes: Event-related brain potentials in a Go/NoGo task. *Internations Journal of Psychophysiology, 72*, 204-211. doi: 10.1016/j.ijpsycho.2008.12.008

Kennedy, D. O., Dodd, F. L., Robertson, B. C., Okello, E. J., Reay, J. L., Sholey, A. B., & Haskell, C. F. (2010). Monoterpenoid extract of sage (Salvia lavandulaefolia) with cholinesterase inhibiting properties improves cognitive performance and mood in healthy adults. *Journal of Psychopharmacology, 25,* 1088-1100. doi: 10.1177/0269881110385594

Kim, H. G., Ju, M. S., Shim, J. S., Kim, M. C., Lee, S. H., Huh, Y., ... & Oh, M. S. (2010). Mulberry fruit protects dopaminergic neurons in toxin-induced Parkinson's disease models. *British Journal of Nutrition, 104,* 8-16. doi: 10.1017/S0007114510000218

Krikorian, R., Nash, T. A., Shidler, M. D., Shukitt-Hale, B., & Joseph, J. A. (2010). Concord grape juice supplementation improves memory function in older adults with mild cognitive impairment. *British Journal of Nutrition, 103,* 730. doi: 10.1017/S0007114509992364

Krikorian, R., Shilder, M. D., Nash, T. A., Kalt, W., Vinqvist-Tymchuk, M. R., Shukitt-Hale, B., & Joseph, J. A. (2010). Blueberry supplementation improves memory in older adults. *Journal of Agricultural and Food Chemistry, 58,* 3996-4000. doi: 10.1021/jf9029332

Krueger, G. P. (1989). Sustained work, fatigue, sleep loss, and performance: A review of the issues. *Work and Stress: An International Journal of Work, Health, and Organisations, 3,* 129-141. doi: 10.1080/02678378908256939

Kutas, M., & Donchin, E. (1980). Preparation to respond as manifested by movement-related brain potentials. *Brain Research, 202,* 95-115. doi: 10.1016/S0006-8993(80)80037-0

Lafayette Instrument Company. (2002). Grooved pegboard test. IN, USA: Author.

Lafayette Instrument Company. (2004). Dynamometer hand test. IN, USA: Author.

Lal, S. K. L., & Craig, A. (2001). A critical review of the psychophysiology of driver fatigue. *Biological Psychology, 55,* 173-194. doi: 10.1016/S0301-0511(00)00085-5

Langner, R., Steinborn, M. B., Chatterjee, A., Sturm, W., & Willmes, K. (2010). Mental fatigue and temporal preparation in simple reaction-time performance. *Acta Psychologica, 133*, 64-72. doi: 10.1016/j.actpsy.2009.10.001

Langner, R., Willmes, K., Chatterjee, A., Eickhoff, S. B., & Sturm, W. (2010). Energetic effects of stimulus intensity on prolonged simple reaction-time performance. *Psychological Research, 74,* 499-512. doi: 10.1007/s00426-010-0275-6

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 451-468. Retrieved from http://www.psychol.ucl.ac.uk/attention.lab/reprints/Lavie%20perceptual%20load%20selective%20attn%20JEPHPP95.pdf.

Lieberman, H. R. (2001). The effects of ginseng, ephedrine, and caffeine on cognitive performance, mood and energy. *Nutrition Reviews, 59,* 91-102. doi: 10.1111/j.1753-4887.2001.tb06995.x

Lim, J., Wu, W., Wang, J., Detre, J. A., Dinges, D. F., & Rao, H. (2010). Imaging brain fatigue from sustained mental workload: An ASL perfusion study of the time-on-task effect. *NeuroImage, 49,* 3426-3435. doi: 10.1016/j.neuroimage.2009.11.020

Lindheimer, J. B., Loy, B. D., & O'Connor, P, J. (2013). Short-term effects of black pepper (*piper nigrum*) and rosemary (*rosamarinus officinalis* and *rosmarinus eriocalyx*) on sustained attention and on energy and fatigue mood states in young adults with low energy. *Journal of Medicinal Food, 16,* 765-771. doi: 10.1089/jmf.2012.0216

Lorist, M. M., Bezdan, E., ten Caat, M., Span, M. M., Roerdink, J. B. T. M., & Maurits, N. M. (2009). The influence of mental fatigue and motivation on neural network dynamics; an EEG coherence study. *Brain Research, 1270,* 95-106. doi: 10.1016/j.brainres.2009.03.015

Lorist, M. M., Boksem, M. A., & Ridderinkhof, K. R. (2005). Impaired cognitive control and reduced cingulate activity during mental fatigue. *Cognitive Brain Research, 24,* 199-205. doi: 10.1016/j.cogbrainres.2005.01.018

Lorist, M. M., & Faber, L. G. (2011). Consideration of the influence of mental fatigue on controlled and automatic cognitive processes and related neuromodulatory effects. In P. L. Ackerman (Ed.), *Cognitive fatigue: Multidisciplinary perspectives on current research and future applications* (pp. 105-126). Washington, DC: American Psychological Association.

