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The Post-Lunch Dip in Performance

Timothy H. Monk, PhD, DSc

Western Psychiatric Institute and Clinic, University of Pittsburgh Medical Center, 3811 O'Hara Street, Pittsburgh, PA 15213, USA

Human performance, whether cognitive or physical, is not constant over the waking day. As noted elsewhere in this issue, there are circadian rhythms in performance ability just as there are in physiological variables such as core body temperature and melatonin levels. These circadian performance rhythms are a function of two processes: the status of the individual's endogenous circadian pacemaker and the length of time since sleep (and the duration and quality of that preceding sleep). For most variables, these two processes combine to produce a performance time-of-day function. For most performance measures and individuals, this function comprises an increase from a low at morning wake time to a peak in the early evening. However, for some variables and some individuals, a dip during the midafternoon hours is superimposed on this function. This dip is referred to as the *post-lunch dip*.

Siesta naps: an afternoon human propensity for sleep

In the hot desert and savanna climates, which apparently formed the cradle of the development of *Homo sapiens* as a species, an afternoon nap is a good way of getting through the hottest part of the day. As Dinges and Broughton [1] remark in their treatise on napping, the afternoon siesta is an integral part of many different cultures throughout the world. Arguably, most of the human beings on this planet view the early afternoon as a suitable time for rest, and

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E-mail address: monkth@upmc.edu

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for many, a short nap at that time is the norm rather than the exception. In North American and Northern European cultures, this afternoon propensity for sleep is recognized, but viewed as a nuisance and labeled the post-lunch dip or the "afternoon blahs."

In his review of the timing of naps, Dinges [2] concluded that the afternoon was by far the most frequent time for naps, with a nap zone from 2 PM to 4 PM appearing in a large-scale study of college students. In an earlier study of adults in general, Tune [3] also found a peak between 2 PM and 4 PM in nap timing. Our studies of nap patterning have found an earlier peak time of 1:34 PM for elderly ($\geq$70 years) males and 2:56 PM for elderly females using the Social Rhythm Metric [4], and a mean nap time of 2:36 PM from an overlapping sample of 45 elderly subjects aged 79 years or older assessed by 2-week sleep diary [5]. From a number of different survey and diary studies, Dinges [2] concluded that the pattern of nap durations was remarkably consistent, with the vast majority lying between 0.5 hours and 1.6 hours (overall mean 1.21 hours). Our diary data of 45 humans aged 79 years or older found an average nap duration of 53 minutes [6]. In our study of siesta naps in the elderly [7], it was found that about 60 minutes of sleep could, with practice, be obtained in a 90-minute siesta nap opportunity, even in those who did not habitually nap.

A number of different strands of empirical evidence weave together to build a case that an afternoon sleep, or nap, propensity is a universal phenomenon. From the sleep laboratory, Broughton [8] has made the case for bicircadian rhythms having 12-hour and 24-hour components reflecting pressure for slow-wave sleep. Possible circadian mechanisms for this are discussed later. In the disentrainment studies by Campbell and Zulley [9], subjects in a totally unstructured temporal routine still chose to sleep more in the post-lunch dip interval (even though there was no lunch). Also, Lavie [10] has demonstrated a secondary "gate to sleep" in the early afternoon in his ultra-short sleep–wake cycle studies (the primary gate to sleep being at the nocturnal bedtime). Increased sleep propensity in the early afternoon is also evidenced by the classic M-shaped time-of-day function observed in the Multiple Sleep Latency Test, at which sleep onset latency is measured at intervals over the day [11]. Furthermore, Carskadon and Dement [12] have shown that the post-lunch dip still occurs, even when the subject has a constant routine with no knowledge of time of day and does not eat lunch. Although undoubtedly worsened by a heavy lunch, the post-lunch dip is an endogenous effect, predicting, rather than reacting to, the midday meal. Thus, even if the individual comes from a temperate nonsiesta culture and has not had a heavy lunch, there will be an extent to which he or she is fighting off the desire for sleep during the early afternoon. Of course, athletes typically do not fall asleep during a competitive event, but often the difference between winning and losing is only a few tenths of a second. Therefore, any physiological negative, however much it is masked by the heat of competition, may have an adverse impact on athletic performance. Having made that point, though, one must remember that there are large interindividual differences, with some people much more affected than others.

