The effect of the circadian rhythm of body temperature on A-level exam performance

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Previous research points towards an effect of performance (both mental and physical) tests with performance improving during the afternoon, where the circadian rhythm peaks. However, this effect has only been studied on a small scale. In this study, the effect of the circadian rhythm of body temperature on performance by examining sixteen A-level exam papers across both science and humanities subjects (n= 346,825). No effect for time of day on performance was found (t=-.97, p= <.34). These results do not support the current hypothesis that body temperature regulates neurobehavioral function. Suggestions are made as to why no relationship was found in relation to the evolutionary function of certain brain regions and further experiments are suggested.

Key words: Physiology, Body Temperature, Exam, Performance, Circadian Rhythm

A circadian rhythm is any biological process that displays an endogenous oscillation of about twenty-four hours. Circadian rhythms are regulated by the suprachiasmatic nucleus (SCN), a group of distinct cells in the hypothalamus. The SCN transforms information from light gathered from the eyes' photosensitive ganglion cells into neural signals that regulate the body's temperature. The signals follow a retinohypothalamic tract pathway, leading to the SCN. From here they travel to the pineal gland to modify the production of melatonin. If cells from the SCN are removed, they maintain their own rhythm in the absence of external cues.

Aschoff (1972) discovered that core body temperature (CBT) is determined both by changes in heat production and changes in heat loss. This is modulated by melatonin. It is responsible for initiation distal vasodilation and sleepiness and is consequently secreted more in the evening. Both distal and proximal skin temperature increase rapidly during this relaxation phase.

Our temperature is reflected in our energy levels. The circadian covariation of neurobehavioral activity is correlated with CBT. As Wright, Hull and Czeisler (2002) explain, body temperature influences human performance, most notably when CBT is at its circadian peak; performance is worse when it is low in the circadian rhythm. By studying the correlation between body temperature and performance, Wright et al., (2002) found that many neurobehavioural measures vary as a result of internal circadian rhythms, such as working memory, subjective alertness and reaction times. As they describe, these findings demonstrate that an increased body temperature, associated with and independent of internal biological time, is correlated with improved performance and alertness. Moreover, Dijk et al. (1992) found a similar correlation, with increased performance when wakefulness was at its peak.

Body temperature not only impacts our sleep/wake cycle but also effects neurobehavioral functioning, as reflected in alertness and performance in the classroom or laboratory setting (from here on, referring inclusively and most commonly to exams, reaction times, priming speed etc.). Johnson, Duffy, Dijk, Ronda, Dyal and Czeisler (1992) suggest that the human circadian pacemaker, which drives the body temperature cycle, is the primary determinant of endogenous circadian variations in subjective alertness and calculation performance. There have been a number of studies documenting the relationship between body temperature and performance (Johnson et al., 1992). None, however, have documented this effect on a large scale. Research has been limited to a small number of participants and this is cause for concern in the current literature.

By using national data collected by the English exam board AQA (A-level), This study has managed to document this effect on a national scale with data from 346,825 students over sixteen different subjects in both sciences and humanities. Moreover, no prior studies have documented the relationship between the time at which an exam is taken and performance on that exam in an academic way, merely focusing on other performance variables such as reaction times. I therefore hypothesise from previous experiments that an effect of better exam performance will be found during the afternoon where body temperature peaks.

Method

Data was collected through the AQA website which is available to the public.

A-level exams are undertaken in controlled settings with moderators at the same time of the day as nearly every other student sitting the same exam (under special circumstances, such as overlapping exams, exams are taken later or earlier than the rest of the country).

The relationship between test score and time taken was calculated using UMS (uniformed marking scheme). UMS is a way of standardizing the marking of papers across different examination boards, allowing someone to compare marks on two papers marked by two different examination boards. Raw marks awarded in an exam are converted to UMS marks according to the difficulty of the exam paper and the performance of candidates. For example, one year, a candidate may only need 68 raw marks to get an A grade (80%), but another year 68 marks may only be equivalent to a B grade (70%).

A comparison of the raw mark required to achieve a UMS mark of 80 from the same exam taken in either the morning or the afternoon to determine whether there was an effect. Only exams that had both morning and afternoon sittings in the 2011/2012 exam period were selected.

Participants and Design

A total of 346,825 students were classed as participants across the UK who took controlled and examined A-level papers in 2011 and 2012 in sixteen subjects (see Table 1) with an age range estimated of 16 to 18.

The independent variable was the time at which the A-level paper was taken: either morning or afternoon. The dependent variable was the raw score required to achieve 80 UMS.

Results

Not in line with the prediction, using a two-sample t-test, no significant difference was found between the raw scores for morning and afternoon exams $t(30)=-.97$, $p=.34$) also as seen in Figure 1.

Similarly, no significant difference was found when science subjects $t=(2)-0.02$, $p=.98$) and arts subjects ($t=(9)-1.06$, $p.30$) were evaluated separately.

Discussion

A lack of effect on this scale suggests that endogenous circadian rhythms in temperature have no effect on performance in written exams. This is not to suggest that all performance is not directly affected by body temperature. For example, Reilly, Atkinson, Edwards, Waterhouse and Farrelly (2007) suggest that diurnal variation of some aspects of football performance is affected by body temperature. This would therefore lend itself to the conclusion that written and physical performance is a distinct skill sets.

