

The Consolidation of Memory
During Sleep

By

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
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Master of Arts

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Winnipeg, Manitoba

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Marc Nesca

To Tanya Nesca, with love and respect.

"Shine on you crazy diamond"

Abstract

This experiment was designed to examine three salient issues concerning the effect of sleep on memory. First, the source of the sleep effect was examined. That is, this study sought to determine whether the facilitating effect of sleep on memory is due to a post learning reduction in interference, or to a consolidation of the memory trace. Second, this study sought to separate the effects of sleep itself on memory from those of circadian rhythms. The third and final goal of this study was to replicate and extend seminal work in this area by establishing the sleep effect within the context of recognition memory. To address these issues the study employed a five group design. All subjects learned under conditions of emotional arousal as the literature seemed to indicate that arousal is necessary for memory consolidation. Arousal was induced by having the subjects view an emotionally arousing film. Immediately following the film subjects were exposed to a list of neutral words. Memory for these words was tested after intervals which did or did not include sleep. The results of this investigation revealed an effect of point of sleep interpolation and a circadian rhythm effect on memory. This investigation also extended previous work by documenting the sleep effect within the context of recognition memory. These results are discussed in light of the notion of memory consolidation. Suggestions for future research are also discussed.

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Introduction

In 1885 Ebbinghaus published the results of what are generally acknowledged (e.g. Finkenbinder, 1913; van Ormer, 1933) as the first rigorous investigations of human memory. In this series of now classic studies Ebbinghaus, serving as both subject and experimenter, charted the rate of forgetting for nonsense syllables. He required himself to learn each list of syllables to a criterion of two perfect recitations. Retention was then tested after intervals ranging from 20 minutes to 31 days. Retention was measured by the "method of savings". In brief, the method of savings involves recording the amount of practice initially required to reach a criterion. Then, at the desired interval, the amount of practice required to relearn the list to the same criterion is measured. The difference between the two trials is then expressed as a percentage of the original learning. Ebbinghaus plotted these percent-saving scores against time to derive his curve of forgetting. This steeply sloped, negatively accelerating curve reveals that most forgetting occurs within the first 48 hours; after which the line becomes approximately parallel to the axis. However this otherwise smooth curve was marred by the fact that forgetting slowed dramatically between the 8 and 24 hour interval. Ebbinghaus dismissed the slow down in forgetting as artefactual. Accordingly he

conducted a series of control tests in which his learning criterion was lowered from two to one perfect recitation. The results from these additional tests confirmed his earlier observation: forgetting did indeed slow dramatically at the 24 hour interval. Subsequent researchers (i.e. Radossawljewitsch, 1907; Finkenbinder, 1913; Luh, 1922) have reported a similar slowdown at the same point of the curve suggesting this is a rather robust phenomenon.

Despite the fact that sleep occupied a large part of the 8 to 24 hour interval Ebbinghaus refused to accept the possibility that it was somehow responsible for the observed results (van Ormer, 1933). Subsequently however, investigations designed to isolate the effects of sleep on memory were conducted. Jenkins and Dallenbach (1924), for example, systematically compared the rate of forgetting during sleep and waking. They had two subjects learn lists of nonsense syllables either at night or in the morning. The subjects were then asked to recall the lists at intervals of one, two, four, and eight hours. When learning occurred at night the retention intervals were occupied by sleep, when it occurred in the morning the retention intervals were comprised of normal waking activity. The researchers found that in all cases recall was superior in the sleep condition. Moreover recall at two, four, and eight hours remained constant in the sleep condition while

showing a steady decline in the awake condition. The systematic decline in the awake condition is entirely consistent with Ebbinghaus' work. However, insofar as retention remains constant during a period when most forgetting should occur, the results from the sleep condition are inconsistent with the well documented curve of forgetting. Van Ormer (1932) obtained very similar results. However, he found that forgetting stopped at one hour rather than at two hours, and that recall at the one hour interval did not differ between the sleep and awake conditions.

The effect of sleep on memory, or the sleep effect, is typically interpreted in terms of interference theory (e.g. Jenkins & Dallenbach, 1924; Ekstrand, 1967). In brief, interference theory holds that all forgetting is due to interference from other learning. The interference may come from prior learning in which case forgetting is due to proactive interference (PI), or it may come from subsequent learning so that forgetting is caused by retroactive interference (RI). According to this view sleep exerts its influence by protecting memory from the noxious effects of RI. Since RI depends on learning, and learning is not believed to occur during sleep, the memory trace is assumed to remain unchanged during a sleep filled retention interval. The simplicity and intuitive appeal of this interpretation have made it the dominant view. However, the

model does not seem entirely capable of explaining the sleep effect. Consider, for example, van Ormer's (1932) results which show that retention after one hour of sleep is equal to retention after one hour of waking. If the lack of interference during sleep was the only cause of the sleep effect then, based on the steeply sloped curve of forgetting, a difference would have been apparent even after one hour. In fact the study revealed that both the awake and the asleep conditions showed a loss of approximately 56% in the first hour, a figure which is remarkably close to the 55.8% loss reported by Ebbinghaus. Also, Jenkins and Dallenbach (1924) showed that forgetting progressed normally for the first two hours during sleep and then stopped. These results create a powerful paradox for interference theory. Specifically, the model is left the unenviable task of explaining why forgetting progresses normally during the early part of the night and then for no apparent reason stops. The alternatives available for solving this conundrum are limited: either interference occurs during sleep or it does not. The first alternative can account for the forgetting observed during the early part of the night. However, this position cannot explain why forgetting seems to stop during the middle and later portions of the night (Jenkins & Dallenbach, 1924; van Ormer, 1932). The second alternative, the belief that sleep protects memory from interference is more widely

accepted, but is unable to account for the amount of forgetting which occurs during sleep. Therefore, as presently formulated, interference theory seems unable to completely account for the sleep effect.

Consolidation theory offers an alternative explanation of the sleep effect. Although there is some disagreement over the specifics of the consolidation process (e.g. Wickelgren, 1976; Eysenck & Frith, 1977) it is argued that memory traces require some time to stabilize. This period of stabilization is thought to influence the permanence of the memory trace, as well as the probability of recall. Thus, according to this view, the environment of sleep may work to promote the consolidation of the memory trace thereby making it more resistant to disruptive forces. This line of reasoning is more consistent with the van Ormer (1932) results because the one hour period of forgetting during sleep can be explained in terms of the time required for consolidation. After consolidation is complete little forgetting is expected to occur until morning reinstates the noxious effects of interference. There is some debate however as to whether sleep or simply "nighttime" per se is involved in the process of consolidation. More precisely, some (e.g. Wickelgren, 1976; Idzikowski, 1984) have questioned whether the sleep effect is indeed dependent on sleep or simply a function of circadian rhythms. Researchers who raised this question pointed to the fact

that some circadian variations are entirely dependent on sleep, while others are completely independent of sleep but tend to share the same time period (e.g. Idzikowski & Oswald, 1983).

It seems fair to conclude that a number of issues concerning the effect of sleep on memory remain unresolved. This paper will address some of the more salient questions surrounding the sleep effect by: 1) contrasting the rival interference and consolidation interpretations of the sleep effect, and 2) separating the effects of sleep from those of circadian rhythms. To set the stage overviews of the interference and consolidation positions will be provided. The link between memory consolidation and arousal will also be explored. Finally the existing literature addressing the issue of sleep and forgetting will be reviewed and interpreted.

Memory Storage Dynamics and Forgetting

Interference Theory

In one form or another interference theory is generally accepted as the dominant theory of forgetting (e.g. McGovern, 1964; Keppel, 1968; Postman, Stark, & Fraser, 1968; Loftus & Loftus, 1976; Mensink & Raaijmakers, 1988). The classical two-factor theory of interference (Melton & Irwing, 1940) emerged from the multi-list, laboratory experiments which dominated memory research during this time period. Not surprisingly the theory more than adequately explained the observed data. However the theory seemed unable to deal with extra-experimental sources of forgetting. Consequently a number of interference models emerged which attempted to address this shortcoming. One such model-- the Keppel (1968) nonspecific interference theory-- will be reviewed along with two-factor theory.