Post-lunch dips in performance: laboratory studies

From laboratory performance studies there is some empirical evidence for a post-lunch dip, although its presence appears to be less universal than in measures related to sleep propensity. Blake's [13] classic studies of performance and time of day showed a clear post-lunch dip in measures of card sorting, serial search, and signal detection. Colquhoun [14] also showed the effect to be there, even in the absence of a meal. The phenomenon was further studied by Craig et al [15], who demonstrated by using a size-judgement task that the effect could be worsened by taking a high-carbohydrate lunch, but that the effect was still present even with a light lunch. Although they were unable to find a clear post-lunch effect, Christie and McBrearty [16] found complicated gender- and personality-related interactions related to this phenomenon. In a similar vein, when Folkard and Monk [17] performed a meta-analysis of time-of-day effects in various laboratory measures of performance efficiency and subjective activation, there was little evidence of a clear post-lunch dip.

Post-lunch dips in performance: field studies

Leaving the laboratory and considering real-life field data, the evidence for a post-lunch dip becomes more compelling. A collection of actual-task circadian performance curves [18] and an international meta-analysis of traffic accidents [19] show evidence for a post-lunch dip in performance. There are two possible interpretations of these results. First, many real-life performance decrements may result from the individual actually falling asleep, rather than to an actual performance decrement. Second, most laboratory performance evaluations are brief in duration and may be insufficiently powerful to detect post-lunch dip performance decrements, compared with real-life tasks that go on for hours at a time.

Underlying circadian mechanisms: the 12-hour harmonic

Studies of human circadian rhythms have invariably used body temperature as a benchmark, particularly when performance is being considered. Ever since the seminal work of pioneers such as Kleitman [20] and Colquhoun [14], time-of-day fluctuations in performance have been tied to those in body temperature. In 1950, a paper by Kleitman and Jackson [21] asserted that performance tests were largely unnecessary and could be replaced by a thermometer. In contrast, Colquhoun [14] later asserted a parallel rather than a causal relationship between circadian rhythms in temperature and performance. Thus, current thinking is that body temperature and performance are driven by the same circadian processes, rather than the performance differences being driven by brain temperature per se, for example. Furthermore, Colquhoun's colleagues [22,23] were able to show that for certain tasks and measures, performance and temperature may demonstrate very different time-of-day functions. However, for many tasks, particularly those with a low cognitive load, the parallelism between performance and body temperature appears good [24,25] and there is, in some cases, evidence for a post-lunch dip [26].

It has long been recognized that under normal nychthemeral conditions (ie, asleep at night and awake during the day), the circadian temperature rhythm is not a pure sinusoid, but is better modeled by 24-hour and 12-hour components [27]. By definition, of course, a 24-hour plus 12-hour fit must be better than (or as good as) a 24-hour single fit (which essentially has a zero amplitude 12-hour harmonic), but in most cases the size of the improvement, typically from about 80% (with one 24-hour sinusoid) to about 97% (with 12-hour and 24-hour sinusoids) of the variance explained, amply justifies the addition of the harmonic. It is possible that even better fits could be obtained if non–12-hour ultradian components (eg, 8 hour, 16 hour) were added, but a priori the choice of 24 hours and 12 hours is clearly more desirable from a time-series analysis perspective, especially when discussing the post-lunch dip.

