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The Effect of Gender and Time-of-Day on Time Perception and Mental Workload

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Two experiments are reported which investigated how subject gender and time-of-day influenced the estimation of duration and the perception of task-related mental workload. In the first experiment, 24 subjects performed a filled time-estimation task in a constant blacked-out, noise-reduced environment at 0800h, 1200h, 1600h, and 2000h, respectively. In the second experiment, 12 different subjects performed an unfilled time estimation task in similar conditions at 0900h, 1400h, and 1900h. At the termination of all experimental sessions, participants completed the NASA Task Load Index workload assessment questionnaire as a measure of perceived mental workload. Results indicated that physiological response, reflected in body temperature change, followed an expected pattern of sequential increase with time-of-day. However, estimates of duration and the perception of mental workload showed no significant effects for time-of-day. In each of the experiments there were significant differences in time estimation and mental workload response contingent on the gender of the participant. These results are interpreted in light of the previous positive findings for circadian fluctuation in performance efficiency and the equivocal findings of a gender difference in time estimation. A unifying account of these collective results is given based on gender by time-of-day interactional effects.

In order to survive and prosper in uncertain conditions, performers need the ability to synchronize their actions with the dynamics of differing environmental demands. To provide choice between such courses of action and thereby to promote adaptive capability, the performer must possess some degree of autonomy with respect to space and time. Our ability to navigate through three spatial dimensions is transparent and is subsumed by information assimilated principally by the visual system and acted upon by the process of attention. What is less obvious is the ability to navigate through a temporal dimension. Indeed, when time is considered simply as an immaleable and homogeneous flow in which events "occur," a postulate intrinsic to Newtonian dynamics, then the necessity to "navigate" is completely obviated. While the sterility of this latter position with respect to human actions has been recognized for over a century

(Bergson, 1910; Guyau, 1890), one difficulty still lies in the fact that unlike vision for space, there is no comparable single sensory system directly responsible for time. It was perhaps the inability to link the perception of time to focal models of behavior that diluted its past impact on mainstream psychology (Adams, 1964). However, it is the very ubiquity of time that is one reason for its renaissance in contemporary research (Gibbon & Allan, 1984; Jones, 1976).

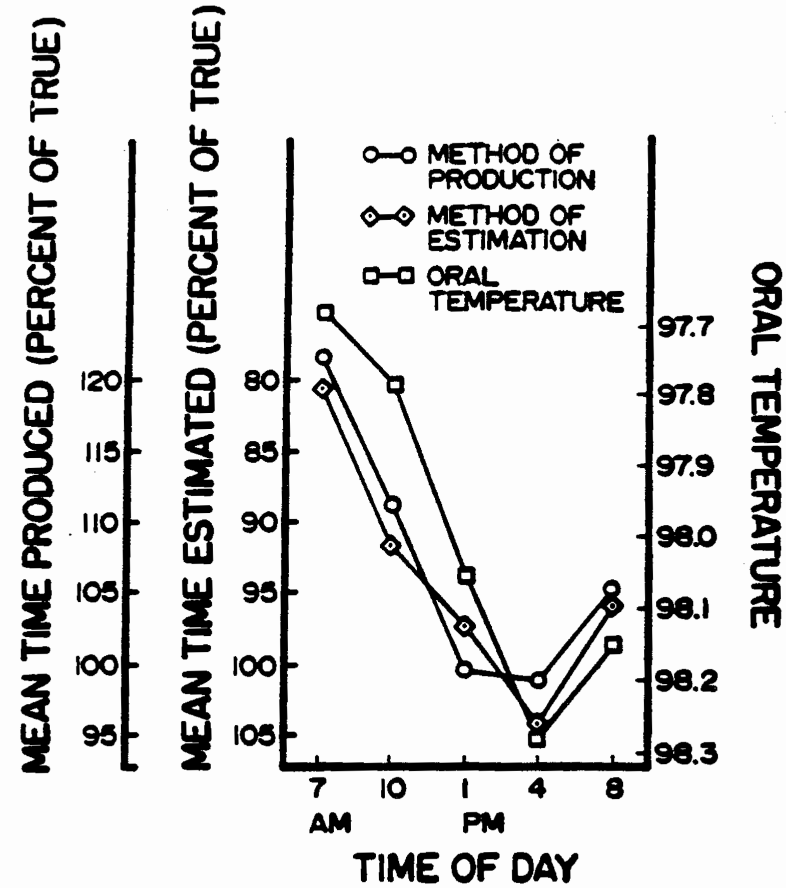
Two competing views of time perception suggest that, on the one hand, duration estimations are subsumed by cognitive capabilities and are extracted from information on change and complexity of the stimuli presented in the environmental display. On the other hand, a second more physiological perspective postulates the presence of an internal time source, based upon which the estimation of duration is organized. Some models (e.g., Treisman, 1963, 1984) have generated a compromise between these two extremes and have suggested that some processes intrinsic to cognitive action can be combined with a physiologically-based pulse generator to provide an overall timing mechanism. While much effort has been directed to the study of stimulus-based factors as influences on the perception of duration (see Gibbon & Allan, 1984; and Levin & Zakay, 1988) and considerable insight has been gained into the purely physiological aspects of central pacemakers (Moore-Ede, Sulzman, & Fuller, 1982), relatively little progress has been made on integrative efforts which promote an understanding of their respective contributions to an overall time sense. With the growing focus on attempts to decipher information structures intrinsic to environmental displays, what remains most problematic are the relative influences of a central pacemaker(s) and what individual characteristics affect its output as reflected in duration estimates and mental workload.

The composite model originally proposed by Treisman (1963) includes a single pacemaker whose frequency is sensitive to input from a specific arousal center. The only established influence on this latter center that has been identified is body temperature (although see Treisman's 1984 discussion on the role of EEG alpha rhythm). The identification of the influence of temperature emanates from Hoagland's (1933) earlier observations concerning a chemical clock responsible for changes in the perception of duration. Previous evaluations of the chemical clock hypothesis, and by implication Treisman's later model, have produced seemingly equivocal evidence (although see Hancock, 1990), but most experimental studies have used artificial methods to manipulate the body temperature of the participant. There are, however, natural variations in body temperature which allow a test of these models without the potential confound that artificial heating might introduce. The first of these natural occurrences are the changes in temperature across times of day.