The effect of body temperature may be limited to repetitive functions. It is possible that the participants learned over time to perform better. Edwards, Waterhouse and Reilly (2007) designed an experiment that required participants to flick counters towards a target: the closer the counter to the target, the higher the score obtained. Participants undertook the experiment every four hours throughout the day, covering a full circadian rhythm. Normally phased circadian rhythms ($p<0.0001$) in oral temperature and alertness were detected. This experiment suggests that the circadian rhythm of body temperature affects protocols where repetitive measurements during the course of the day are required.

Complex thought processes such as executive function, as involved in A-level exams, are likely to be undertaken in the dorsolateral prefrontal cortex (Alvarez & Emory, 2006) as compared to the neocortex (Bergerbest, Ghahremani & Gabrieli, 2006) in repetitive function: this may be the underlying reason why no significant difference was found. It may in fact be that the more triune brain regions are more dependent on circadian rhythms for evolutionary function than the dorsolateral prefrontal cortex, thus explaining the variance in results.

Such evolutionary functions are likely to include repetition used for priming. Priming is a form of implicit memory formed by perceptual, semantic processing or in this case, repetition. This means that later experiences of the stimulus will be processed more quickly by the brain (Forster & Davis, 1984). The evolutionary function of priming is clear: by creating implicit memories, our ancestors would have been able to know whether flight or flights were necessary far more quicker than if no memory was formed. Its relationship to circadian rhythms is rather more complex. It is likely, however, that less complex functions such as those involved in priming would be more advantageous the more alert the person is. This is, however, hypothetical, and further experiments examining why repetition is evolutionarily advantageous at certain stages of the day are recommended.

The methodological weaknesses of the present study must be acknowledged. There were a larger number of arts subjects compared to sciences (thirteen art subjects and three science subjects). This was due to the availability of statistics for comparable morning and afternoon exams. Furthermore, certain subjects were grouped together as the data was collected like that from the exam board rather than by choice. Moreover, factor such as the time students woke up prior to he exam, the collection of body temperature on the day of the exam would effect if significance was found. The sleep/wake cycle is a circadian rhythm itself and thus effects body temperature. This could skew results as, for example, a poor or good night sleep could easily affect body temperature. To strengthen this study, one could implement that the students get a set amount of sleep at the same time prior to the experiment. This is suggested in further experiments.

The overwhelming number of participants used in this experiment is a clear factor in its influence on current hypotheses of performance and body temperature. No study has begun to match the size established in this experiment. It is therefore unlikely that the result found was due to systematic error or chance. I therefore conclude that further experiments are advised to study why this effect is not found in exam-based performance, with an emphasis on studying the differences between the neocortex and dorsolateral prefrontal cortex in the evolutionary function of simple processes such as repetition versus higher processing such as executive function.

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Figures

Table 1

Number of students sitting the exam for each subject

Exams	Number of students taking exams
Chemistry	51818
Psychology	56088
Applied Science	3477
Economics	26139
Business Studies, Applied business studies and Accounting	27673
Economics	26139
General Studies	31562
Geography	32872
Government and Politics	15393
History of Art, Archaeology and Anthropology	6443
Sociology	30688
Law	12523

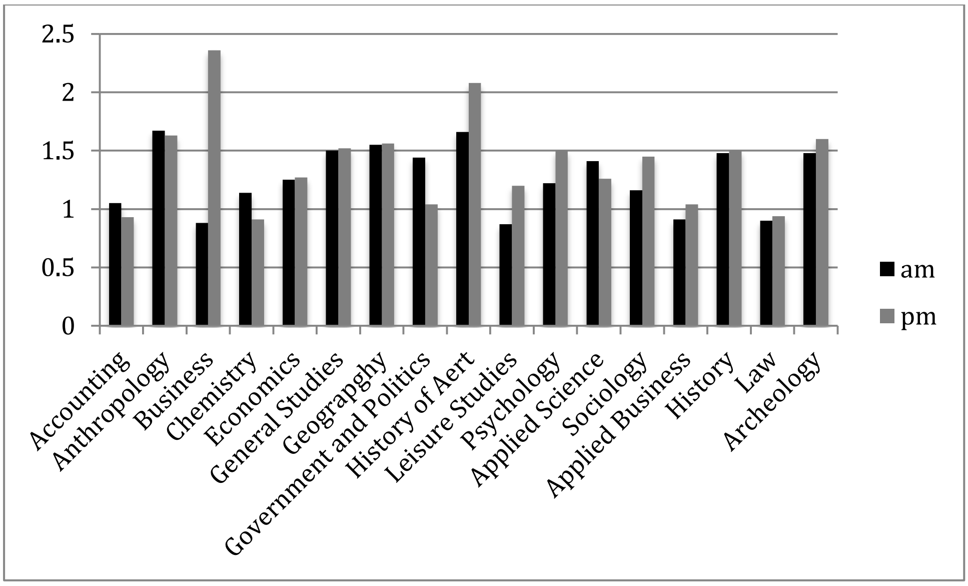

Figure 1: UMS weighting for morning compared to evening exams