Current sophisticated techniques to analyze body temperature rhythms have fitted 24-hour and 12-hour sinusoids as their basic analytic foundation [28]. This raises the intriguing possibility that the relative strength of the 24-hour and 12-hour components of the body temperature rhythm may be predictive of how much of a post-lunch dip is seen. This is represented in Fig. 1, where it can be seen (upper panel) that in rectal temperature data from 18 healthy young men and women (10 men and 8 women, aged 19 to 28 years) on a normal nychthemeral routine can be modeled by a mixture of 24-hour and 12-hour sinusoids. The rhythm is double plotted, expressed as deviation from a 24-hour mean, and the fitted model (smooth curve) superimposed. The four parameters used in the model (24-hour amplitude, 24-hour acrophase [time of fitted peak], 12-hour amplitude, and 12-hour acrophase) were the averages obtained from 18 individual least-squares sinusoid fits at each of two time periods. When only one of those parameters (12-hour amplitude) was doubled in value, a clear post-lunch dip in temperature emerged at around 14:00. Thus it is reasonable to hypothesize that for body temperature, at least, the presence or absence of a post-lunch dip is dependent on the size of the 12-hour component rhythm amplitude (Fig. 1).

We tested this harmonic model of the post-lunch dip in a study in which performance on a monotonous vigilance task was tested every 2 hours in a condition of constant wakeful bedrest under temporal isolation (the subject had hourly nutritional supplements instead of meals and had no knowledge of clock time). Nine healthy young adults were studied and temperature recorded every minute. We found that the hypothesis was confirmed. When those showing a post-lunch dip in performance, called *dippers*, were compared with those not showing a post-lunch dip in performance, called *non-dippers*, the dippers showed a stronger 12-hour harmonic in their body temperature rhythm than did non-dippers. Thus, at a preliminary level at least, it appears that performance

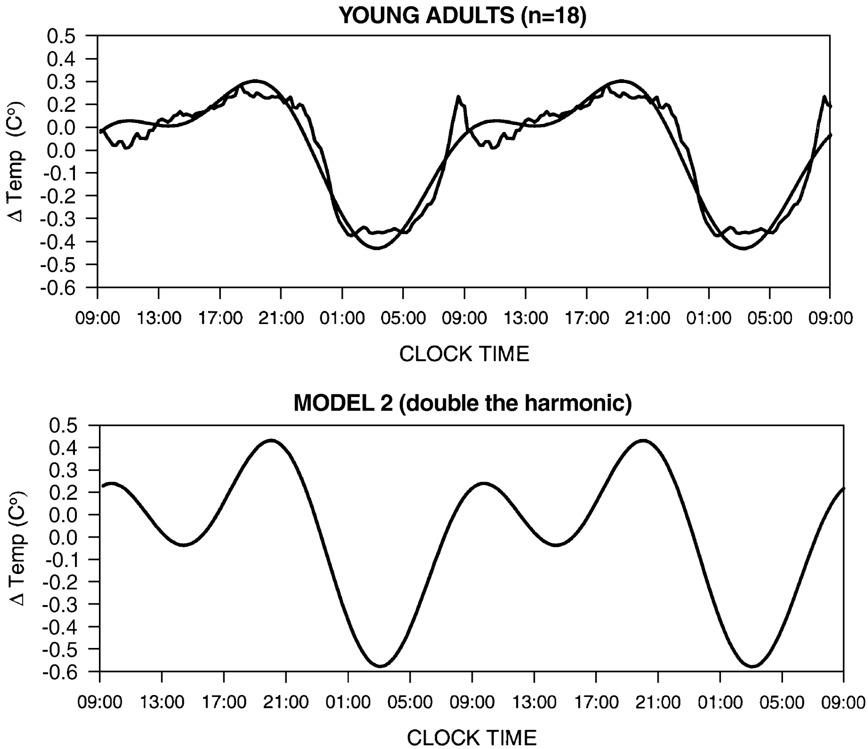

Fig. 1. Actual double-plotted circadian core body temperature data from 18 young controls (*upper panel*) plotted together with a best-fitting model involving 24-hour and 12-hour fitted sinusoids (*upper panel*). Temperature rhythm data are plotted as deviation from 24-hour mean value. The lower panel presents the same model with the amplitude of the 12-hour harmonic simply doubled in value.

post-lunch dip propensity may have been related to the size of the 12-hour harmonic component of the physiological circadian rhythm of body temperature [29].