Under normal conditions, performance level commonly maps to circadian oscillation in which time-of-day and body temperature play dual and key roles (Moore-Ede, Sulzman & Fuller 1982; Webb 1982). Typically, task performance is poorest in the lowest portion of the sinusoid at approximately 0400h and rises to peak efficiency at the highest point of the rhythm around 2000h (Colquhoun, 1971; Kleitman, 1939/63). This effect is substantiated in tasks requiring speeded or time-limited response, in which diurnal effects themselves were first noted (Dresslar, 1892). The exceptions to this mapping are rare and somewhat controversial (see Folkard & Monk, 1979, 1980; Folkard, Weaver, & Wildgruber, 1983). Duration estimation is one of those tasks in which the relationship between time-of-day and performance change has yet to be fully resolved. Thor (1962) was perhaps the first to test the implied relationship between time-of-day and time estimation. Using the production technique, he asked six subjects, five males and one female, to estimate three periods of 30 and 120 s alternately. Across all subjects he found that productions increased from 0600h, the start of his testing period, to 1500h. From 1500h to 2100h productions decreased until at 2100h the end of the test period, the estimates were similar to those at 0600h. This global inverted-U shaped pattern was consistent for both the 30 and 120 s intervals. However, the one female subject did not follow this general pattern. Her estimates rose from 0600h to a peak at 0900h after which productions decreased across time-of-day. Also, Thor noted a difference in pattern between day active and night active individuals in which there was a completely reversed, or U-shaped, pattern for the night active subjects. Subsequently, Thor and Baldwin (1965) asked 75 subjects to estimate the correct time-of-day without reference to their watch. There was only one trial per person which represented a response by verbal estimation. Thor and Baldwin plotted their data as a deviation from the actual time in minutes. They found subjects overestimated in the window 0800h-1000h and 1800h-2000h, but underestimated between these times, falling to the largest underestimation between 1400h-1600h. As verbal estimation and production are related inversely, the mean data from Thor's two studies are consistent and represent evidence of a diurnal variation in time estimation (Thor, 1962; Thor & Baldwin, 1965).

It was Pfaff (1968) who subsequently pointed out the overall contradiction in Thor's collective findings. He noted that previous studies on the relationship between circadian phase and task efficiency had shown faster performance as body temperature increased across time-of-day (e.g., Kleitman, 1939/1963). In terms of time estimation this would be reflected by shorter produced intervals, not longer ones as reported by Thor. Pfaff therefore tested 10 male subjects across times-of-day ranging from 0700h to 2000h. Participants engaged in five estimates each of 15, 30, and 60 s using interval production and a like number of trials at 10, 20, and 30 s for verbal estimation. Pfaff reduced responses to a percentage value of the target duration and plotted these estimates against both oral temperature and time-of-day. Produced estimates and the reciprocal of verbal estimates both decreased systematically across temperature. Also estimates followed oral temperature with time-of-day such that produced times decreased with ascending temperature up to 1600h and then increased as oral temperature decreased between 1600h and 2000h. These data are reproduced in Figure 1. Pfaff's data follow his original prediction and appear to confirm Hoagland's chemical clock model using natural fluctuation in body temperature (see also Francois, 1927). One way to reconcile these findings with those of Thor is to suggest that the subjects in Pfaff's study behaved more like the night active individuals. However, this appears unlikely given the explicit notation of the use of daytime active subjects by Pfaff (1968, p. 420). There are other differences in the subjects to which such a variation in response might

FIGURE 1
Variation in time judgments and oral temperature as a function of time-of-day.



Notes: Both estimations and productions are expressed as a percentage of the target time. Note that estimates decrease and productions increase up the vertical scale.
Source: Reprinted with permission from Pfaff, D. (1968). Effects of temperature and time-of-day on time judgments. *Journal of Experimental Psychology, 76*, 419–422.

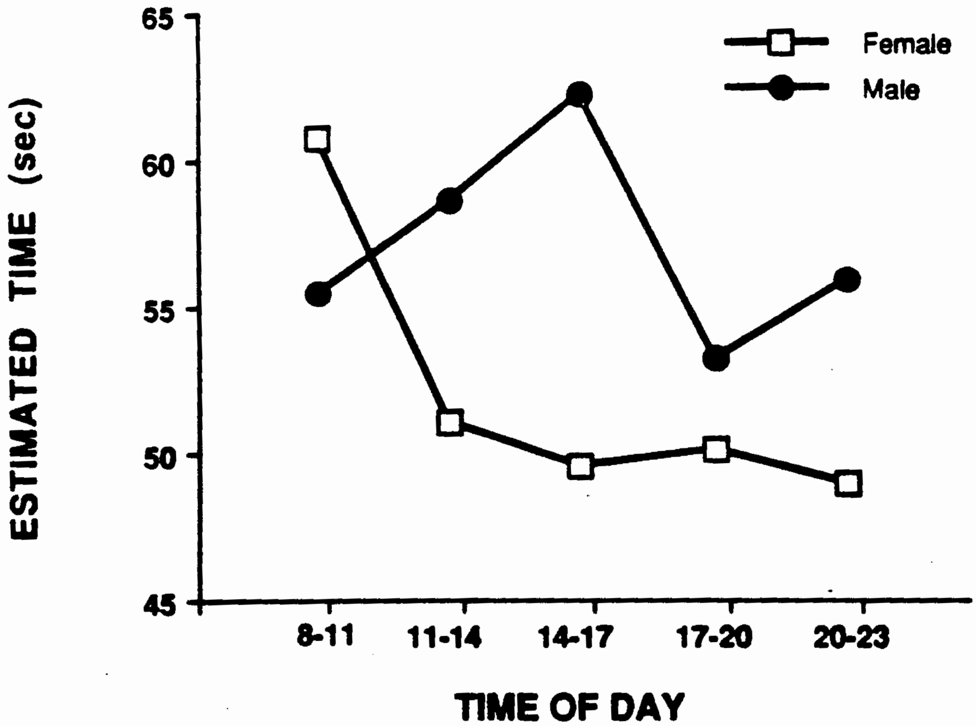
be attributed. One potential effect can be found in the data for the one female subject included by Thor, an effect discussed in more detail below.

However, perhaps the most persuasive argument for a time-of-day influence on time perception is given in the work of Poppel and Giedke (1970). They carried out a series of experiments, the first of which is particularly germane to the present argument. They asked eight male and four female subjects, on a regular day-active nighttime-sleep regimen, to estimate a period of 10 s using the production technique. Seven recordings were taken at 2-hour intervals during the day starting at 0800h and ending at 2000h. The recordings were repeated on 3 sequential days and the average of the three trials were taken to give a representative mean. Poppel and Giedke found results substantively similar to those reported by Pfaff. That is, produced time decreased from 0800h to 1400h and then subsequently rose again. At 1800h the estimates were equivalent to the 0800h level and at 2000h they were higher still. It is interesting to note that the two lowest estimates were at 1200h and 1400h respectively, some hours earlier than the 1600h identified by Pfaff. It should be recalled, however, that while Pfaff tested all male subjects, one-third of the subjects in the study of Poppel and Giedke were female. Overall, the reported studies might be taken for strong support of a time-of-day variation in time perception tied, at least in part, to body temperature (Pfaff, 1968; see also Poppel, 1978). However, this would be to dismiss the clear inconsistency between Thor's findings and subsequent work, and would also mask the subtle differences between studies which seem initially in agreement. There is one further point of interest. There are studies (e.g., Moore, 1982) which have found no change in the perception of duration across time-of-day, even though marked and expected changes in body temperature were observed. There is, of course, an intrinsic bias against the publication of null results, and what cannot be ascertained is the general propensity toward this finding (see also Kirkcaldy, 1984).