Two-Factor Theory.

According to this model all forgetting can be explained in terms of two factors: unlearning and competition. The former is believed to be a storage phenomenon occurring at the time of interpolated learning,

while the latter occurs at recall. Retroactive interference (RI) is produced by the joint action of the two factors, while proactive interference (PI) is solely a function of response competition. Classically, unlearning was explained in terms of unreinforced or punished first list intrusions during the acquisition of second list responses (Melton & Irving, 1940). In other words, it was believed that in a typical two list paired-associate paradigm (i.e. A-B, A-C) the learning of the second list would, to a certain degree, elicit the first list responses. Insofar as these first list responses were incorrect they went unreinforced, or were even punished, resulting in a weakening of the original S-R relationship. In short then, this hypothesis predicts a direct relationship between unlearning and any variable which influences the degree of elicitation of first list responses. In support of this position researchers found that increasing the probability of intrusions by increasing the interlist similarity increased the amount of RI (Postman, Keppel & Stark, 1965; Friedman & Reynolds, 1967). Conversely, decreasing the likelihood of intrusions by prompting the subjects decreased the amount of RI (Goggin, 1967). Despite this limited success unlearning was not definitively demonstrated until 1959 when Barnes and Underwood developed the Modified Modified Free Recall (MMFR) test. The logic behind the test was quite simple: remove the

effects of competition and any observed RI can be attributed solely to unlearning. The MMFR test achieved this goal by providing subjects with unlimited time to reproduce both the B and C responses to each stimulus. By asking for both responses, and allowing the subject unlimited time to respond, this test was believed to completely circumvent the competition factor. However, it should be noted that researchers (e.g. Koppenaal, 1963; Ceraso & Henderson, 1965; Postman, Stark & Fraser, 1968) have consistently found evidence of PI with the MMFR test suggesting that the test either fails to completely circumvent the competition factor, or the two-factor analysis of PI is incomplete.

The distinction between the second factor, competition, and unlearning is based on item availability. Unlearning is believed to result in a permanent loss of memory, while the loss associated with the competition factor is believed to be temporary. This second factor is typically subdivided into specific and generalized competition. Specific competition refers to the blocking of individual responses at recall. This blocking is thought to occur as a function of incompatible responses becoming associated to the same stimulus (Postman & Underwood, 1973). Generalized competition, on the other hand, refers to the "... the tendency to continue to give second-list responses on the retention test for the first list"

(Postman & Underwood, 1973; p.23). Finally, both types of competition are believed to be positively related to the degree of interlist similarity. The two-factor model is plagued by a number of problems. For example, unlearning is never complete (Keppel, 1968; Postman, 1972; Postman & Underwood, 1973; Spear, 1978). With the almost total abandonment of the elicitation hypothesis (Keppel, 1968) two-factor theory cannot offer a plausible explanation for this differential sensitivity to unlearning. Nor can the model explain why PI is consistently found in situations presumably devoid of competition (i.e. the MMFR test). Perhaps most importantly two-factor theory is unable to account for extra-experimental sources of forgetting (Underwood & Postman, 1960; Keppel, 1968; Spear 1978). This last problem has been addressed by a number of researchers. Underwood and Postman (1960), for example, initially identified PI as the major source of extra-experimental forgetting. According to this view existing language habits are suppressed during learning. However, these habits later recover to interfere with recall. The model was initially well received as an extension of two-factor theory. Subsequently however the model was abandoned when it became apparent that its predictions were not being supported (e.g. Underwood & Keppel, 1963; Underwood & Ekstrand, 1966; Keppel, 1968; 1972). A nonspecific interference theory (Keppel, 1968), which shifted the

emphasis back to RI, was later proposed. This model has enjoyed considerably more longevity than its predecessor and will therefore be discussed in some detail.

Nonspecific Interference theory.

According to this model forgetting is due to general linguistic activity occurring during the retention interval (Keppel, 1968). Moreover this interference is not thought to be stimulus specific (Keppel, 1972). In other words, this retroactive interference is not dependent on any relationship between original learning and the interpolated activity. Any type of linguistic activity can produce RI. Indeed, interpolated linguistic activity is defined broadly enough so that RI is thought to result from any waking activity (Keppel, 1968). According to Keppel interpolated linguistic activity results in an unlearning of the original material. Therefore this nonspecific interference produces a nonreversible loss of memory. The degree of unlearning is thought to depend on two factors: strength of the original learning and amount of postlearning linguistic activity

The existence of nonspecific RI has been documented (e.g. Keppel, Henschel, & Zavortnik, 1969). However, the two factors governing the degree of unlearning have proven more elusive. By and large research has focused on the

manipulation of the postlearning linguistic activity. For instance, Keppel (1972) compared the retention of subjects exposed to forty five minutes of "intense" postlearning verbal activity to that of a group of subjects who engaged in "minimal" verbal activity during the retention interval. The results failed to support the prediction of the model: retention of the "intense" subjects did not differ from that of the "minimal" subjects. In fact the only real support for this model comes from studies comparing the differential effects of waking and sleeping during the retention interval (e.g. Radossawljewitsch, 1907; Jenkins & Dallenbach, 1924; van Ormer, 1932; Ekstrand, 1967; Benson & Feinberg, 1977; Idzikowski, 1984). According to this model the sleep effect is due to an obvious curtailment of verbal activity during the retention interval (Keppel, 1972). To be sure the sleep effect is robust. However there are some problems with the interference interpretations of the results. First, this position does not rule out the rival consolidation hypothesis. The observed sleep effect could just as likely be due to a consolidation of the memory trace, as it could be due to the absence of RI during sleep. Second, as an extension of two-factor theory, the nonspecific interference model is specifically designed to deal with the permanent effects of unlearning. However, the primary measure utilized in the available sleep effect studies is free recall. It is now commonly accepted that

free recall is not an appropriate measure of response availability (e.g. Wickelgren, 1976; Eysenck & Firth, 1977; Spear, 1978; Tilley, 1981). Therefore this index should not be used to address the issue of unlearning. On the other hand recognition tests are believed to be relatively pure measures of response availability (e.g. Loftus & Loftus, 1976; Wickelgren, 1976; Eysenck & Firth, 1977; Spear, 1978; Tilley, 1981), and accordingly are thought to more appropriately index the contents of memory (e.g. Tulving & Pearlstone, 1966; Wolford, 1971; Loftus & Loftus, 1976; Wickelgren, 1976; Eysenck & Frith, 1977;). In short then, the interference interpretation of the sleep effect is vitiated by the confounding elements of retrieval interference. A more appropriate test of the nonspecific interference model would seem to require some sort of recognition test.

In summary, according to two-factor theory (Melton & Irving, 1940) and its offshoot the nonspecific model of interference (Keppel, 1968), all forgetting can be accounted for in terms of interference. Moreover this interference is due to two basic mechanisms: competition and unlearning. Single-list forgetting (i.e. extra-experimental forgetting) is accounted for completely in terms of unlearning. This extra-experimental unlearning apparently occurs as a function of interpolated linguistic activity which produces a permanent loss of item

availability. Most importantly, extra-experimental unlearning is believed to occur during any waking interval, but not during sleep (Keppel, 1968; 1972).

Memory Consolidation

The idea that memory traces continue to develop after active learning ceases dates back to the turn of the century (Wickelgren, 1976). This process of consolidation is postulated to be a neurophysiological phenomenon dependent on nonspecific changes in brain chemistry (Idzikowski & Oswald, 1983; Idzikowski, 1984). Essentially there are two basic classes of consolidation theories: One class postulates an actual increase in trace strength for a period of time following active learning. The other suggests that trace strength remains constant, but that some other property changes so as to make the trace less susceptible to disruption. Thus, although there is some disagreement as to the specifics of the consolidation process itself, all models agree that a consolidated memory trace is best able to withstand disruption.