Lorist, M. M., Klein, M., Nieuwenhuis, S., De Jong, R., Mulder, G., & Meijman, T. F. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology, 37,* 614-625. doi: 10.1111/1469-8986.3750614

Lukaski, H. C. (2004). Vitamin and mineral status: Effects on physical performance. *Nutrition, 20,* 632-644. doi: 10.1016/j.nut.2004.04.001

Lundberg, U., Forsman, M., Zachau, G., Eklof, M., Palmerud, G., Melin, B., & Kadefors, R. (2002). Effects of experimentally induced mental and physical stress on motor unit recruitment in the trapezius muscle. *Work and Stress: An International Journal of Work, Health, and Organisations, 16,* 166-178. doi: 10.1080/02678370210136699

Macready, A. L., Butler, L. T., Kennedy, O. B., Ellis, J. A., Williams, C. M., & Spencer, J. P. E. (2010). Cognitive tests used in chronic adult human randomised controlled trial micronutrient and phytochemical intervention studies. *Nutrition Research Reviews, 23,* 200-229. doi: 10.1017/S0954422410000119

Maggini, S., & Spitzer, V. (2013). Ginseng and micronutrients for vitality and cognition. In R. R. Watson, & V. R. Preedy (Eds.), *Bioactive food as dietary interventions for arthritis and related inflammatory diseases* (pp. 319-336). doi: 10.1016/B978-0-12-397155-5.00033-7

Malmstrom, T. K., Wolinsky, F. D., Andresen, E. M., Miller, J. P., & Miller, D. K. (2005). Cognitive ability and physical performances in middle-aged African Americans. *Journal of the American Geriatric Society, 53,* 997-1001. doi: 10.1111/j.1532-5415.2005.53318.x

Manly, T., Robertson, I. H., Galloway, M., & Hawkins, K. (1999). The absent mind: further investigations of sustained attention to response. *Neuropsychologia, 37,* 661-670. doi: 10.1016/S0028-3932(98)00127-4

Marcora, S. M., Staiano W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology, 106,* 857-864. doi: 10.1152/japplphysiol.91324.2008

Matthews, G., Campbell, S. E., & Falconer, S. (2001). Assessment of motivational states in performance environments. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 45,* 906-910. doi: 10.1177/154193120104501302

McNair, D. M., Lorr, M., Heuchert, J. W. P., & Droppleman, L. E. (2003). POMS brief form. NY: MHS Inc.

Mehta, R. K., & Agnew, M. J. (2011). Effects of concurrent physical and mental demands for a short duration static task. *International Journal of Industrial Ergonomics, 41,* 488-493. doi: 10.1016/j.ergon.2011.04.005

Mehta, R. K., & Agnew, M. J. (2012). Influence of mental workload on muscle endurance, fatigue, and recovery during intermittent static work. *European Journal of Applied Physiology, 112,* 2891-2902. doi: 10.1007/s00421-011-2264-x

Mehta, R. K., & Parasuraman, R. (2013). Effects of mental fatigue on the development of physical fatigue: A neuroergonomic approach. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* Advance online publication. doi: 10.1177/0018720813507279

Miller, M. G., & Shukitt-Hale, B. (2012). Berry fruit enhances beneficial signalling in the brain. *Journal of Agricultural and Food Chemistry, 60,* 5709-5715. doi: 10.1021/jf2036033

Morin, K. H. (2011). Nutrition and cognition. *American Journal of Maternal Child Nursing, 36,* 396. doi: 10.1097/NMC.0b013e31822de614

Müller-Gethmann, H., Rinkenauer, G., Stahl, J., & Ulrich, R. (2000). Preparation of response force and movement direction: Onset effects on the lateralized readiness potential. *Psychophysiology, 37,* 507-514. doi: 10.1111/1469-8986.3740507

Myers, C. S. (1937). Conceptions of mental fatigue. *The American Journal of Psychology, 50,* 296-306. Retrieved from http://www.jstor.org/stable/1416638