While time-of-day is one natural occurrence of variation in body temperature, subject sex[1] represents a second. It has been observed that females have a higher resting temperature than males (e.g., Hancock, 1983). By implication, unless dominated by some more powerful exogenous influence, it is reasonable to affirm the potential for a sex difference in time estimation. While a summation of evidence supports this difference, there has been controversy as to the consistency of this effect (cf., Gilliland, Hofeld, & Eckstrand, 1946; Gulliksen, 1927). Some studies have reported significant differences (Axel, 1924; Bell, 1972; Carlson & Feinberg, 1970; Delay & Richardson, 1981; Goldstone, 1968; Greenburg & Kurz, 1968; Gulliksen, 1927; Hornstein & Rotter, 1969; MacDougall, 1904; Martin, Shumate, & Frauenfelder, 1981; Rammsayer & Lustnauer, 1989; Yerkes & Urban, 1906) usually showing females overestimate time intervals relative to males when using the verbal estimation technique. Others have reported no obvious effects (Baldwin, Thor & Wright, 1966; Geer, Platt, & Singer, 1964; Getsinger, 1974; Gilliland & Humphreys, 1943; Loehlin, 1959; Montare, 1985; Ornstein, 1969; Roeckelein, 1972; Smythe & Goldstone, 1957; Swift & McGeoch, 1925). Differences between such findings appear in part dependent on confusion as to the method chosen to record temporal estimates. Clarification of such a confound tends to confirm a sex difference (Hancock & Vercruyssen, 1992).

In addition to established amplitude differences in body temperature between the sexes, there appears also to be a phase difference (see Baker, Holding, & Loeb, 1984; Baker, Quinkert, Holding, & Colquhoun, 1989; Quinkert, 1985). While each retain the same general circadian morphology, females tend to peak earlier in the day compared to males. Therefore, in the search for the relationship between temperature and performance, the individual and interactive effects of time-of-day and gender are important to consider in tandem; otherwise mutual interference effects may obscure or distort findings. The one previous study that has looked at this combination explicitly was reported by Kirkcaldy (1984). He asked 105 subjects, 61 females and 44 males, to produce a period of 60 s. Reported methodological details were sparse, but it appears that each subject produced only one estimate and subjects were randomly assigned to one of five general test times ranging from 0800h to 2300h. It is worth considering his results in detail. First, he found a tendency for females to give lower productions than males (F: $\overline{x} = 52.13$, s.d. = 19.87; M: $\overline{x} = 56.19$, s.d. = 15.08). However, Kirkcaldy found

FIGURE 2
The estimate of a 60-second interval by male and females group by five intervals throughout the day.



Source: Reprinted with permission from Kirkcaldy, B.D. (1984). Individual differences in time estimation. *International Journal of Sport Psychology*, *15*, 11–24.

no effect for time-of-day. Despite the pattern of results shown in Figure 2, he found no significant interaction between time-of-day and gender on duration estimation. While the reasons for this may involve the use of only one observation per subject, and the grouping of these data into broad time bands, the pattern shown is instructive. For example, the inversion of estimates early in the day is consistent with the notion of a circadian phase difference between the sexes. Unfortunately, Kirkcaldy did not record body temperature so a direct connection has yet to be established. It is instructive to consider Kirkcaldy's own summary of his results. He concluded that females were most accurate earlier in the day and thereafter were prone to make negative time errors. Males, in contrast, produced positive estimations around 1400h–1700h. Although these patterns were not significantly different, Kirkcaldy noted that statistical results were in the expected direction but fell short of significance which could be altered had the sample size been increased. Following these results, therefore, it appears important to include comparative observations of gender effects in the experimental procedures testing time-of-day effects on duration estimation.

There are also several potential confounding effects in previous studies that may have affected the pattern of reported data. These include the method used to assess the perception of time, a potential order effect in testing, and most significantly the number of trials used in each study. It is clear from even a cursory examination of the literature on time estimation that individual differences predominate. When considering gender effects, it is insufficient to sample a single trial as representative of such a difference. Synthesis of existing evidence suggests that a lack of repetition is a key factor in whether sex differences are or are not reported. Similarly, the reliance on single trials in some time-of-day studies (e.g., Thor & Baldwin, 1965) is affected by similar constraints. Also, no study on time-of-day effects on time estimations quoted here, used more than five trials at any one time-of-day. With time-of-day studies there are potential order effects (Damos & Lyall, 1986; Poulton, 1982), which in previous studies have only infrequently been considered with respect to experimental design. Further, the inability of some previous authors to distinguish their procedure with respect to standard approaches (Bindra & Waksberg, 1956) has led to evidence that appears, but in reality is not, contradictory. Each of these potential issues render the existing data on natural variation in body temperature and time perception somewhat suspect, and the test of Hoagland's and Treisman's models incomplete.

Previous studies have also relied solely on performance output as indicative of subject response. While time estimates are of primary importance, there are other measures which help to elucidate response pattern. One avenue of evaluation that can be conducted in parallel with performance measurement is workload assessment (Chignell & Hancock, 1985; Derrick, 1988; Gopher & Donchin, 1986; Hancock & Meshkati, 1988; Kantowitz, 1987; Moray, 1979; Vidulich, 1988; Yeh & Wickens, 1988). For a task which presents a constant level of demand (Hancock, Chignell, & Kerr, 1988), there are a number of possible patterns of response for both performance and workload. It may be that both performance and workload follow the typical sinusoidal function of the circadian rhythm in parallel. It is possible that duration estimation remains stable and that circadian variation in workload is a reflection of the effort expended to stabilize this important organismic characteristic. Alternatively, performance may vary while the particular method of subjective workload assessment may reveal no change across time-of-day. Further, the question of gender differences in time estimation may be clarified by workload measurement. For example, gender differences in time perception may be founded on physiological characteristics such as core body temperature values, or may reflect other fundamental differences in the subjective approach to duration estimation. Therefore, the aim of the present investigation was to examine the time perception of male and female participants, at differing times of day, and to determine whether the perception of task-related mental workload fluctuated in a circadian fashion in the presence of a task of consistent demand.

EXPERIMENT 1

METHOD

Subjects

Twenty-four healthy subjects (12 males, 12 females) were solicited as unpaid volunteer participants in the experiment. Their ages ranged from 21–40. None of the participants had any previous experience with the interval production task. They were members of the faculty, staff, and student body of the University of Southern California.