Two specific models of memory consolidation--- the trace strength model (Eysenck & Frith, 1977) and the trace fragility model (Wickelgren, 1974)--- will be discussed in the following section. The following section will also include a discussion of the relationship between arousal

and memory consolidation. This is desirable since, with few exceptions (i.e. Wickelgren, 1974), most theorists believe that the process of consolidation is somehow related to arousal.

The Trace Fragility Model.

Wickelgren (1974) suggests that learning establishes a memory trace with given strength and fragility--- both of which decline with age. Trace strength is postulated to determine the probability of recall or recognition. Fragility, on the other hand, determines trace susceptibility to degradation (i.e. time decay, disruption etc.). Moreover strength and fragility are assumed to be independent of each other. According to this model then, consolidation represents a progressive decline in trace fragility (i.e. susceptibility to degradation).

Wickelgren (1974; 1976) argues that his model is congruent with a number of well established memory phenomena. For example, the model predicts that the greatest amount of forgetting will occur at the time of greatest fragility (i.e. immediately after acquisition) and then slowdown as fragility declines (Wickelgren, 1976). This is consistent with the well established decelerating rate of forgetting (e.g. Ebbinghaus, 1885; Murdock, 1961). The model can also account for the fact that retrograde

amnesia typically results in the loss of the most recently acquired memories (Russell, 1959). According to the trace fragility model the most recent memories are the most fragile and therefore should be the most easily disrupted (Wickelgren, 1976). Wickelgren also contends that the model can account for the effects of spaced learning. Briefly, the available data show that memory is improved by increasing the time between successive study trials (Madigan, 1969). Wickelgren argues that this is to be expected since increasing the lag between trials decreases trace fragility thereby decreasing susceptibility to RI. However, since trace strength also declines with age it is not clear why the beneficial effects of reduced fragility would not be offset by the concomitant reduction in trace strength. Finally, Wickelgren (1976) contends that the sleep effect provides strong support for his model. He points specifically to a 1972 study by Ekstrand which reported that memory was best if sleep immediately followed learning. Wickelgren argues that sleep protects the trace from degradation. Thus having sleep immediately follow learning produces the greatest protection since this is the time of greatest fragility (Wickelgren, 1976). The trace fragility model is difficult to evaluate. To be sure the model does provide a reasonable fit for the available data. However it is not clear why one needs to assume the existence of an independent trace characteristic such as

fragility. Logically, fragility and strength would seem more likely to occupy opposite ends of the same continuum rather than be completely independent. In fact the data which ostensibly supports the fragility model can be accounted for, more parsimoniously, by a strength model. Consider for instance, the decelerating curve of forgetting. The fragility model suggests this curve is due to decreasing fragility. In contrast a strength model would interpret the decelerating curve of forgetting in terms of a finite increase in trace strength. Hence the two models make the same predictions, however the strength model is more parsimonious. Indeed virtually all phenomena which are accounted for in terms of decreasing fragility can readily be accounted for in terms of increasing strength. The only real difference between the two models is that the strength model predicts reminiscence (i.e. improved performance during rest) while the fragility model does not.

The Trace Strength Model.

Most strength models explain consolidation in terms of some potentiating factor which rises from a minimum to a maximum during rest (Eysenck & Frith, 1977). In this view consolidation fulfills two basic functions: First, it protects memory traces from being destroyed by future events. This assumption is supported by studies

demonstrating that electric shock will only disrupt learning if it occurs within a circumscribed period of time (Eysenck & Frith, 1977). Data showing that retrograde amnesia typically influences only the most recently acquired information also supports this proposal (Russell, 1959). Second, consolidation improves performance. This is supported by data showing that administration of stimulants during rest improves post-rest performance (Garg & Holland, 1968), and by the phenomenon of reminiscence (Ballard, 1913; McGeoch, 1935).

The Eysenck and Frith (1977) model of memory consolidation draws heavily from Walker's (1958) theory of action decrement. According to this position the consolidation process which follows acquisition is assumed to progress through three distinct stages (Walker, 1958; Eysenck & Frith, 1977). In the first stage the learning is neither available for improving performance, nor is it protected from disruption. The negative bias against performance observed at this stage is believed to occur in order to protect the trace from any disruption due to repetition (Walker, 1958). This stage is sometimes termed the perseveration stage. The second stage which follows is typically called the reverberatory period. During this stage the learning is thought to be available but not protected. Passage from the first to the second stage is termed primary consolidation (Eysenck & Firth, 1977). Disruption

of the primary consolidation process has long been thought to produce retrograde amnesia (Russell & Nathan, 1946; Russell, 1959). During the third and final stage of consolidation the learning is both available and protected. This accounts for the finding that insults to the central nervous system will only disrupt the most recently acquired memories (Russell, 1959). Passage from the second to the third stage is termed secondary consolidation (Eysenck & Firth, 1977). The movement of the trace through the stages of consolidation is believed to depend mostly on trace intensity, which is itself dependent on the degree of arousal present during learning. (Walker, 1958; Eysenck & Firth, 1977). The lower the intensity (ie. arousal) the quicker the movement through the stages. Rapid movement through the stages is believed to produce better initial recall, but poorer long term retention. Conversely slower movement through the stages, because of higher trace intensity, is believed to produce poorer initial recall but better long term retention. This prediction has been supported (e.g. Kleinsmith & Kaplan, 1963; Walker & Tarte, 1963).

By way of summary then, the trace strength model assumes that consolidation performs the dual function of improving performance and protecting memory from disruption. As a result it is believed that prior to complete consolidation learning cannot be totally

manifested, nor is it immune to disruption (Walker, 1958; Eysenck & Firth, 1977). The consolidation process proper is thought to progress through three distinct stages. The movement of the memory trace through the stages of consolidation is believed to depend heavily on overall arousal. The next section will be devoted to a more complete discussion of the relationship between arousal and memory consolidation. However, before proceeding it is interesting to note that some researchers have argued that sleep is (Marr, 1970), or may be (Eysenck & Firth, 1977) a necessary part of the consolidation process.

Arousal and Memory Storage.

Historically the link between arousal and memory was made explicit by Walker's (1958) theory of action decrement. In brief, Walker proposed that memory traces are laid down in a gradual fashion. Initially these traces are very labile and thus easily disturbed. Therefore Walker proposed the existence of a temporary inhibition of recall during this perseverative phase of development. The duration of this perseverative stage, and the long term retention of material was believed to be a function of arousal. Specifically, Walker (1958) believed that high arousal produced greater initial inhibition, but also

greater long term retention. Conversely low arousal was thought to produce a reverse effect. This prediction was in complete accordance with the available animal literature (e.g. Walker, 1958; Walker & Paradise, 1958).

The first study involving human subjects which supported the action decrement hypothesis was reported by Kleinsmith and Kaplan in 1963. This study employed the typical paired-associate learning paradigm. However one group of subjects was exposed to arousing stimulus words, while the other received neutral words. Five retention intervals were used: immediate, 20 minutes, 45 minutes, 1 day and 1 week. Arousal was operationally defined as an increase in skin resistance. The GSR recording equipment was also attached during the recall phase " To ensure constancy of conditions..." [pp. 191]. The results were in complete accordance with the action decrement position: The low arousal group exhibited significantly better immediate recall, and significantly worse long-term recall than the high arousal group. These results have been replicated by studies using the same procedure (e.g. Walker & Tarte, 1963; Kaplan & Kaplan, 1969; Butter, 1970), by studies manipulating arousal via white noise (e.g. Berlyne & Carey, 1968; McLean, 1969), and by studies comparing the long term retention of personality types (i.e. introverts/extroverts) thought to differ in level of arousal (e.g. Howarth & Eysenck, 1968; McLean, 1969).

