The effect of metabolic loading on statistical learning

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Abstract

We investigated whether concurrent exercise would affect statistical learning (SL). During familiarization, participants were exposed to pictures that appeared sequentially, in a seemingly random fashion. In fact, the pictures were grouped into triplets. In the surprise test phase, participants identified triplets they had seen during familiarization. There were three groups: a group that performed familiarization seated on an exercise bike (CON), a group that performed familiarization while engaged in resistance free cycling (RF), and a group that performed familiarization while cycling at 60% of maximum effort (EX). The CON group correctly identified 72% of triplets in the test phase. The RF and EX groups correctly identified 61% and 55%, respectively. Only the CON group demonstrated performance that was significantly greater than chance. The RF group only just failed to demonstrate significant SL. Thus, concurrent exercise can suppress SL. Work is underway to determine the mechanism by which such suppression occurs.

Keywords: Statistical learning; exercise; metabolic loading.

Introduction

Statistical learning (SL) refers to the ability to detect statistical regularities implicitly and use this information to guide related behavior. Since the seminal research conducted by Saffran, Aslin and Newport (1996) demonstrating that 8-month old infants are capable of learning syllables embedded in an auditorily presented sequence, this area of research has increased rapidly. SL has now been shown to operate on sequential auditorily presented stimuli (Aslin, Saffran & Newport, 1998; Saffran et al., 1996; Saffran et al., 1997) and sequential visually presented stimuli (Arciuli & Simpson, 2011; Fiser & Aslin, 2001; Turk-Browne & Scholl, 2009). It has been shown to operate on adjacent dependencies (Lany & Gómez, 2008; Newport & Aslin, 2004) and non-adjacent dependencies (Creel, Newport & Aslin, 2004; Gebhart, Newport & Aslin, 2009). SL operates on spatial as well as temporal regularities (Turk-Browne & Scholl, 2009). Recently, researchers have linked a capacity for SL with key cognitive activities such as spoken language proficiency (Conway, Karpicke & Pisoni, 2007; Evans, Saffran & Robe-Torres, 2009) and reading (Arciuli & Simpson, in press).

In short, SL is a robust process that develops early in life and is linked with a wide range of cognitive and perceptual activities. As such, it is important to understand whether SL can be enhanced or suppressed. While there have been a handful of studies investigating brain activity during SL (Turk-Browne, Scholl, Chun & Johnson, 2009; Turk-Browne, Scholl, Johnson & Chun, 2010), little is known about the physiological processes that underpin the capacity for SL. In this study, we sought to learn more about these physiological underpinnings by examining the effects of metabolic loading (i.e., exercise) on SL.

It is well known that exercise can affect brain activity and cognitive function; however, these effects can operate in different ways. Cognition appears to be enhanced over the longer term as a result of *ongoing* exercise (Hill, Storandt & Malley, 1993; Ratey & Loehr, 2011). Researchers studying the behaviors of animals have demonstrated exercise-related increases in brain-derived neurotrophic factors as well as increasing levels of neural plasticity of brain tissue (for a comprehensive review, see Hertzog, Kramer, Wilson & Lindenberger, 2009).

There is conflicting evidence related to cognition during *acute* exercise, with several researchers finding an enhancement (Chmura, Nazar, Kaciuba-Uscilko, 1994; Yagi, Coburn, Estes & Arruda, 1999), others finding suppression (Audiffren, Brisswalter, Brandet & Bosquet, 1998; Dietrich & Sparling, 2004), and some finding no difference (Davranche et al., 2006; Dietrich & Sparling, 2004; McMorris et al, 2003;). Yagi et al. (2006) suggested that neural activation in the brain is enhanced by exercise, whereas Dietrich and Sparling (2004) suggested that exercise causes function in the prefrontal lobe to become depressed during exercise; hence, they found suppression in some cognitive tests, but no effect in others.