Experimental Task

The performance task was time estimation (Gilliland, Hofeld, & Eckstrand, 1946; Guay & Hall, 1977), the reliability of which has itself been the subject of argument (e.g., Bakan & Kleba, 1957; McCauley, Kennedy, & Bittner, 1980). Using a filled production technique (Bindra & Waksberg, 1956), each subject estimated a period of 11 s by depressing a telegraph key and after the estimated interval, releasing it. At the termination of a single trial, the experimenter recorded the time produced to the nearest millisecond and the subject commenced a following trial. The task was self-paced and there was no communication between the experimenter and subject during the 100 trials, which constituted a single session. All procedures occurred in a blacked-out sound attenuated facility. Every five trials the experimenter recorded the temperature value from an Arbrook-LaBarge Tympanic Temperature monitor. The measurements were made deep in the auditory canal and followed a procedure we have previously employed (Hancock, 1983).

Experimental Procedure

Upon the subject reporting to the testing facility, the experimenter attached temperature recording equipment and calibrated the physiological and performance data collection system. The experimenter allowed a brief time for the temperature reading to stabilize. At 15 min to the hour the subject began the time estimation task described in detail below. The 100 trials in each session took approximately 25 min (depending upon individual subject estimates). After finishing the task the subject completed the mental workload assessment instrument. The experimenter then removed the physiological recording equipment and the subject was released at approximately 15 min past the hour. Each subject engaged in one practice session at 1200h. The subject was then assigned to one time-of-day exposure sequence, where order was selected by random lot but matched between participant gender. Four assessments were made one on each successive day. The times of testing were 0800h, 1200h, 1600h, and 2000h respectively, and were administered according to the sequence selected for each gender matched pair of subjects.

Workload Evaluation

At the termination of the individual session, the subject completed the National Aeronautics and Space Administration, Task Load Index (NASA-TLX) workload assessment scales (Hart & Staveland, 1988). In this procedure, the subject is presented with six defined sources of mental workload, namely; mental demand, physical demand, temporal demand, performance, effort, and frustration. Each of these dimensions was matched for pairwise comparison and the subject indicated which of the two alternatives represented, to them, the greater source of workload. These comparisons were used to derive a weighting for each dimension depending upon the number of times the subject selected a dimension in comparison with its five companions. After each condition, the subject scored the task they had completed on a 0–100 scale for each dimension. These values were recorded as the raw scores. The weights were used to multiply the raw score for each dimension to give weighted workload values. The total of each weighted scale was added together and the sum divided by 15 (the total number of weightings) to give a workload average for the condition. In the present work, the physiological assessment technique employed was the measurement of auditory canal temperature (Hancock, Meshkati, & Robertson, 1985; O'Donnell & Eggemeier, 1986; Wilson & O'Donnell, 1988).

Treatment of Data

Mean duration estimates, physiological response, the raw and weighted ratings from each workload dimension, and the overall workload value from the NASA-TLX instrument were analyzed according to a 2 × 4 (gender × time-of-day) mixed analysis of variance (ANOVA) design with repeated measures on the second factor. To examine sequence effects, the 100 trials were partitioned into 10 blocks of 10 trials each and analyzed in a 2 × 4 × 10 mixed ANOVA with repeated measures on the last two factors. All *post hoc* evaluations were conducted using Fisher's procedure. The .05 level of significance was used to distinguish effects throughout the experimental series. There were no missing data and truncation of the data for outliers was not employed.

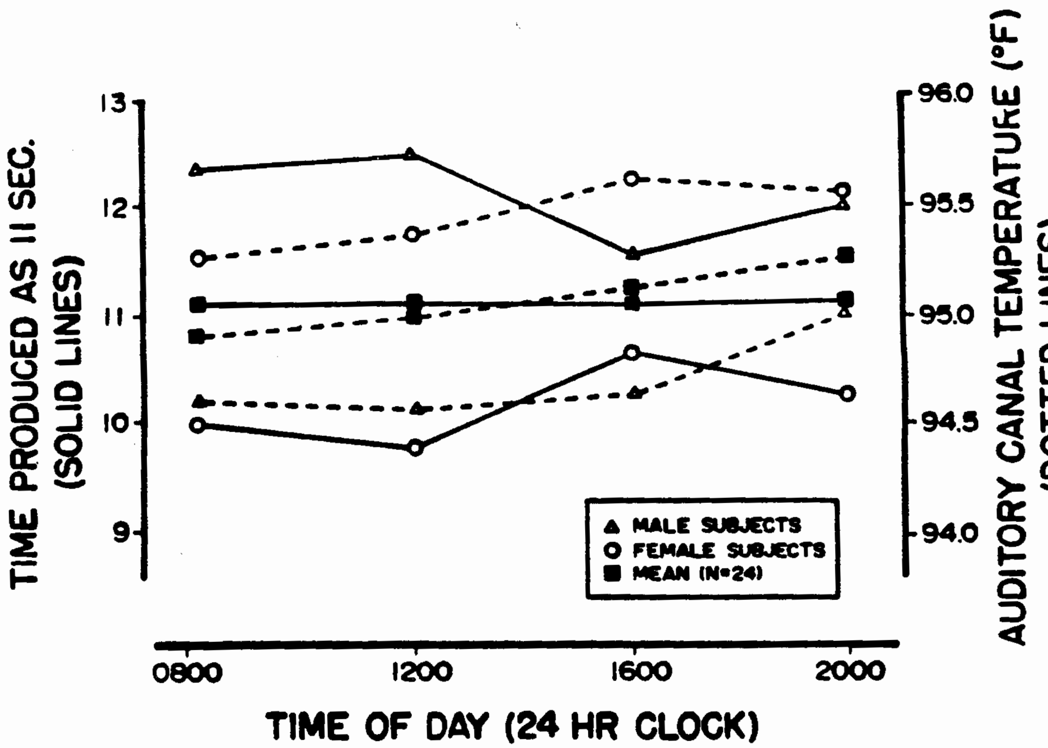
RESULTS

Physiological Responses

For the body temperature data, there were significant main effects for subject gender ($p<.0001$), time-of-day ($p<.0001$), and the interaction between these factors ($p<.001$). Female participants exhibited a consistently higher temperature than their male counterparts (female = 95.46°F, male = 94.71°F) and for the mean of all subjects, temperature increased consistently across time-of-day (0800h = 94.93°F, 1200h = 94.97°F, 1600h = 95.13°F, and 2000h = 95.30°F), as seen in Figure 3. These results replicate effects established in the literature (see for example Colquhoun, 1971; Kleitman, 1939/1963). With respect to the interaction between gender and time-of-day for the temperature data, female participants tended to increase more rapidly in the early intervals 0800h-1600h and subsequently plateau, while males showed little early increase which was followed by a sharper rise between the later intervals 1600-2000h. Again, this interaction has been noted by previous investigators (see Baker, Holding, & Loeb, 1984; Quinkert, 1985).

There was a significant effect of trial block on auditory canal temperature. As this did not interact with the time-of-day, this effect did not depend upon specific test session. The effect was a sequential increase in temperature across successive blocks.

FIGURE 3
The effect of time-of-day on auditory canal temperature (dotted lines) and time estimation by interval production (solid lines) for male and female participants.