The above studies have implicitly assumed that arousal refers to some nonspecific elevated state of functioning. This is at odds with the more recent position that arousal should be specifically defined (Hockey, 1978; Parker & Weingartner, 1984). To this end consolidation theorists have begun to link emotional arousal to memory consolidation. The belief is that consolidation may be mediated by the neural structures involved in the processing of affectively charged material (Parker & Weingartner, 1984). More specifically, it is believed that emotions work within neocortical reward systems to augment the significance of an event and hence the probability of recall (Esposito, 1984; Parker & Weingartner, 1984). The proposed link between emotions and memory consolidation is consistent with evidence suggesting that the limbic system is involved in both memory storage (Esposito, 1984) and emotional arousal (MacLean, 1952). Also recent evidence shows that neocortical neurons in rats do indeed undergo extensive changes in response to hedonically relevant environmental input (Squire, Cohen & Nadel, 1984). Finally, the idea that emotional arousal mediates memory consolidation is consistent with animal learning studies which show strong consolidation effects in avoidance learning (e.g. Smith & Kelly, 1988; Smith, 1990).

Summary.

According to interference theory all extra-experimental forgetting is due to RI (Keppel, 1968). This extra-experimental RI is believed to occur as a function of interpolated linguistic activity, which results in a permanent loss of item availability. Most importantly, "interpolated linguistic activity" is broadly defined to include all language based activities (i.e. talking, reading, listening, etc.). In short, all waking activity is assumed to produce RI (Keppel, 1968; 1972). As a result, sleep is simply viewed as a passive protector of the memory trace. Once sleep is terminated erosion of the memory trace is expected to continue unabated until the next sleep period, or until unlearning mysteriously ceases (Postman & Underwood, 1973; Spear, 1978). It is important to note that the memory trace is believed to emerge from sleep in exactly the same form as it entered. Thus fundamental changes to the memory trace are expected to occur only in response to the RI produced by normal waking activity.

Consolidation theories offer a plausible alternative to interference theory. All consolidation models share three basic assumptions: a) a memory trace takes some time to stabilize, b) a memory trace is most easily disrupted during its period of instability, and c) memory performance

is a direct function of trace strength. There is some disagreement however as to the specific nature of the consolidation process. The trace fragility model (Wickelgren, 1974; 1976) postulates the existence of two independent trace qualities --- strength and fragility. Both qualities are assumed to decline with age. Consolidation is thus believed to represent a progressive decline in trace fragility (i.e. susceptibility to degradation). Like interference theory, this model assumes that sleep functions as a protector of the memory trace. However, the trace is now assumed to undergo fundamental changes (i.e. a decline in fragility) during the course of the night. Since the decline in trace fragility is assumed to depend exclusively on time, sleep is simply viewed as providing an environment conducive to memory consolidation.

Rather than postulate the existence of two independent trace qualities, the trace strength model explains consolidation in terms of some potentiating factor (i.e. strength) which rises from a minimum to a maximum during rest (Eysenck & Frith, 1977). The process of consolidation proper is thought to progress through three distinct stages. The movement of the memory trace through the stages was initially believed to depend on general arousal (Walker, 1958). However recent evidence suggests that emotional arousal in particular is related to memory consolidation (Esposito, 1984; Parker & Weingartner, 1984).

Because consolidation is defined simply in terms of a finite increase in trace strength, this model predicts that maximum performance will occur at the end of the consolidation process. Therefore the model can account for the growth of recall over time (i.e. reminiscence). Like the previous two positions the trace strength model also views sleep as an essentially passive protector of the memory trace. However this position differs from that of the trace fragility model in that the memory trace is now thought to increase in strength during the night, rather than to decrease in fragility. Parenthetically it should also be mentioned that, of the three, only this model allows for the possibility that sleep may actively promote memory consolidation.

According to both consolidation models, and interference theory, sleep exerts its influence on memory by simply protecting the memory trace from degradation. Despite this congruence all three models differ as to what occurs to the memory trace during the night. Interference theory suggests that the trace remains unchanged over the course of the night, because only waking activity can produce changes in the memory trace. Conversely, although they disagree as to the exact reason why, both consolidation models propose that the memory trace emerges from sleep better able to withstand degradation. Thus, regardless of the specific model, the consolidation

position predicts that sleep will be most beneficial when it immediately follows learning (Wickelgren, 1974; Eysenck & Frith, 1977). This prediction follows from the belief that a memory trace is most easily disrupted during the period of instability which immediately follows learning. Since interference theory assumes no change in the memory trace during sleep it predicts no effect of point of sleep interpolation. Instead the nonspecific interference theory predicts that, all things being equal, groups will only differ as a function of the overall amount of waking activity. In other words, as long as groups are equated in terms of overall wakefulness they should not differ with regard to memory performance. Bearing these discrepant predictions in mind the available sleep and memory literature will now be reviewed and interpreted.

Sleep and Memory.

Extant research. Research has generally shown that subjects who sleep during a retention interval remember more than those who remain awake (Jenkins & Dallenbach, 1924; Spight, 1928; van Ormer, 1932; Graves, 1937; Ekstrand, 1967; Idzikowski, 1984). Interest in this area is often traced to a study by Jenkins and Dallenbach (1924). In this seminal study two subjects were repeatedly tested over the course of three months. The subjects learned lists of nonsense syllables either in the morning or at night, and then were tested at intervals of one, two, four, and eight hours. In addition to showing that retention in the sleep condition was superior at every interval, the study also contained a number of other interesting results. First, it was shown that forgetting progressed at a relatively normal pace for the first two hours. Second, and perhaps most importantly, forgetting seemed to stop completely at the two hour interval. Finally, the overnight retention curves for both subjects revealed an actual increase in recall so that retention at eight hours was superior to that observed at the two hour interval. Van Ormer (1932) later obtained an essentially identical pattern of results. However, he found no difference in the rate of forgetting between the sleep and awake conditions for the first hour; after which forgetting once again

stopped. These results were later replicated in a study (Lovatt & Warr, 1968) which controlled for small group size and time of day effects. Tangentially, the possibility that time of day is a confounding factor is very real in studies of this nature. Accordingly this issue has been addressed by a number of investigations (e.g. Ekstrand, 1967; Yaroush, Sullivan & Ekstrand, 1971; Barrett & Ekstrand, 1972; Benson & Feinberg, 1975; 1977; Idzikowski, 1984) which have, without exception, concluded that the sleep effect is not dependent on the time of original learning.

Ekstrand (1967) argued that the sleep effect provides an ideal opportunity for investigating the processes involved in RI and PI. He tested this notion within a 3 (RI/PI/no interference) x 2 (retention interval) factorial design. The conditions for the interference groups (i.e. RI & PI) conformed to the standard two list (i.e. A-B, A-C) interference paradigm, while the no interference groups only learned a single list. The recall interval was varied so that retention was measured immediately, or after eight hours of sleep. Therefore the study involved a total of six groups. Retention was measured by successive tests of paced recall, free recall, and MMFR. The results of this study revealed that the sleep effect was significant for all measures in the no interference condition. However, for the interference groups the sleep effect reached significance only on the MMFR test. This finding is noteworthy in that

it highlights the importance of choosing interference free tests when investigating a storage phenomenon such as the sleep effect, a position which is reinforced by the fact that even in the no interference condition the sleep effect was noticeably smaller on the two recall tests than on the MMFR. Therefore this study demonstrated that recall tests, because of their extreme sensitivity to retrieval interference, may actually underestimate the amount of material in store. In this study retrieval interference actually offset the benefits of sleep on two of the three measures in the interference conditions. These results lend further support to the belief that recall measures do not provide an accurate index of response availability (e.g. Wickelgren, 1976; Spear, 1978; Tilley, 1981).

Yaroush, Sullivan, and Ekstrand (1971) reasoned that the distinctly different physiological patterns of NREM and REM sleep may produce differential effects on memory. The researchers decided to capitalize on the fact that NREM sleep predominates during the first half of the night, while REM sleep dominates the latter half. Thus they compared the effects of the first and second half of the night on retention. The study involved three groups of subjects; all of which learned a paired-associate list and were tested after a four hour retention interval. Two groups spent one night in the laboratory. Group one learned, slept, and was tested during the first four hours

of the night. The second group first slept for four hours and then was treated in exactly the same manner as group one. Thus group one was tested after sleeping for the first half of the night, while group two was tested after sleeping for the second half of the night. A third group learned during the day and was subsequently tested after four hours of normal waking activity. The results revealed that sleeping during the first half of the night produced significantly better retention than sleeping during the second half, or remaining awake during an equivalent daytime interval. Moreover, the study reported that retention scores from group two did not differ from the scores of the awake group. Based on these results the authors concluded that NREM but not REM sleep is beneficial to memory. However, insofar as one group (#2) slept before learning, the study failed to control for prior sleep. In this regard research has shown that sleep prior to learning is detrimental to recall after subsequent sleep (Grosvenor & Lack, 1984). Thus the difference between the sleep groups could conceivably have been due to the four hours of prior sleep in the second half condition. Barrett and Ekstrand (1972) replicated and extended the Yaroush et al. study by controlling for prior sleep. They obtained an essentially identical pattern of results. Based on these two investigations Ekstrand and his associates concluded that REM sleep, because of its

association to dreaming, acted as a source of RI and therefore hindered retention.