Nozaki, S., Tanaka, M., Mizuno, K., Ataka, S., Mizuma, H., Tahara, T., ... & Watanabe, Y. (2009). Mental and physical fatigue-related biochemical alterations. *Nutrition, 25,* 51-57. doi: 10.1016/j.nut.2008.07.010

O'Connor, P. J. (2004). Evaluation of four highly cited energy and fatigue mood measures. *Journal of Psychosomatic Research, 57,* 435-441. doi: 10.1016/j.jpsychores.2003.12.006

Okada, T., Tanaka, M., Kuratsune, H., Watanabe, Y., & Sadato, N. (2004). Mechanisms underlying fatigue: a voxel-based morphometric study of chronic fatigue syndrome. *BMC Neurology, 4*, 14-19. doi: 10.1186/1471-2377-4-14

Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology, 114*, 1095-1105. doi: 10.1007/s00421-014-2838-5

Pageaux, B., Marcora, S., & Lepers, R. (2013). Prolonged mental exertion does not alter neuromuscular function of the knee extensors. *Medicine & Science in Sports & Exercise,* Advance online publication. doi: 10.1249/MSS.0b013e31829b504a

Papandreou, M. A., Dimakopoulou, A., Linardaki, Z. I., Cordopatis, P., Klimis-Zacas, D., Margarity, M., & Lamari, F. N. (2009). Effect of a polyphenol-rich wild blueberry extract on cognitive performance of mice, brain antioxidant markers and acetylcholinesterase activity. *Behavioural Brain Research, 198,* 352-358. doi: 10.1016/j.bbr.2008.11.013

Pattyn, N., Neyt, X., Henderickx, D., & Soetens, E. (2008). Psychophysiological investigation of vigilance decrement: Boredom or cognitive fatigue? *Physiology & Behaviour, 93*, 369-378. doi: 10.1016/j.physbeh.2007.09.016

Paus, T. (2001). Primate anterior cingulate cortex: where motor control, drive and cognition interface. *Nature Reviews Neuroscience, 2*, 417-424. doi: 10.1038/35077500

Rincón-León, F. (2003). Functional foods. In B. Caballero (Ed.), *Encyclopaedia of Food Science and Nutrition,* (2nd ed.) (pp 2827–2832). London: Elsevier Science.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). 'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35,* 747-758. doi: 10.1016/S0028-3932(97)00015-8

Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: where top-down meets bottom-up. *Brain Research Reviews, 35,* 146-160. doi: 10.1016/S0165-0173(01)00044-3

Scerbo, M. (1998). What's so boring about vigilance? In R.B. Hoffman, M. F. Sherrick, & J. S. Warm (Eds.), *Viewing psychology as a whole: The integrative science of William N. Dember* (pp. 145-166). Washington, DC: American Psychological Association.

Schwid, S. R., Tyler, C. M., Scheid, E. A., Weinstein, A., Goodman, A. D., & McDermott. M. P. (2003). Cognitive fatigue during a test requiring sustained attention: a pilot study. *Multiple Sclerosis, 9*, 503-508. doi: 10.1191/1352458503ms946oa

Shukitt-Hale, B., Carey, A., Simon, A., Mark, D. A., & Joseph, J. A. (2006). Effects of Concord grape juice on cognitive and motor deficits in aging. *Nutrition, 22,* 295-302. doi: 10.1016/j.nut.2005.07.016

Shukitt-Hale, B., Cheng, V., & Joseph, J. A. (2009). Effects of blackberries on motor and cognitive function in aged rats. *Nutritional Neuroscience, 12,* 135-140. doi: 10.1179/147683009X423292

Shukitt-Hale, B., Galli, R. L., Meterko, V., Carey, A., Bielinski, D. F., McGhie, T., & Joseph, J. A. (2005). Dietary supplementation with fruit polyphenolics ameliorates age-related deficits in behaviour and neuronal markers of inflammation and oxidative stress. *Age, 27,* 49-57. doi: 10.1007/s11357-005-4004-9

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition, 13,* 657-690. doi: 10.1016/j.concog.2004.06.003

Smit, A. S., Eling, P., & Coenen, A. M. L. (2004). Mental effort affects vigilance enduringly: after-effects in EEG and behaviour. *International Journal of Psychophysiology, 53,* 239-243. doi: 10.1016/j.ijpsycho.2004.04.005