Notes: The different patterns of body temperature increase by males and females produces an expected increase for the mean value across time-of-day. For duration estimates, the mirror image effect across genders leaves the mean value constant across time-of-day and also close to the target value of 11 s.

Fisher's *post hoc* test distinguished the majority of blocks from each other, with only adjacent blocks (e.g., 1 vs. 2, 2 vs. 3 etc.) showing no significant differences. Care was taken that the subject had stabilized temperature value prior to commencing performance. This stabilization period was 5 min, hence the increases shown appear due to the demands of the performance task undertaken, a finding consistent with previous results (Edelstein, 1982; Hancock, 1983).

Performance Measures

With respect to estimates of duration, results indicated a number of interesting patterns. There was a main effect for subject gender (p<.0001), and an interaction between gender and time-of-day (p<.0001). However, there was no main effect for time-of-day as has previously been reported (Pfaff, 1968; Poppel & Giedke, 1970; Thor, 1962; Thor & Baldwin, 1965). These null results for a time-of-day effect follow the findings of Moore (1982) and Kirkcaldy (1984) in this respect. The difference between mean estimates for males and females was large (male = 12.099s, female = 10.195s), which parenthetically gave an overall mean close to the requested interval (x = 11.147s). The interaction between gender and time-of-day arises from the respective decrease in the estimates of male subjects, and increase in the estimates of female subjects at the 1600h (see Figure 3). For duration estimates there was also a significant effect of trial block. Estimates of duration tended to lengthen across successive blocks. Fisher's *post hoc* test distinguished block 1 from all other blocks, with the exception of block 10. This is a general example of the lengthening effect with increasing numbers of trials on the estimation of duration, which has been observed by Treisman (1963) among others.

Subjective Workload Evaluation

For the raw ratings on the TLX workload dimensions, females produced significantly higher scores on the mental demand ($p<.05$) and frustration ($p<.001$) dimensions and significantly ($p<.001$) lower scores on the performance dimension, where a lower score indicates higher perceived success on the task (see Figure 4). There were no interactive or main effects for time-of-day on any of the raw scores. The results from the weighted performance and frustration dimensions confirmed the significant differences observed in the raw scores for these dimensions. There were no significant main effects for time-of-day or interaction with gender in any of the workload measures (0800h = 45.6, 1200h = 46.4, 1600h = 45.3, 2000h = 45.6). For the overall workload level, there was a nonsignificant trend ($p = 0.12$) for females to rate overall workload higher than their male counterparts. As with other investigations of mental workload, there were significant differences between the individual participants (Damos, 1988).

EXPERIMENT 2

METHOD

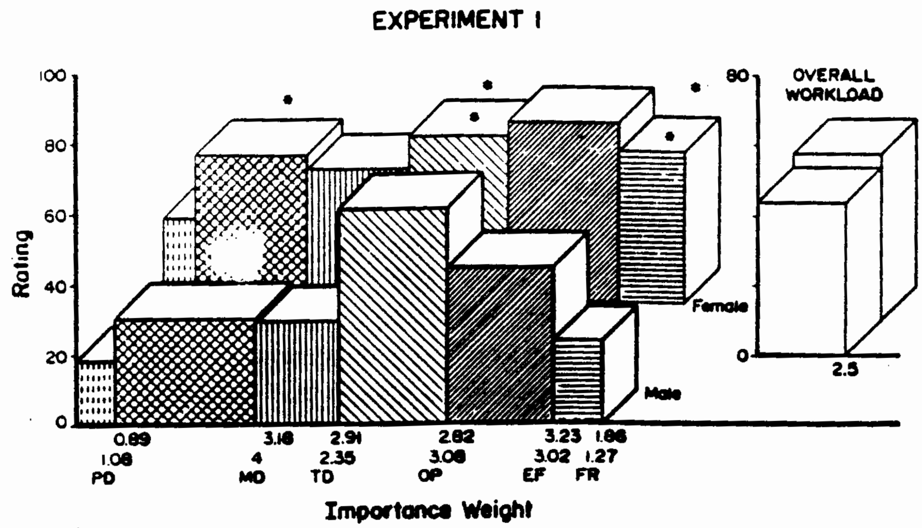
The method from Experiment 1 was replicated exactly, but with three exceptions. First, 12 different subjects (6 male, 6 female) were used. Second, the subjects were tested at three times of day, which were different from those selected in Experiment 1 (0900h, 1400h, and 1900h). Finally, the task in this experiment was an unfilled production of 11 s in which the subject depressed a button to start the estimate, released that button immediately and pressed a second button to terminate the trial (Bindra & Waksberg, 1956). The unfilled procedure means that no activity was undertaken during the interval of the estimate.

RESULTS

Physiological Responses

For the physiological measure, both the interaction and the main effects for time-of-day and gender were again significant ($p<.001$). As with Experiment 1, auditory canal temperature increased with time-of-day (0900h = 93.49°F, 1400h = 93.87°F, and 1900h = 93.98°F). *Post hoc* analysis distinguished each of these temperature values as significantly different from each other. The pattern again showed a higher temperature

FIGURE 4
Subjective task workload on the NASA TLX for male and female subjects.



Notes: The horizontal axis gives the value of the weights for each scale. The upper value represents that for the female subjects while the lower values are for the male subjects. From left to right, these scales are: PD = physical demand, MD = mental demand, TD = temporal demand, OP = own performance, EF = effort, and FR = frustration. The numbers for each scale are located at the bottom right corner of the box to which they refer. The vertical axis provides the raw rating on each scale. Therefore, the height of the box represents unweighted values, while the volume of each box represents its weighted value. Significant differences between the genders for weighted values are indicated inside the box structures, while significant effects for raw ratings are those illustrated outside the boxes.

for female participants, a difference which was increased as the day progressed and which resulted in the interaction noted (see Figure 5). As with the first experiment, there was a significant effect for trial block on auditory canal temperature. In keeping with results from the first experiment, there was a sequential increase in temperature across block.