The work by Ekstrand and his associates seems to suggest that REM sleep contributes little if anything to memory consolidation. However the literature concerning the contribution of individual sleep stages to memory is not consistent. For instance, Grieser, Greenberg and Harrison (1972) report that REM sleep facilitates the retention of affectively charged material, while NREM sleep contributes to the consolidation of neutral material. These results, later replicated by Schoen and Badia (1984), are consistent with more recent investigations of the relationship between REM sleep and memory. For instance, Tilley and Empson (1978) compared the effects of REM versus NREM deprivation on the retention of complex material. They found that the REM-deprivation group retained significantly less than the NREM-deprivation group. Even more interesting was their finding that the rate of deterioration during the recovery night was significantly slower for the REM-deprivation group. Based on these results the authors concluded that the re-establishment of REM sleep during the recovery night had restored the course of memory consolidation. These results were later replicated by Tilley (1981). More recently Smith (in press) examined the role played by REM sleep in the processing of a "... personally relevant, emotionally involving life

situation..."[pp.2] of university students. The experimental group included 6 fourth year honours students. Five individuals of similar age who had completed the honours program the year before were chosen as control subjects. The experimental design conformed to the typical A-B-A learning paradigm. Baseline sleep recording was conducted for four consecutive days during a time (summer) when neither group was involved in significant learning. The next four days of sleep recording occurred shortly after the experimental subjects had written their Christmas exams. This recording session was delayed for 1-3 days to allow subjects to recover from any self imposed sleep deprivation. The final four day recording session occurred two months after final exams. The results revealed a significant increase in the number of REMs and a higher REM density for the experimental group during the exam recording session. Moreover these differences were almost entirely due to changes occurring in the fourth and fifth REM periods of the night. The groups did not however differ in terms of overall REM time, nor did they differ in any regard during the two baseline sessions. These cyclical post learning REM changes are consistent with the animal literature (e.g. Smith & Kelly, 1988), and a recent dream model (Wright & Koulack, 1987) which predicts a cyclical pattern of incorporations following an arousing event. These data are not however at odds with the work by

Ekstrand and his associates because their work dealt exclusively with neutral (i.e. paired associate) material. Thus the literature seems to consistently support the Grieser et al. (1972) conclusion that REM facilitates the retention of emotionally laden material, while NREM promotes the retention of neutral material.

The literature contains a number of studies in which the retention interval is a multiple of 24 hours. Utilizing a 24 hour retention interval accords researchers two important advantages: Namely, circadian variables are held constant (Idzikowski, 1984), and subjects can be equated in terms of total sleep time. The latter is especially important for comparing the interference and consolidation interpretations of the sleep effect. For example, consider a two group study where one group learns in the morning and the other learns at night. Assuming an eight hour period of sleep, the groups are equated in terms of exposure to interference (i.e. 16 hours). Therefore interference theory would predict no difference between the groups. On the other hand consolidation theories predict superior recall if learning is immediately followed by sleep. This prediction is based on the belief that a consolidated memory trace is better able to withstand disruption (Wickelgren, 1976; Eysenck & Firth, 1977). In short then, consolidation theories predict an effect of point of sleep interpolation, interference theory does not. Heine (1914)

was the first to vary the point of interpolated sleep within a 24 hour period. The study employed two groups of subjects. One group learned immediately before going to sleep, the other remained awake for three hours after learning. Her results clearly indicated superior retention for the group who retired immediately after learning. Similarly McGaugh and Hostetter (1961) reported that retention for a group of subjects who immediately went to bed was enhanced relative to a group who remained awake for eight hours. Later Richardson and Gough (1963) investigated the long term retention of nonsense syllables. They exposed 18 subjects to repeated learning and testing sessions. The retention intervals were 24, 48, and 144 hours. Fifty percent of the learning and testing sessions occurred at night just before subjects went to bed. The remaining fifty percent took place in the morning. In total each subject participated in 12 learning and testing sessions, and each list was learned to a criterion of three perfect recitations. The results indicated that night and morning learning did not differ at the 24, and 48 hour intervals. However, a significant difference in favor of the sleep condition did emerge at the 144 hour interval. Therefore, although the study does suggest that long term retention is enhanced by immediate sleep, the Heine (1914) results were not confirmed. This failure to find effects at the earlier intervals may be ascribed to a number of procedural

problems. For example, the researchers acknowledged that rehearsal was not adequately controlled. In fact they reported that all subjects engaged in some discussion of the study. More importantly, the subjects were forced to overlearn the material (i.e. three perfect repetitions). This overlearning is at odds with the belief that memory consolidation is best for partially learned acts (e.g. Eysenck & Firth, 1977). Moreover, research has shown that "... the greater the degree of original learning, the longer can subjects in the waking condition retain a level of performance matching that of subjects in the sleep condition..." (Benson & Feinberg, 1977; pp. 383). Therefore the observed lack of effect at the early intervals can, at least partially, be ascribed to overlearning.

In 1975 Benson and Feinberg compared the effects of immediate versus delayed sleep on the retention of nonsense syllables. This study utilized four groups of subjects: two groups learned at night immediately before going to sleep, and two groups learned in the morning before a day of normal activity. Two of the four groups (one morning and one evening) were tested after an 8 hour retention interval, the remaining two groups were tested after a 24 hour interval. Benson and Feinberg reported data which showed that night learning resulted in better retention than morning learning at the 8 hour interval. However the retention scores of the 24 hour groups did not differ. Thus

this study replicates the original Jenkins and Dallenbach (1924) results, but fails to support Heine's (1914) study. Surprisingly, the researchers ascribed the lack of difference at the longer retention interval to a growth in recall in the morning condition. In other words, subjects tested after 24 hours reported better recall than those tested after 8 hours. In order to further investigate this unexplained increase in recall, Benson & Feinberg (1977) extended their 1975 paradigm by adding a 16 hour interval. In all other aspects this study was identical to the earlier one. This time the evening groups exhibited superior retention at the 8 and 24 hour intervals, but did not differ at the 16 hour interval. Again the lack of difference was due to a growth of recall between the 8 and 16 hour intervals in the morning condition. More recently Idzikowski (1984; experiment 1) also compared the effects of immediate or delayed sleep. He found no evidence of a sleep effect at the 24 hour interval. The literature therefore remains essentially inconclusive in regard to this seemingly simple contrast of consolidation and interference predictions.