Spencer, J. P. E., Vauzour, D., & Rendeiro, C. (2009). Flavonoids and cognition: The molecular mechanisms underlying their behavioural effects. *Archives of Biochemistry and Biophysics, 492,* 1-9. doi: 10.1016/j.abb.2009.10.003

Tanaka, M., Ishii, A., Watanabe, Y. (2014). Neural effect of mental fatigue on physical fatigue: A magnetoencephalography study. *Brain Research, 1542,* 49-55. doi: 10.1016/j.brainres.2013.10.018

Tanaka, M., Mizuno, K., Tajima, S., Sasabe, T., & Watanabe, Y. (2009). Central nervous system fatigue alters autonomic nerve activity. *Life Sciences, 84,* 235-239. doi: 10.1016/j.lfs.2008.12.004

Trevena, J. A., & Miller, J. (2002). Cortical movement preparation before and after a conscious decision to move. *Consciousness and Cognition, 11,* 162-190. doi: 10.1006/ccog.2002.0548

van der Linden, D., & Eling, P. (2006). Mental fatigue disturbs local processing more than global processing. *Psychological Research, 70*, 395-402. doi: 10.1007/s00426-005-0228-7

van der Linden, D., Frese, M., & Meijman, T. F. (2003). Mental fatigue and the control of cognitive processes: effects on perseveration and planning. *Acta Psychologia, 113,* 45-65. doi: 10.1016/S0001-6918(02)00150-6

van der Linden, D., Frese, M., & Sonnentag, S. (2003). The impact of mental fatigue on exploration in a complex computer task: rigidity and loss of systematic strategies. *Human Factors: The Journal of Human Factors and Ergonomics Society, 45,* 483-494. doi: 10.1518/hfes.45.3.483.27256

van der Linden, D., Massar, S. A. A., Schellekens, A. F. A., Ellenbroek, B. A., & Verkes, R. J. (2006). Disrupted sensorimotor gating due to mental fatigue: Preliminary evidence. *International Journal of Psychophysiology, 62*, 168-174. doi: 10.1016/j.ijpsycho.2006.04.001

Van Dongen, H. P. A., Belenky, G., & Krueger, J. M. (2011). Investigating the temporal dynamics and underlying mechanisms of cognitive fatigue. In P. L. Ackerman (Ed.), *Cognitive fatigue: Multidisciplinary perspectives on current research and future applications* (pp. 127-148). Washington, DC: American Psychological Association.

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 50*, 433-441. doi: 10.1518/001872008X312152

Westenhoefer, J., Bellisle, F., Blundell, J. E., de Vries, J., Edwards, D., Kallus, W., … Tuorila, H. (2004). Mental state and performance. *European Journal of Nutrition, 43,* 85-117. doi: 10.1007/s00394-004-1204-5

Whelan, R. (2008). Effective analysis of reaction time data. T*he Psychological Record, 58*, 475-482. Retrieved from http://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1077&context=tpr&sei-redir=1&referer=http%3A%2F%2Fscholar.google.co.nz.ezproxy.massey.ac.nz%2Fscholar%3Fhl%3Den%26q%3DEffective%2Banalysis%2Bof%2Breaction%2Btime%2Bdata%26btnG%3D%26as_sdt%3D1%252C5%26as_sdtp%3D#search=%22Effective%20analysis%20reaction%20time%20data%22

Yang, B., Xiao, W., Liu, X., Wu, S., & Miao, D. (2013). Mental fatigue impairs pre-attentive processing: A MMN study. *Neuroscience Letters, 532,* 12-16. doi: 10.1016/j.neulet.2012.08.080

Appendices

Appendix A: Motivation Questionnaires

MASSEY UNIVERSITY
COLLEGE OF HUMANITIES
AND SOCIAL SCIENCES
TE KURA PŪKENGA TANGATA

Amelioration of the effects of cognitive fatigue on motor performance by phytochemicals

MOTIVATION QUESTIONNAIRE

Participants will respond to each statement on a 5-point likert scale where:

0= not at all 1= a little 2= moderately 3= quite a bit 4= extremely

1. I would be disappointed if I failed to do well on this task……………………………………0……1……2……3……4
2. I become fed up with the tasks ....0……1……2……3……4
3. I am eager to do well ……………………………………..0……1……2……3……4
4. I would rather spend this time doing something else …………..……………………………...0……1……2……3……4
5. I want to succeed on the task ………………………...0……1……2……3……4
6. I get bored on long tasks………………………….. ….0……1……2……3……4
7. I want to perform better than most people do ……………………………………………….0……1……2……3……4
8. The content of the task sounds interesting……………0……1……2……3……4