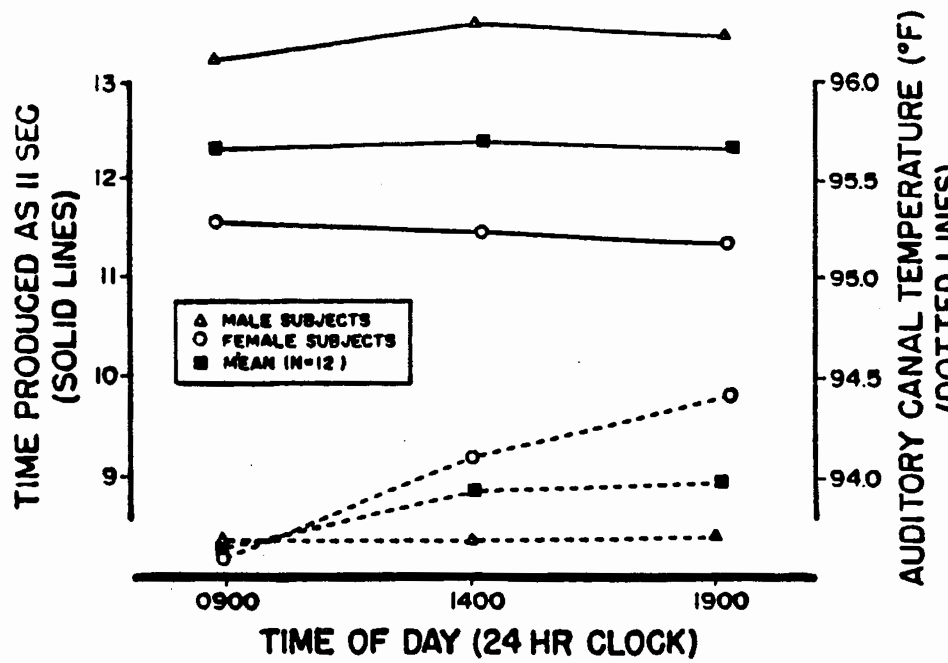
Performance Measures

For the duration estimations, results followed a similar pattern to those expressed in Experiment 1. Of prime interest is the replication of the gender effect and the repeated absence of a time-of-day effect (see Figure 5). In addition, the interaction between gender and time-of-day was again significant, with the divergence between performers of different gender noted at 1400h. In accord with the findings of the first experiment, there was a sequential lengthening of the time estimate across the ten performance blocks. As with the first experiment, the increase was somewhat erratic with a small decrease in the final block.

Subjective Workload Evaluation

In the second experiment, the workload evaluation gave a slightly different pattern of results. One common finding, however, was a significant difference between male

FIGURE 5
The effect of the time-of-day on auditory canal temperature (dotted lines) and time estimation by unfilled interval production (solid lines) for male and female participants.

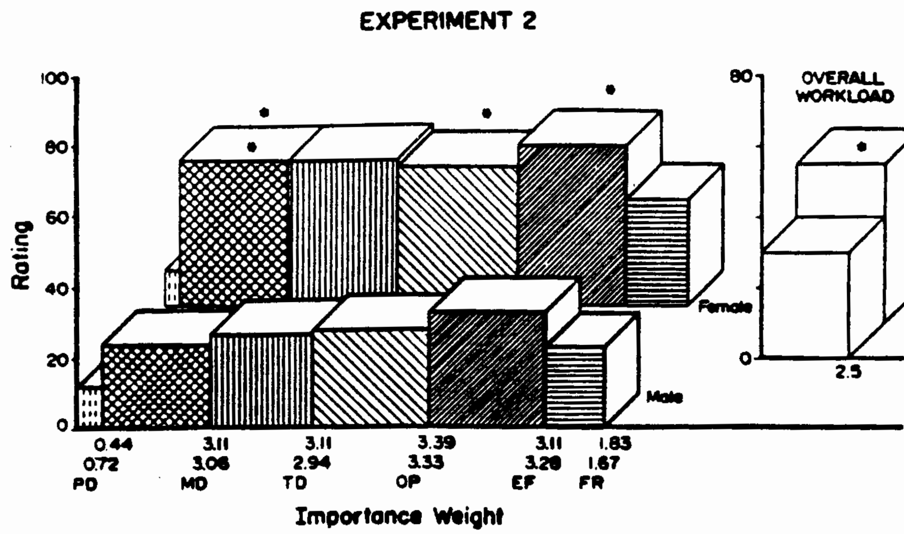


Notes: As with Experiment 1, higher temperature values are recorded for the female participants who show a relatively strong increase compared to male subjects across the times-of-day evaluated. The pattern for duration estimates is similar to Experiment 1 with a strong effect for gender and little change across time-of-day. The average estimate here is further from the target value of eleven seconds and this change in accuracy may be a result of the change in procedure from a filled to an unfilled interval production method.

and female subjects on the raw mental load dimension ($p<.005$). The females again scored this dimension significantly higher than their male counterparts. This trend was also true for the raw performance dimension where the females repeated the pattern of scoring this source of load significantly higher ($p<.05$) than the male participants. The weighted ratings confirmed these differences with significant effects ($p = .01$) for the weighted mental dimension, and a corresponding, but non-significant trend ($p = .08$) in the same direction for the weighted performance dimension. In this procedure, females also rated raw effort as significantly higher than their male counterparts. The major difference between the present results and those for Experiment 1 was the effect on overall workload level. The trend noted in Experiment 1 became a significant effect here and with the raw and weighted subscales, the females gave a significantly higher overall load response ($p<.01$) with respect to the task than the male subjects. These effects are illustrated in Figure 6.

There is an apparent contradiction in the results for the performance dimension, where the significant effects change direction between the two experiments. This is probably due to an artifact of the subscale design. In the Task Load Index (TLX), five of the six subscales have end points that read low/high from left to right. From left to right, the performance subscale goes from good to poor, reflecting the concept that as

FIGURE 6
Subjective task workload on the NASA TLX for male and female subjects.



Notes: The horizontal axis gives the value of the weights for each scale while the vertical scale provides the raw ratings, as detailed in Figure 4. Significant differences for weighted values are indicated inside the box structures, while significant effects for raw ratings are provided outside the boxes.

satisfaction in accomplishing performance goals decreases, subjective workload increases. In the first experiment this was not communicated directly to the subject who was required only to read the subscale definitions from the TLX workbook. In the second experiment, the experimenter was required to point out this reversal to the subject, and it is this procedure which appears to have influenced the current results. Again, there were no significant effects on workload for time-of-day (0900h = 34.9, 1400h = 37.9, 1900h = 39.1). Overall, these findings are taken as a general confirmation of the principal trends noted in Experiment 1. Namely, the effect on perceived workload depends on subject gender with little apparent influence for time-of-day.

DISCUSSION

The results from the present experiments indicate a coherent and consistent account of the effects at hand that may explain some of the contradictions in previous findings. For the purpose of explanatory clarity we consider first the effects of gender, secondly the time-of-day effects, and finally the interactive effects between these influences. The most consistent finding of the present work is the clear and impressive differences in duration estimation depending upon participant gender. In common with many other studies on time perception there were large individual differences; however, the gender effect is obviously present in each experiment. Our findings are consistent with the majority of previous results (e.g., MacDougall, 1904; Rammsayer & Lustnauer, 1989). Our experimental procedure required the production of durations, and as underestimation with this technique is the equivalent to overestimation using verbal estimates, our results are in accord with those cited earlier on sex differences. The workload assessment measures also reflected this gender difference. In the first experiment, overall workload difference approached traditional significance levels and in the second experiment they exceeded these levels, indicating that female subjects rated this task as more demanding than their male counterparts. With respect to ratings on each of the TLX dimensions, females in each experiment gave significantly higher responses on the raw mental demand and performance scales compared to males, and the propensity for the weighted value of each of these scales also to show significant differences was in evidence in each experiment. The only basic difference between the patterns of workload were in the frustration scale which showed large differences in the first experiment but failed to reach a significantly different level in the second experiment.