Some researchers (e.g. Wickelgren, 1976) have questioned whether the sleep effect is actually due to sleep or simply a function of circadian rhythms. Typically this question is investigated by having subjects (often shift workers) sleep during the day. The retention of these

"day sleepers" is then compared to that of a group who remained awake during the same interval (Folkard & Monk, 1980). It is difficult to accept the results of such studies because sleep is displaced onto a different biological background (Idzikowski, 1984). However, the literature does contain two studies which have addressed this issue without artificially displacing sleep. The first (Hockey, Davies, & Gray, 1972) utilized four groups of subjects: two learned in the late evening (11pm), the other two learned in the early morning (7am). Two of these four groups (one morning & one evening) were allowed to sleep during the retention interval, and two were kept awake. For all groups the retention interval was five hours. The researchers reasoned that comparing the retention of the two night groups (one of which was sleep deprived) would isolate the effects of sleep. Moreover if sleep per se is beneficial then the morning sleep group should not differ from the night sleep group. The researchers found that night sleep resulted in less overall forgetting than the other groups. However, since day sleep had no effect they concluded that sleep per se is not conducive to memory consolidation. Unfortunately a number of factors seem to undermine any conclusion based on comparisons with the morning groups. First, both morning groups learned almost immediately after awakening. Research has shown that retention is impaired if learning is closely preceded by

sleep (Grosvenor & Lack, 1984). Second, given a previous night of uninterrupted sleep, it is difficult to accept that the morning sleep group actually slept throughout the retention interval. Third, the morning sleep group, assuming they actually slept, received in excess of 13 hours of sleep. In this regard previous research (Taub & Berger, 1969) has shown that "...extended sleep can produce decrements in performance similar to those which occur with sleep deprivation." [pp.204]. Finally, the morning subjects were described as "still tired" during their learning sessions. This state of tiredness could conceivably have undermined the acquisition process itself thereby offsetting any benefit accrued from sleep. These confounding factors combine to undermine any comparisons with the morning groups. Accordingly an accurate assessment of this study is problematic unless one ignores the results from both morning groups. However discarding the data from the morning groups leaves the study without adequate controls for sleep deprivation effects. Therefore the study does little to isolate the effects of sleep per se on memory.

In 1984 Idzikowski conducted a relatively comprehensive investigation of the sleep effect. This study included two groups which were designed to address the circadian rhythm question without artificially displacing sleep. Both of these groups learned paired associate lists

in the morning and were tested 24 hours later. One group was sleep deprived for the entire interval, the other was allowed a normal night's sleep. Idzikowski reasoned that any observed differences could be ascribed to sleep because both intervals included the entire circadian cycle. Not surprisingly the results revealed better retention in the sleep condition. Accordingly the author concluded that the benefits of sleep on retention are not dependent on circadian variables. Parenthetically it should be noted here that since the groups differed in terms of overall time awake these results are also consistent with interference theory. That is, interference theory would predict superior recall in the sleep condition because those subjects were exposed to less overall RI. Unfortunately the author did not address this issue preferring instead to simply assume that sleep promotes consolidation. He did however address the possibility that the observed results were due to sleep deprivation rather than enhanced retention. In order to control for any nonspecific sleep deprivation effects the author later added two more groups (exp. II). Both learned and were tested at the same times (48 hours later). The groups differed in that one was allowed to sleep both nights, while the other was sleep deprived on the second night. It was reasoned that any deprivation effects would manifest themselves in the recall scores of the deprivation group.

On the other hand, if the memory trace had been fully consolidated during the first night's sleep then the recall scores of these groups would not differ. As predicted the group retention measures did not differ suggesting consolidation had indeed taken place during the first night. These results lend credence to the belief that a consolidated memory trace is better able to withstand degradation. However, as the groups did not differ in terms of immediate post learning environment (i.e. both groups slept at night), these results actually do little to isolate the effects of circadian variables on memory consolidation. All that is shown is that a night of deprivation will not disturb an already consolidated memory trace. The question of whether sleep is itself a necessary component of the consolidation process remains unanswered.

Interpreting the Sleep Effect. Investigations of the effect of sleep on prior learning revealed a number of interesting results. First, there appears to be no doubt that subjects who sleep during a retention interval remember more than those who remain awake (e.g. Jenkins & Dallenbach, 1924; Spight, 1928; van Ormer, 1932; Ekstrand, 1967; Lovatt & Warr, 1968; Idzikowski, 1984). Second, the two seminal studies in this area (i.e. Jenkins & Dallenbach, 1924; van Ormer, 1932) show that forgetting progresses at a relatively normal pace during the first few

hours of sleep. Unfortunately, subsequent studies have not attempted to replicate this important finding. Third, REM sleep seems somehow involved in the processing of affectively charged material (e.g. Grieser et al., 1972; Smith, in press), while NREM sleep seems to facilitate the retention of neutral material (e.g. Ekstrand, 1967; Ekstrand et al., 1971). This strongly suggests that sleep per se is indeed involved in memory processes. However, the final point to be made is that investigations designed to isolate the effects of sleep from circadian variables have been inconclusive (i.e. Hockey, Davies, & Gray, 1972; Idzikowski, 1984). Each point bears directly on the question of whether the sleep effect is due to a reduction of interference or to a consolidation of the memory trace. As such each point will be discussed within this context.

The early studies by Jenkins and Dallenbach, and van Ormer have been described as "... one of the empirical bases of interference theory." (pp. 253; Lovatt & Warr, 1968). Insofar as researchers, including Jenkins and Dallenbach, have typically agreed with this interpretation, these results warrant a more detailed discussion. Recall that the classic interference position (Jenkins & Dallenbach, 1924) is predicated on the belief that sleep protects memory from the noxious effects of RI. Accordingly retention after a period of sleep is expected to exceed retention after an equivalent period of waking.

This prediction is of course consistent with the overall pattern of results. However a more detailed analysis reveals this position to be logically inconsistent with the data reported by Jenkins and Dallenbach (1924), and van Ormer (1932). For example, both studies observed a relatively normal rate of forgetting during the early portion of the night. As currently formulated (Melton & Irving, 1940; Keppel, 1968) interference theory is incapable of accounting for forgetting in the presumed absence of interference. Therefore the partial forgetting reported by both studies remains unaccounted for. Also unaccounted for is van Ormer's data which shows that recall at the one hour interval did not differ as a function of sleep. Clearly if sleep protects memory from RI then one hour should be sufficient time to produce a difference. This position is based on Ebbinghaus' work which revealed that approximately 56% is forgotten within the first hour. Therefore, since interference theory holds that forgetting does not occur during sleep, the conditions should have differed by approximately 56% at the one hour interval. To be sure interference theory could easily account for these findings by assuming the alternative position that sleep does not protect memory from interference. However this alternative would predict no main effect of sleep, and certainly no stoppage of forgetting during the course of the night. Moreover neither of the interference

alternatives can account for the observed growth of recall during sleep. Despite the historical tendency to interpret the sleep effect in terms of interference theory, this data is actually more consistent with the consolidation position. For example, the initial forgetting is easily explained in terms of a weak memory trace. As trace strength increases forgetting slows and eventually stops; until the following morning when the effects of RI are reinstated. Finally, depending on circumstances which are not yet completely understood, reminiscence may occur due to continually increasing trace strength. It is important to understand that consolidation theory does not deny the role of RI. On the contrary, it is simply argued that a consolidated trace is better able to withstand the noxious effects of RI (Wickelgren, 1976; Eysenck & Firth, 1977).

The early work by Ekstrand and his associates (e.g. Yaroush, Sullivan, & Ekstrand, 1971; Barrett & Ekstrand, 1972) suggested the NREM, but not REM sleep enhanced retention. Based on this work Yaroush, Sullivan, and Ekstrand (1971) suggested that REM sleep, by virtue of its close association with dreaming, acted as a source of RI. This position allowed interference theory to account for the observed superiority of NREM sleep by arguing that unlearning was occurring during REM sleep. Although not implausible this suggestion was clearly at odds with subsequent studies which showed that REM sleep facilitated

the retention of meaningful and/or affectively charged material (e.g. Greiser, Greenberg & Harrison, 1972; Tilley & Empson, 1978; Tilley, 1981; Schoen & Badia, 1984). Furthermore, were it really the case that REM interfered with previous learning then one would logically expect that REM, by virtue of its temporal position, would annul the beneficial effects of NREM. This argument follows from the well documented finding (e.g. Postman & Underwood, 1973) that RI is most noxious when occurring close to the time of recall. To date consolidation theorists have not concerned themselves with specifically explaining the differential effects of REM and NREM sleep. Therefore there is no putative consolidation position. However an explanation in terms of the different physiology associated with these sleep stages seems to easily fall within the realm of consolidation theories.