Importantly, existing research has used tasks of explicit cognitive processing to assess performance. The task that has been most commonly utilized is the choice reaction time task (e.g. Audiffren et al., 1998; McMorris et al, 2003). However, a range of cognitive tasks have been used. For example, Dietrich and Sparling (2004) used a mathematics test (to test pre-frontal function) and a vocabulary test (which they suggested was a test of non pre-frontal function). We are not aware of research on the effects of exercise on implicit cognitive processing. Specifically, to date, no researchers have examined the impact of exercise on the brain's capacity to learn statistical regularities.

The primary aim of this experiment was to examine how metabolic loading affects concomitant SL. The exploratory nature of this research meant that directional hypotheses could not be easily formulated. It seemed likely that concomitant exercise might suppress SL in comparison with a non-exercising control group; however, it was important to control for the possibility that some kind of dual-task loading, rather than the exercise itself, might also affect SL. Thus, we included an additional condition where participants performed the SL task while engaging in resistance-free cycling.

Methods

Subjects

A total of 24 participants (age 24±3.3; 14 females, $\dot{V}O_2$max = 47.8 (± 4.9) $ml.kg^{-1}.min^{-1}$, no known neurological or physical problems) were recruited from the University of Sydney population. Ethics approval was granted by the institution.

Statistical learning task

Participants undertook the embedded triplet learning task created by Arciuli and Simpson (2011; 2012). The task is comprised of a *familiarization* and then a surprise *test* phase, controlled by Eprime presentation software (v2.0, Psychology Software Tools, PA, U.S.A.). Stimuli were eighteen cartoon-like figures sourced from the website http://www.clipartconnection.com/en/. Six were used exclusively for instruction and practice. The remaining twelve appeared only in the familiarization and test phases. None resembled real-world animals, people or popular cartoon characters. The twelve stimuli used for the familiarization and test phases can be found in the Appendix sections of Arciuli and Simpson (2011; 2012). These twelve experimental stimuli were divided into four groups of three (four base triplets), hereafter referred to as *ABC*, *DEF*, *GHI* and *JKL* (see Appendix 1).

The familiarization phase consisted of a continuous stream of stimuli, with each cartoon character shown in isolation in the centre of the display against a white background. Each was visible for 800msec with an inter-stimulus-interval (ISI) of 200msec. Each base triplet was selected for inclusion 24 times each (resulting in a total of 96 triplets). For six of these 24 instances, one of the cartoon characters was presented twice in a row in order to provide a cover task (detection of repeated characters). Detection of these repeated characters was the cover task during familiarization. This cover task ensured that participants paid attention to the familiarization stream because participants were required to watch the screen and press a button whenever they saw a repeated character. Repetitions were counterbalanced among and within each triplet. So, for example, the repetitions for base triplet *ABC* meant there were two occurrences of the sequence *AABC*, two occurrences of the sequence *ABBC*, and two occurrences of *ABCC* (along with 18 occurrences of the sequence *ABC*). This procedure meant that for each base triplet the strict triplet structure was violated (e.g., *ABBC*) on two of twenty-four occasions. The repetition was done in this way (all three items in a triplet used for repetition) to ensure that the repetitions did not inadvertently cue the participants to the existence of the triplet boundaries. The familiarization phase consisted of 312 individual characters, with each of the 12 characters appearing 26 times each. The order of the triplets within the familiarization phase was randomized. The sole restriction was that the same base triplet could not appear consecutively (e.g., *ABCABC*).

In both of the previous studies reported by Arciuli and Simpson the familiarization phase was followed immediately by the surprise test phase. However, in the present study, the surprise test phase was given to participants after a time delay of 5 minutes. This was necessary because participants required time to move from the bike to a desk where they performed the surprise test phase.

The surprise test phase consisted of 64 trials with each trial containing two triplets: one of the four base triplets and one of four impossible triplets. These impossible triplets never appeared in the familiarization stream and each was created by taking one character from three different base triplets (e.g., *AEI*, *DHL*, *GKC* and *JBF*). The stimuli in the test trials were presented individually with the same duration and ISI as was used in the familiarization stream. A 1,000 msec gap separated the two triplets in each test trial. After all six characters had been presented participants were prompted to identify which of the two triplets had appeared previously (during familiarization). This procedure constituted a 2-alternative forced-choice task (2AFC). The presentation order of base triplets and impossible triplets was counterbalanced. Across the 64 test trials each base triplet and each impossible triplet was seen 16 times, and each individual character was seen 32 times. Participants received a different random order for the test trials.