Another line of evidence emphasized the gender difference in the approach to the estimation task. In Experiment 1, all 12 male volunteers completed the experimental sequence without drop outs. It took 19 female volunteers to complete the cells of the matched design as 7 females exercised their right of voluntary withdrawal at varying stages of completion. While some complained of the conditions of black-out and noise attenuation, the major identified problem was the boredom associated with the task. In other work (Hancock & Warm, 1989), we have established that traditionally viewed low stress and infrequent response tasks, e.g., vigilance, do not always result in low mental workload response. Indeed, the necessity to maintain attention in an unchanging and unstimulating environment appears to impose one of the highest levels of workload. Even without considering drop outs, and when tolerant participants are matched across gender, there is still evidence for a strong sex difference in scores from both subsidiary dimensions and summated workload level. If this represents a lower tolerance to ostensibly "boring" tasks on behalf of female participants then this difference is itself of importance, but in other work (Hancock, 1989) we have observed gender differences for workload in high demand tasks. This illustrates one facet of gender differences in performance, that are in general complex and need considerably greater elucidation (see Baker, 1987).

With respect to the original postulate concerning a central pacemaker mechanism, from a pure amplitude argument, the collective data on gender differences are consistent with a body temperature effect on time estimation. Results followed the expected pattern in that females had significantly higher mean temperatures which were accompanied by significantly shorter productions. Taken at this surface level, the findings are consistent with the hypotheses of both Hoagland (1933) and Treisman (1963) concerning temperature effects on duration estimation. However, this is to ignore the more critical and complex patterns that emerge when comparisons are made between the sexes across time-of-day. It is these more involved, interactive patterns that are considered below.

While the main effect of gender showed consistent differences on performance and workload, those for time-of-day represent a very different pattern. First, there was a significant effect for time-of-day on participant body temperature. In both experiments, body temperature increased with time-of-day to the end of the test period, 2000h and 1900h respectively. While this pattern is in general agreement with other findings on circadian variation, it is interesting to note that the peak of body temperature identified by Pfaff (1968) (see Figure 1) occurs at 1600h. At that time participants in the present experiment were still on the ascendant phase of the rhythm. Although the peak is often identified as 2000h on average, it is important to note that differences exist across individuals and, as will become important in explanation later, across the sexes.

With respect to time-of-day effects on time estimation and perceived workload, there were no main effects on performance, overall workload, or any dimension of workload. This is not an unprecedented finding (see Hart, 1988; Kirkcaldy, 1984; Moore, 1982), but one that is contrary to the received position that time estimation follows other performance tasks in changing consistently with time-of-day (Colquhoun, 1971; Pfaff, 1968; Poppel & Giedke, 1970). It is important to remember here though that these latter findings are themselves in conflict with the earlier reports by Thor (Thor, 1962; Thor & Baldwin, 1965) which found a completely reversed pattern. The reason for these contradictory reports lies perhaps in other characteristics of the participants. It should be recalled that Thor found large differences between day active and night active individuals, but his data allowed a cursory evaluation of a gender difference in which some resolution of the conflicting findings may be found. Such evidence is seen with greater clarity in the interactions between gender and time-of-day in the present results that are considered below.

The critical data are those shown in Figure 3. It is important to consider the patterns for men and women separately at first. For the women, body temperature shows a steady increase from 0800h to 1600h and then plateaus in preparation for a slow reduction in accord with circadian rhythm. Time estimates show a small decrease from 0800h to 1200h and then increase to a peak at 1600h followed by a drop to 2000h. In this respect, the females behave as expected in the first interval 0800h to 1200h where an increase in temperature is accompanied by a decrease in produced time. However, in the second interval 1200h to 1600h the pattern reverses and follows Thor's observations on day-active people where productions increase with temperature. In the final interval they return to the more expected pattern as productions again decrease with temperature as it passes the peak of the rhythm.

Initially, for the males it seems that the pattern is distinct and different as might be inferred from the significant interaction between gender and time-of-day on both body temperature and time estimation. However, let us consider the following. The peak temperature for female subjects is at 1600h whereas the males are at their highest temperature at 2000h. This may represent a phase shift between male and female subjects. If so, the identified start of the increase in temperature in females at 0800h should be considered equivalent to the start of ascending temperature in males at 1200h. Using these points as coincident origins, and if we superimpose the subsequently matched periods (i.e., females, 0800h-1200h-1800h; males, 1200h-1600h-2000h) we see a slight increase followed by a sharp increase in temperature for each gender. For time estimation we see a decrease for females followed by an increase in production. For the males we also see the same pattern of a decrease followed by an increase.

This suggests that the phase lagging previously noticed in the body temperature[2] of the respective genders is replicated in time estimation. This represents an explanatory account of the present finding of no difference, which extends also to others who have found significant differences. That is, the phase lagging between males and females cancel each other out as in wave interference when the addition of a trough and a peak give a constant value. This phenomenon is represented most clearly by the significant interaction at 1600h. This may well be why Kirkcaldy (1984) found no difference across time-of-day, as he sampled both sexes across the same time period as the present work, while Pfaff (1968), who tested only males, found significant effects because of a lack of gender-driven interference. Pfaff used only male subjects but there is also evidence concerning a female cycle in time estimation across time-of-day. Adkins (1964) asked 15 female subjects to estimate 15 s at 0400h, 1000h, 1600h, and 2200h. As might be expected, productions were lowest at 1600h and highest at 0400h. These data accord with those of Pfaff, yet the measurement interval is so large that the time-of-day at which lowest productions occurred cannot be ascertained beyond the 6-hour time window chosen for measurement. What is clear is that the size of the change, 1.64 s in 15 s is much smaller than the percentage change reported by Pfaff. However, as Pfaff included a number of different intervals in his summed data direct comparison cannot be relied upon without reservation. What is crucial to understand is that rhythmicity occurs for both genders but with a phase shift in time. Unfortunately, the sample window used by Adkins (1964) does not allow us to confirm this directly although the present evidence supports the phase shift explanation.

This account also helps understand why Thor found such a contradictory pattern of findings. As noted above, he found both a sex difference and a day-vs.-night active difference. In the present work, the females during the period 1200h and 1600h, acted like day-active individuals increasing productions as temperature increased. This effect is replicated by the male subjects but at a later time between 1600h and 2000h. Clearly the pattern of results elicited depends upon the time-of-day selected to sample and the ratio of male-to-female subjects under consideration. Differing combinations of those selections are apt to yield differing and even contradictory results. It is important to consider this explanation with respect to the comprehensive findings of Poppel and Giedke (1970). In their experiment they found differences of over 1 s across the day from 0800h to 2000h, for a 10-s target interval. The effect noted in Experiment 1 is much smaller, approximately 0.8 seconds in an 11 s estimate for males and slightly smaller for females. Poppel and Giedke however, used only three estimates at each time and had twice as many male subjects as females. It is probably this latter predominance that permits their results to resemble more those of Pfaff (1968) with only males, compared to the present work.