The question of whether the sleep effect is actually due to sleep or simply circadian biological rhythms remains largely unresolved. The available literature (e.g. Hockey, Davies & Gray, 1972; Idzikowski, 1984) does suggest some sort of a circadian involvement in memory storage. However the evidence is not conclusive. It is interesting to note that neither alternative is especially damaging to the consolidation position. Consolidation theories simply argue that memory consolidation is a function of nonspecific biological changes. These changes may be associated with

sleep, or they may simply occur as a function of circadian rhythms. Therefore, from a consolidation standpoint, this question is simply a matter of isolating the source of the process. Conversely, a conclusive demonstration that the sleep effect is actually a circadian effect would appear to place this phenomenon outside of the scope of interference theory. After all RI is assumed to occur during any waking interval (Keppel, 1968). It therefore appears this issue may ultimately decide between the interference and consolidation positions.

In summary, although some researchers (e.g. Keppel, 1984) still adhere to an interference interpretation of the sleep effect, it would appear that the available data is better interpreted from a consolidation standpoint. In this regard it is interesting to note that B.R. Ekstrand, a noted interference theorist, acknowledged this point in his 1972 review of the area. As a theoretical concept the notion of memory consolidation predates that of interference. The predominance of interference theory appears at least in part attributable to a reliance on tests (especially free recall) which are extremely sensitive to response interference (Wickelgren, 1976). The impact of such tests was amply demonstrated by Ekstrand (1967) who demonstrated that the magnitude of the observed sleep effect varied according to the chosen test. This reliance on recall measures is curious given that the sleep

effect is, even in interference terms, a storage phenomenon (Keppel, 1968). It would therefore seem more appropriate to use recognition tests which are generally acknowledged to more accurately index response availability (Loftus & Loftus, 1976; Wickelgren, 1976; Eysenck & Firth, 1977; Spear, 1978; Tilley, 1981; Murdock, 1982), and to be relatively free of response interference (Willis & Underwood, 1983). The general reluctance of psychologists to accept purely physiological explanations may also have contributed to the predominance of interference theory (Weingartner & Parker, 1984). At any rate, regardless of the status of consolidation constructs, it is concluded that interference theory does not adequately explain the available data. Therefore alternative explanations must be explored.

Overview and Predictions

According to interference theory sleep exerts its influence by preventing the unlearning of recently acquired memory traces (Keppel, 1968). This unlearning is thought to occur as a function of nonspecific post learning linguistic activity, and is believed to produce a nonreversible loss of memory (Keppel, 1968; 1972). However, according to consolidation theory the beneficial effects of sleep on memory are due to a process of consolidation which makes the memory trace more resistant to disruption (Wickelgren, 1976; Eysenck & Frith, 1977; Idzikowski, 1984).

The goals of the present study were: A) to contrast the rival interference and consolidation positions, B) to partially replicate the original Jenkins and Dallenbach study using a more appropriate measure of trace availability (i.e a recognition test), and C) to disentangle circadian effects from those of sleep per se. To meet these goals the study utilized five groups of subjects (Appendix A). Each group was exposed to the same general learning procedure. Specifically, all groups viewed a short film which was previously found to induce emotional arousal (De Koninck & Koulack, 1975). This film was included so as to generate the arousal which is believed to be a component of the memory consolidation process (Walker, 1958). Immediately following the film the subjects were

exposed to forty neutral words. The words were projected onto a screen at the rate of one every five seconds. A pilot study was conducted to ensure the success of the arousal component of the procedure.

Groups 1 and 2 (Appendix A) were designed to compare the rival interference and consolidation positions. Both groups were tested over a 24 hour retention interval. However, one group learned in the morning, while the other learned in the evening. Since both groups were awake for an equivalent period of time, this procedure effectively equated them in terms of overall interference. Accordingly interference theory predicted no difference. However, according to consolidation theory, retention should be superior when sleep closely follows learning. In other words, the consolidation model leads one to expect an effect as a result of how soon after learning sleep occurs. The two models therefore make different predictions where a 24 hour retention interval is concerned. Interference theory predicts retention will vary only as a function of the total amount of waking activity which intervenes between learning and testing. Conversely, consolidation theory predicts that retention will benefit more from immediate sleep than delayed sleep. These discrepant predictions were tested by contrasting the retention scores of groups 1 and 2. Note also that, for this contrast, circadian variables were strictly controlled

since within group learning and testing occurred at the same times.

Groups 3 and 4 were designed to replicate the Jenkins and Dallenbach study within the context of recognition memory. For both groups the retention interval was approximately eight hours. Group 3 learned in the morning and was tested in the evening. Conversely group 4 learned in the evening and was tested in the morning. Thus group 4 differed from group 3 in that the retention interval was occupied mostly by sleep. This replication was desirable because a study by Ekstrand (1967) suggested that Jenkins and Dallenbach, and subsequent researchers, may have underestimated the magnitude of the sleep effect by relying on free recall measures.

The inclusion of a deprivation condition (group 5) allowed the study to examine the role played by circadian variables in the sleep effect. For this group the retention interval was again 8 hours. However, these 8 hours spanned the time normally spent asleep. Therefore, comparing the retention scores of subjects in group 5, who were kept awake, and group 4, who were allowed to sleep during the same interval, isolated the effects of sleep from those of circadian rhythms. Thus, the only difference between these groups was that one slept while the other did not. That is, both groups were treated in an identical manner except that the post-learning environment of group 4 included both

sleep and overnight circadian rhythms, while that of group 5 included the same circadian rhythms but was completely devoid of sleep. Consequently any differences between these two groups could be ascribed to the effects of sleep itself.

The question of nonspecific deprivation effects was addressed by comparing the recognition scores from the deprivation condition to those of group 3. Thus, in addition to being part of the replication of the Jenkins and Dallenbach (1924) study, group 3 also served as a control for deprivation effects. Group 3 was ideally suited to the task of acting as a control group for group 5 as its retention interval spanned an equivalent period of daytime wakefulness. In accordance with previous research, this study found that a single night of sleep deprivation does not adversely effect recognition memory (Williams, Giesecking, & Lubing, 1966).

In accordance with recently published guidelines for conducting recognition memory experiments (Murdock, 1982) , the entire study was conducted within the context of signal detection theory. The use of d' , the main dependent variable in signal detection theory, offered two main advantages over the use of simple group means. First, it combined performance on new and old items into a single convenient summary statistic. Second, and most importantly, it provided an effective way of separating memory from

decision. The result was a relatively pure measure of recognition memory.

It was previously concluded that interference theory did not adequately explain the available data. Accordingly this paper adopted the consolidation standpoint. The specific hypotheses arising from this point of view were as follows:

1. Based on the belief that a consolidated memory trace is better able to withstand the effects of RI (Wickelgren, 1976; Eysenck & Firth, 1977) group 2 was expected to report better retention than group 1.

2. Based on the work of Jenkins and Dallenbach (1924) retention was expected to be better if learning was followed by sleep rather than wakefulness. Accordingly group 4 was expected to show better retention than group 3.

3. Based on the belief that the observed memory effects were indeed due to sleep, rather than simple circadian rhythms, group 4 was expected to show better retention than group 5.

Method

Subjects

Two hundred and ten introductory psychology students (42 per group), who reported English as their first language, were recruited to participate in an experiment investigating the relationship between sleep, arousal, and memory. The language restriction was desirable given the importance of verbal learning for the present experiment. In accordance with seminal research in this area (i.e. Jenkins and Dallenbach, 1924; van Ormer, 1932), all subjects were fully aware that they were participating in a memory experiment. All subjects were also aware that the study involved viewing a stressful film. In short, all subjects were fully informed as to all aspects of the study before they agreed to participate. An additional group of 11 students was recruited to participate in a pilot study designed to ensure the success of the arousal component of the procedure. All students, except those who participated in the pilot study, received course credit for their participation. Pilot study subjects volunteered their time.

All of the original 210 students were subjected to a two-stage screening procedure. The first stage was designed to ensure that all subjects typically enjoyed at least "average sleep", were not currently being treated for any sleep disorders, and were not currently taking any psychoactive drugs (Appendix B). For the purposes of this

study "average sleep" was defined in terms of three self-report measures: a) typically falling asleep in 30 minutes or less, b) on the average, no more than 2 awakenings per night, and c) one's sleep, in general, was to receive at least an "average" rating on an 8-point scale ranging from very poor (0) to very good (7), with "average" occupying the median position.