Procedure

Participants performed a $\dot{V}O_2$max test on a Lode Cycle ergometer. The $\dot{V}O_2$max test required participants to cycle until fatigued. They started at a low intensity and it was increased every minute until either the participant chose to stop or the investigator ended the test (for safety or diagnostic reasons). Heart rate was collected with a heart rate monitor (Polar) and $\dot{V}O_2$ were collected throughout the test using an electronic metabolic cart (MedGraphics) (Thompson, Gordon & Pescatello, 2009).

Participants were randomly allocated into 3 groups, with 8 participants in each; a control group (CON) who performed *familiarization* while seated, a resistance free group (RF) who performed familiarization while free pedaling on the cycle, and the exercise group (EX), who performed the familiarization whilst cycling at their own 60% $\dot{V}O_2$max to ensure participants in this group were exercising at equivalent levels of intensity (i.e., relative to their personal $\dot{V}O_2$max). This power output was chosen because it is a commonly used power output in studies of exercise and conscious cognition (Arcelin & Brisswalter, 1999; Pesce, Capranica, Tessitore & Figura, 2002; Pontifex & Hillman, 2006).

All participants underwent the familiarization phase while seated on the cycle so that all had the same level of postural discomfort. The Lode Cycle ergometer had the function of allowing a power output to be set which would be automatically maintained even when cadence changed. This was particularly important for the EX as it ensured participants could maintain attention on the SL task without having to focus on maintaining a certain cadence. For the cover task during familiarization, participants were asked to respond by pressing a button that was placed on the handlebars. This button was connected to an E-prime response box which was not fixed to the handle bar, so the participant could choose their preferred hand and move the button into a position for comfort. Each participant in the EX group cycled at their respective 60% $\dot{V}O_2$max values for the duration of the familiarization phase only. These participants cycled for 5 minutes prior to the commencement of the familiarization, during which time metabolic data was collected. Metabolic recording equipment was removed before beginning the familiarization phase so as to not discomfort the participants. Instead, continuous heart rate monitoring was used during familiarization. Upon completion of the familiarization phase, all groups were given a 5 minute rest period before the testing phase. For all participants the surprise *test* phase was performed at a desk while seated on a chair.

Data Analysis

A participant was considered to have learnt about the embedded regularities in the familiarization phase if they identified more than 50% of the triplets (above chance level). Thus, one-sample t-tests were used to determine whether there was significant SL for each group. This was the same data analysis technique used by Arciuli and Simpson (2011; 2012). Overall averages were then compared across the three groups using a one-way ANOVA and follow-up t-tests. An α level of .05 was set for the experiment.

Results

First, detection of repeated aliens during familiarization (the cover task) was examined. These data are reported in Table 1. Participants appeared to be paying similar, high levels of attention during familiarization across each of the three experimental conditions. A one-way ANOVA was conducted on the accuracy of detecting repeated characters during the *familiarization phase*. No significant difference was found ($F_{(2,21)} < 1$), across the three groups.

Table 1: Accuracy of responding during *Familiarization (*±SD*).*

Group	Number of repeated characters identified
CON	97.4% (±2.2%)
RF	98.4% (±3.1%)
EX	99.5% (±1.5%)

The overall degree of SL for each group during the surprise test phase is displayed in Table 2. One-sample t-tests revealed that only the CON group showed significant SL by demonstrating a level of performance that was significantly greater than chance (i.e., greater than 50%), $t_{(7)} = 4.175$, $p < .05$. The RF group just failed to demonstrate statistical learning, $t_{(7)} = 2.311$, $p = .054$ whereas the EX group did not demonstrate statistical learning, $t_{(7)} = 1.050$, $p = .329$.