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Participants will respond to each statement on a 5-point likert scale where:

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2. I became fed up with the task ………………………………0……1……2……3……4
3. I was eager to do well ………………………………………0……1……2……3……4
4. I would rather have spent the time doing the task on something else …………………………0……1……2……3……4
5. I wanted to succeed on the task ……………………………0……1……2……3……4
6. I found the task boring ………………………………………0……1……2……3……4
7. I wanted to perform better than most people do ……………………………………………0……1……2……3……4
8. The content of the task was interesting………………0……1……2……3……4

Te Kunenga
ki Pūrehuroa

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Appendix B: Participant Forms

MASSEY UNIVERSITY
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AND SOCIAL SCIENCES
TE KURA PŪKENGA TANGATA

Amelioration of the effects of cognitive fatigue on motor performance by phytochemicals

INFORMATION SHEET

Hi, my name is Rebecca Ratlidge. I am conducting this research for my Masters degree in Psychology at Massey University.

I will be looking at the effects that cognitive fatigue has on motor performance, and to see whether supplementation through blackcurrant extract influences this relationship through either: reducing the onset of cognitive fatigue; or, reducing the effect of cognitive fatigue on motor performance.

I would like to invite you to participate in this project.

Who can participate?
Anyone between the age of 18years and 35years who:

Has no known neurological condition;
Has no mental health problems, such as clinically diagnosed anxiety or depression;
Has no allergy to berry fruits, particularly blackcurrants;
Is not on medication that effects performance, e.g. tramadol;
Has not had a head injury resulting in concussion;
Does not have impairment to their arms/hands/fingers that will impair performance (e.g. arthritis).

Those who complete the experiment will be given a $30 voucher to compensate for travel and time given to the project.

What do I have to do?

If you agree to take part you will be asked not to consume any alcohol, caffeinated beverages (e.g. coffee, tea, energy drinks) or fruit juices (e.g. fresh juices, berry smoothies, canned fruit juice, etc.) at any time one the day before you are tested.

You will be randomly assigned to either be cognitively fatigued before doing some simple motor tasks, like fitting pegs into holes on a peg board as fast as you can, or you will watch a DVD before doing the motor tasks. The motor tasks take only about 10 minutes to complete. You will also be randomly assigned to either receive blackcurrant extract or not.
Those taking the blackcurrant extract will be reminded to take it 1 hour before coming in to complete their session.
You will be asked to complete the motor tasks to establish a baseline measure. Following this if you are in the cognitive fatigue condition you will be asked to complete a task in which you are asked to concentrate for a period time before repeating the motor tasks.
If you are not in the cognitive fatigue condition you will be asked to watch a DVD documentary before repeating the battery of motor tasks.
Finally, we will be asking you to give three small saliva samples during the session.
At the end of your session, I'll answer any questions you might have about the study, and you can contact me at a later point with any concerns.

The time taken to complete the session is roughly 2 hours.

What happens to the data you get from me?
All data and identifiable material will be stored in a locked filing cabinet in a secure room to protect your information from unauthorized access. We, the researchers, need to record your name, but this

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will be kept completely separate from your data. You will be given a code number to identify your data. Only my supervisors and myself will have access to the data that matches your code to your name.
A summary of the findings of the project will be available to you if you would like to see the results.

Participant's Rights
You are under no obligation whatsoever to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded.

Project Contacts

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Feel free to contact the researcher or supervisor with any questions or concerns you may have.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 13/20. If you have any concerns about the conduct of this research, please contact Dr Brian Finch, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 350 5799 x 84459, email humanethicsoutha@massey.ac.nz.

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Amelioration of the effects of cognitive fatigue on motor performance by phytochemicals

PARTICIPANT CONSENT FORM - INDIVIDUAL

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name - printed ....

Te Kunenga
ki Pūrehuroa

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PARTICIPANT HEALTH SCREEN

Are you on any prescription medication? YES NO

Have you ever had a head injury? YES NO
If so, when? ________________________
Did it result in concussion? YES NO

Do you have any allergies to berry fruits? YES NO
If so, what are you allergic to? ______________________

Do you suffer from any neuropsychological condition
(e.g. cognitive fatigue syndrome)? YES NO
If so, what is the condition? _____________________________

Do you have any mental health condition
(e.g. Depression, anxiety)? YES NO
If so, please list _________________________________

Do you have any impairment to your arm/hand/finger functioning YES NO
(e.g. arthritis)

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