There remains, however, one further question with respect to a simple phase lag account of the differences between male and female subjects. That being that a simple lag would provide a constant value across time-of-day for both physiological and performance measures. However, as evident in both experiments, body temperature rose across time-of-day. This latter pattern, when combined with the flat curve for time estimation suggests some lagged relationship between body temperature and time estimation itself and/or a sensitivity of the latter to a rate of change of body temperature. This account is more closely allied to a physiological understanding of temperature regulation and the collective findings on other manipulations of temperature on duration perception (see Hancock, 1992). The data from these experiments do not directly tes such an assertion, although they indicate the importance of further study in elucidating these complex interactive effects.

The data from Experiment 2 are somewhat mute with respect to the proposition of a phase delay. Although at lower absolute temperature[3] the physiological indicator shows consistency between the two experiments. However, the data for time estimates show little difference across time-of-day. It is tempting to speculate that the sample periods did not include the opportunity to view the interaction as seen in Experiment 1, and indeed the data would bear such an interpretation. However, probably the safest conclusion at present is that the evidence in Experiment 2 does not rule out the phase delay interpretation.

It is important to examine some of the limitations of the present work. First, the time-of-day intervals evaluated in the present work represent only a restricted range of the full circadian cycle. The peak of the circadian rhythm occurs at approximately 2000h, but the lowest point occurs at approximately 0400h, an interval of some 4 hours earlier than the earliest testing time in this work. This limits the power of the circadian effect which might emerge given comparisons across the full range of a single oscillation. It would appear from a second experiment by Poppel and Giedke that the largest changes in performance take place during the hours outside the range investigated here. A full elucidation of the relationship between time-of-day, time estimation, and subject gender requires extensive testing using continuous monitoring over the whole 24-hour range. Also, there is some suggestion that time estimation varies with phase of the menstrual cycle (Montgomery, 1979). As there is a known temperature variation with the menstrual cycle (Asso, 1987), this represents an additional factor to be considered. However, there is also evidence of a male cycle in temperature (Empson, 1977), but with a different frequency. Each of these additional concerns need to be considered in a full exposition.

To conclude, reports in the literature on the effect of time-of-day on time estimation include observations of an increase in produced time across time-of-day (Thor, 1962; Thor & Crawford, 1964) a decrease in productions across time-of-day (Pfaff, 1968; Poppel & Giedke, 1970), and no change in production responses (Kirkcaldy, 1984; Moore, 1980). Typically, these studies have chosen different time windows to examine the effect and differing proportions of each gender in their experimental samples. The data reported here suggest a phase shifted relationship between males and females, which follows findings for body temperature. Differing patterns of results then become a function of the ratio of male to female subjects in the sample (see Pfaff, 1968; Thor, 1962; Poppel & Giedke, 1970), and the sampling window in terms of the range and assessment times selected in the daily cycle (Kirkcaldy, 1984; Adkins, 1964). The present data also suggest a more complex relationship between body temperature and time estimation, and is in agreement with Poppel and Giedke (1970) when they observed that diurnal variation of time perception is triggered, but not exclusively triggered, by variation in body temperature.

How does this account jibe with the earlier proposals by Hoagland (1933) and Treisman (1963) concerning models of an "internal clock." Although the final suggestion that body temperature is not the whole story does not fit with the uncompromising chemical clock of Hoagland, it is true to say that this difference is one of interpretation. Indeed, an account of the data can be made which fits directly with Hoagland's postulate of a master chemical reaction responsible for the perception of duration. However, the data reported here, and earlier findings (Kirkcaldy, 1984; Poppel & Giedke, 1970), favor the more encompassing model given by Treisman (1963), while a synthesis of these two models developed by Hancock (1992), also enables a full explanation of the collected pattern of findings.

SUMMARY

Two experiments were conducted which evaluated the influence of subject gender and time-of-day on time estimation and mental workload. Underlying each of these manipulations was the evaluation of body temperature as an influence on the perception of time. There were large differences in body temperature, time estimates, and workload dependent upon subject gender. These findings agree with a simple chemical clock postulate that the higher body temperature in female subjects would be accompanied by lower time production. The gender differences in workload seem to reflect attitude toward this repetitive and boring task. There were no main effects for time-of-day, except a sequential increase in mean body temperature. We argued that because of a phase lag between the genders in body temperature, there was mutual interference which masked time-of-day effects. Variation in sampling profile of the two independent variables can then provide mutually contradictory findings despite the fact that there is a coherent underlying effect. This is postulated as an account for such differences in the findings for time-of-day effects on time estimation and by implication for the range of human performance capability as it varies across the daily cycle.

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NOTES

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1. In this paper, the terms "gender" and "sex" are used interchangeably, as is common in this area of research. However, there is an increasing trend to use sex as the physiological differentiate between male and females and gender to refer more explicitly to patterns of identified behavior. Gender role includes social stereotyping with which an individual may or may not conform, while gender identity refers to a form of selfawareness. For further elaboration see discussions in Huyck, (1990), Parsons (1980), Tavris and Wade (1984) and Unger (1979).

2. We attribute the first observations of this difference in phase between the genders in body temperature over the daily cycle to Baker and her colleagues (see Baker & Pangburn, 1982; Baker, Holding, & Loeb, 1984; Baker et al., 1989; Quinkert, 1985), although it should be noted that while gender differences in absolute body temperature are frequently noted, the respective differences over the 24-hour cycle reported by Baker and her colleagues and affirmed here have not commonly been found (see Christie & McBrearty, 1977,1979; Horne & Coyne, 1975; Wever, 1984). A discussion of this discrepancy is given by Asso (1987), although as yet insufficient attention has been given to the variation which can occur when measuring deep body temperature at different anatomical sites. Conflicting evidence that has been reported may be due in part to the various use of oral, rectal, and tympanic sites to assess thermal condition. Given such gender differences in physiological cyclicity, the experiments here explain why such a phase lag can mask and obscure effects on performance when gender is not considered explicitly in time-of-day studies.

3. Auditory canal temperature is essentially a combination of temperature at the tympanic membrane with skin temperature down the canal itself. Tympanic membrane temperature is asserted to be a very close reflection of temperature at the active sites of the hypothalamus and is consequently one of the better semi-invasive sites at which to assess core or deep body temperature value. Unfortunately, attaching a thermistor to the membrane itself is painful, so typically auditory canal temperature is measured at some site slightly removed from the membrane. Two different experimenters collected the data in the two experiments. Although they were each shown a common technique for insertion of the measurement thermistor, the two overriding concerns were consistency of thermistor position between subjects within an experiment and awareness of potential discomfort on behalf of participants. Therefore, it is probable that the lower temperatures in Experiment 2 were a reflection of the conservative approach of that experimenter. However, note also the absolute difference in estimates. It cannot be ruled out that the difference is one of sampling and that the results represent veridical findings.

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