Therefore, it seems reasonable to hypothesize that the post-lunch dip in performance is linked to human physiology in the 12-hour temporal domain. Because there is a known relationship between performance and body temperature in the circadian domain, and temperature is an accepted marker of human circadian functioning, it can be posited that the size (or timing) of the 12-hour temperature rhythm component might be predictive of the size (or presence) of a post-lunch dip in performance.

Morningness/eveningness and post-lunch dip propensity

Clearly, it would be useful to predict post-lunch dip propensity without going through the effort of continuous temperature measurement. Fortunately, there is some evidence in the literature that morningness/eveningness (M/E) can be used as a proxy variable. The notion of dividing the world into morning people and night people (ie, into different chronotypes) is a familiar one. Since the early 1970s, various pencil-and-paper questionnaires have been developed so a number can be gleaned that gives an indication of where an individual lies on the M/E continuum [30–32]. An example of an M/E scale can be found in the "Practical Applications" section of this volume. M/E scales reveal that about 80% to 90% of the population are only moderate in their M/E level, and are usually able to change their routines should school or work schedules require it. However, 5% to 10% of people are extreme morning people who find it very difficult to stay up late and wake up late, and about 5% to 10% are extreme evening types who find it very difficult to go to bed early or wake up early. In addition to predicting the timing of sleep onset and offset, these scales have also been associated with interindividual differences in the phase (timing) of the endogenous circadian pacemaker [33], the circadian rhythm in sleep propensity [34], and the homeostatic build up in sleep pressure [35]. M/E-related differences have also been shown in performance rhythms [36], temperature rhythms [37], and temperature and cortisol rhythms [38]. Horne et al [39] explicitly measured time-of-day effects in performance, comparing moderate to extreme morning types with moderate to extreme evening types, or "night owls," and found a clear difference between the two groups, with a post-lunch dip clearly apparent in the performance of morning types (who showed a marked decline in performance between noon and 2 PM, and thereafter), but not in that of night owls (who showed a slight improvement between noon and 2 PM). Thus, morning-type individuals may show a greater likelihood of exhibiting a post-lunch dip. Much more research needs to be done, however, before a definite link can be inferred.

Countermeasures

For most people, simple introspection will reveal the extent to which one is subject to the post-lunch dip in performance. For those who appear to be sufferers, the first action to take is to ensure that adequate amounts of nocturnal sleep are being obtained, thus reducing sleep drive during the day. The next steps are to cut down on the amount of carbohydrates consumed at lunch, to eliminate all alcohol, and to reduce the size of the midday meal. For many people, these steps will eliminate the problem entirely. If the problem remains, then the sufferer might consider either behavioral or pharmacologic countermeasures to increase early-afternoon alertness. One example of a behavioral countermeasure would be to increase the amount of daylight exposure, or use a light box, for about 30 minutes after lunch. Bright light has been shown to improve alertness and performance levels when these have been impaired by circadian processes. An example of a pharmacologic countermeasure would be the intake of caffeine, which has also been effective in increasing alertness and performance. Other stimulants would also work, of course, but should be avoided for ethical and safety reasons.

Future research directions

More research needs to be undertaken on the post-lunch dip. Much of this article is dependent on a few key publications, rather than on a broad research portfolio. Time-of-day effects in human performance are not always easy to detect, even when the entire waking day is covered [23]. Add to this the truth that many subjects do not show a post-lunch dip [16], and there may be insufficient incentive for larger scale studies to be undertaken, particularly when the phenomenon is regarded (especially in North American and Northern European cultures) as a nuisance, rather than a facet of human biology. Such studies should have the aim of further elucidating the role of the endogenous circadian system in producing the post-lunch dip, and in determining just who is and is not vulnerable.

Summary and clinical significance

Although it does not occur in all individuals and all measures, the notion of a post-lunch dip in performance is a real phenomenon that can occur even when the individual has had no lunch and is unaware of time of day. This phenomenon is related to an innate human propensity for sleep during the early afternoon hours. The post-lunch dip has its roots in our biology, and may be linked to the size of the 12-hour harmonic in our circadian rhythms. It is certainly exacerbated by a high-carbohydrate lunch, and may be more likely to occur in extreme morning-type individuals.

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