Table 2: Degree of SL during *Test* phase *(*±SD*).*

Group	Percentage triplets identified
CON	72% (±14%)
RF	61% (±14%)
EX	55% (±13%)

A one-way ANOVA demonstrated that there was no significant difference amongst these means $F_{(2,21)} = 3.011$, $p = .071$; however, given the marginal significance, post-hoc t-tests were conducted. Results demonstrated that the only significant difference was between the CON and EX groups, $t_{(14)} = 2.337$ ($p = .035$).

Discussion

The results reported here provide several insights into statistical learning (SL). First, significant SL was observed in the CON group. This finding adds to a growing body of evidence indicating that humans can implicitly learn regularities embedded in input, even while undertaking a cover task. A novel finding was that metabolic loading appears to impact upon participants' ability to detect these statistical regularities. This effect occurs even during a relatively short bout of exercise. The RF group showed a higher degree of SL compared with the EX group but less learning compared with the CON group. SL in the RF group just failed to reach significance, potentially due to low statistical power. The latter finding may suggest a graded pattern of performance whereby the mental effort associated with dual-task requirements (cycling resistance-free while also performing the SL task) affects SL. We interpret this data to demonstrate that even without any metabolic interference on the brain, the task of simply moving the legs, which in itself is a seemingly automatic task, appears to reduce the level of SL. This reduction appears to be amplified when metabolic loading is introduced.

Given the uncertainty surrounding the mechanisms underpinning explicit cognitive function during acute exercise, and given the possible differences between explicit and implicit cognition, it is difficult to know what caused the reduction in SL we observed in our EX group.

As exercise only lasted for around 15 minutes, at what is classed 'moderate intensity', and given that all participants had eaten and were hydrated, it is highly unlikely that metabolic factors such as dehydration or low blood glucose would have contributed to the results. It seems more likely that some form of psychological or neurological interference induced by exercise may have suppressed SL.

From a psychological standpoint, a similar phenomenon was demonstrated by Audiffren et al. (2008) where reaction time significantly increased during exercise compared to rest. This phenomenon has since been referred to as resource allocation competition. Pontifex and Hillman (2007) demonstrated that EEG activation is reduced when cycling, reflecting an 'inefficiency' of resource allocation. Specifically, they demonstrated reduced N1 amplitude, which has been shown to be part of the visual discrimination resource component (Vogel & Luck, 2000). Turk-Browne et al. (2009) conducted an fMRI study where participants performed a similar statistical visual learning task to the one presented here and found that activation in the occipital regions was increased (along with significant SL). If cycling suppresses some function in the visual cortex, sensitivity to visually presented statistical regularities may be affected. We aim to conduct the same experiment using an auditorily presented version of this SL task to further investigate this hypothesis.

There is another possibility, related to a more general effect of acute exercise on the brain. A review by Williamson, Fadel and Mitchell (2006) highlighted that there is a high neuroelectrical resource demand on the brain to maintain central control over metabolic reactions, such as vascular control for blood pressure, despite these processes being autonomic. Pontifex and Hillman (2007) suggested that additional neuroelectric demands further increase the load associated with dual tasking within the brain. Given that the RF group had the added demand of the resistance free cycling, and the EX group had the even greater demand of cycling plus central metabolic control, this may help to explain why there appeared to a graded pattern of results.

These findings open up many avenues for further research and as such we are currently undertaking several additional studies. To investigate whether exercise causes changes in both implicit and explicit tasks measures of cognitive performance, we will use the same exercise paradigm whilst participants undertake an explicit working memory task, such as digit span. We are also planning to compare the effects of exercise on implicit versus explicit versions of the embedded triplet task. In addition, we are exploring the effect of different exercise intensities so that we can determine at what metabolic level impairments in begin to SL occur. As mentioned, we will also examine whether exercise affects SL similarly regardless of whether stimuli are presented visually or auditorily. It is also interesting to ponder what would happen if we were to reverse the timing of the exercise in order to study how metabolic loading during the *test* phase affects answers after completing the familiarization phase at rest.

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