The second stage of the screening procedure was designed to ensure that participating in the study proper did not undermine the sleep quality of the subjects who had passed the first stage of screening. Accordingly, at the end of each testing session, all subjects were asked to once again respond to the 3 indices of sleep quality, except this time the questions referred to "last night's sleep" rather than "sleep in general". All subjects who failed to meet the predetermined criteria for "average sleep" were not included in the final data analysis. To summarize, only those subjects who were not currently being treated for any sleep problems, who were not taking any psychoactive drugs, and who rated both their usual sleep, and their sleep during the experiment, as at least "average" were included in the final data analysis. In total, 62 subjects failed to meet these criteria. An additional 36 subjects were lost due to attrition. Table 1 provides a summary of the subject selection procedure and the final group sizes.

Table 1

Summary of subject selection procedure

deletions				

GRP.	Recruited	screening	attrition	N

1	42	15	4	23
2	42	7	15	20
3	42	11	10	21
4	42	10	7	25
5	42	19	--	23

Total:	210	62	36	112

Materials.

Film.

The film, entitled It Didn't Have to Happen, is an industrial safety film depicting three workshop accidents. The film is relatively graphic and had previously been used successfully to induce emotional arousal (e.g. De Koninck & Koulack, 1975). Despite its history of success a pilot study was carried out to ensure the film still induces arousal. The film is approximately thirteen minutes long.

Stimulus Materials.

The stimulus materials consisted of 80 two syllable words selected from the Paivio, Yuille, and Madigan (1968) word list. All words had a frequency of 25 or greater per million. The list of words was typed, photographed, and developed into slides. The slides were projected onto a screen at the rate of one slide every five seconds. The learning list consisted of 40 words (Appendix C), with the remaining 40 (Appendix D) serving as distractors during the testing phase. The relatively long learning list (Appendix E) was designed to minimize rehearsal, and avoid ceiling effects during testing. All groups received the same learning and testing lists.

Mood Adjective Check List (MACL).

A modified version of the MACL (Nowlis, 1965) was used to assess post learning changes in emotional arousal. The MACL consists of 8 categories which are grouped on the basis of positive (surgency, social affection), negative (aggression, anxiety, depression, distrust), and neutral (quietness, detachment) affect. Each of the eight categories contains three adjectives which are scored on a four point scale (0-3). The response choices are: not at all (0), don't know (1), little (2), and much (3). Category scores are summed resulting in a range of scores from 0 to 9. The MACL has been used to assess affective changes in a host of previous research (e.g. De Koninck & Koulack, 1975; Nesca & Koulack, in press). Subjects completed pre- and post- film MACLs during the pilot study to ensure that the film induced emotional arousal. Subjects in the study proper also completed pre- and post-film MACLs to ensure the film was arousing for all groups. Arousal was operationally defined as a statistically significant ($p < .10$) increase on the anxiety subscale of the MACL.

Procedure.

Groups 1 through 4.

All the subjects who were recruited participated in the learning sessions. Each group of 42 subjects was run as a complete entity during a single session. At no time were subjects from different groups run together. This restriction was necessary due to the slightly different instructions given to the various groups. For example, group 1 was asked not to nap during the day, while group 2 was expected to sleep during their retention interval.

Upon arrival at the experimental site the subjects were asked to complete a brief screening questionnaire (Appendix B). The pre-film MACLs were handed out once the screening questionnaires were completed and collected. Upon completion of the pre-film MACLs, the experimenter instructed the subjects to prepare for the film. More specifically, the following instructions were verbally presented to all subjects:

A film will be projected onto the screen in front of you. You are to pay close attention to all details of this film. The film is meant to induce arousal therefore you may find it disturbing.

However it is imperative that you pay attention and not avert your eyes. In the event that you find the film too disturbing, you have the option of withdrawing and still receiving your credits. However, for the sake of the other subjects I ask that you simply put your head down and wait until the film ends before you leave.

The post-film MACLs were distributed immediately after the end of the film. While the subjects were completing them the experimenter removed the film projector and replaced it with the projector containing the stimulus materials. Once the MACLs were completed and collected, the subjects were asked to prepare for the word list. The following instructions were presented to all subjects:

A number of words will be individually projected onto the screen in front of you. You are to focus your undivided attention on each word. Further instructions will follow once the last word disappears from the screen.

After the presentation of the final word the subjects were reminded to return at the appropriate time for their second session. All subjects were asked not to discuss the procedure with anyone else. Groups 1 and 3 were asked to

avoid taking naps during the day because "this may weaken the arousal manipulation". Finally questions were answered and the subjects were dismissed for the retention interval.

The screening questionnaires were scored immediately after the subjects were dismissed. The subjects from each group were separated according to whether or not they met the aforementioned criteria for inclusion in the study proper. The subjects who did not meet the criteria were still allowed to participate in their respective testing sessions. However, their data were not included in the final data analysis.

After the appropriate retention interval had elapsed, the subjects reported back to the experimental room for testing. Each subject was given a test form (Appendix F) which contained two columns of numbers corresponding to the number of words to be presented. The words "old" and "new" were printed beside each number. The subjects were instructed to circle one of the two alternatives in response to each word which appeared on the screen. The subjects were asked to respond to each word, " even if it means guessing". The test sheets were collected immediately following the completion of the testing phase. At this point the second screening instrument (appendix G) was handed out and collected upon its completion. Finally all questions were answered, and the experimental credits were assigned.

Group 5.

The subjects in group 5 represented the deprivation condition. These subjects were treated in exactly the same manner as those in the other groups, except that the learning phase was followed by approximately 8 hours of sleep deprivation. During this time subjects were not allowed to leave the experimental room except for trips to the rest rooms. In order to avoid napping washroom breaks were always assigned to pairs of subjects. If the pair was not back within five minutes a third subject was asked to go and check on them. In order to avoid an excessive intake of caffeine the consumption of caffeine laden beverages was prohibited. Except for these two restrictions subjects were free to do as they wished during the retention interval. Reading and recreational materials were provided to keep the subjects occupied. Subjects were also allowed to bring their own recreational materials (i.e. books, games, music, etc.) and snacks. All subjects were asked to keep watch over each other to ensure that everyone remained awake.

Approximately 15 minutes before testing subjects were sent to the rest rooms to "freshen up". After all the subjects had returned to the experimental room the testing procedure was explained to them and testing began. Once again the session ended with the completing of the second screening instrument, the answering of questions, and the

assigning of experimental credits.

Pilot Study.

A pilot study, involving 11 subjects, was conducted to ensure the success of the arousal component of the procedure. These subjects were recruited to participate in a study assessing the emotional impact of a film. Thus the subjects were fully aware, before they agreed to participate, that they would be viewing a stressful film. All subjects completed pre- and post-film MACLs. Once the pre-film MACLs were collected the subjects were instructed that the film would begin immediately. The subjects then received the standard pre-film instructions. All questions were answered once the second MACLs were collected. Arousal was operationally defined as a statistically significant pre-to post-film increase in anxiety.

Results

Efficacy of Arousal Procedure

Scores on the anxiety subscale of the Mood Adjective Check List (MACL) were used to assess the effects of the film on subjects' arousal level. The anxiety subscale of the MACL contains three adjectives (jittery, fearful, clutched up) which are scored on a four point scale (0-3). The scores from each individual adjective are summed resulting in a range of scores from 0 to 9.

Pilot Study. Prior to its use in the study proper, the film was shown to 11 students as part of a pilot study designed to ensure that the film did indeed induce emotional arousal. Subjects for this pilot study were recruited from a fourth year psychology honours course. The subjects were told they were to judge the emotional impact of a film. All of the pilot study subjects volunteered their time.

Subjects in the pilot study completed pre- and post-film MACLs. The presentation of the film immediately followed the completion of the pre-film MACLs. The post-film MACLs were completed immediately after the film was over. The entire procedure took approximately 20 minutes.

Emotional arousal was operationally defined as a statistically significant ($p < .10$) pre- to post-film increase in anxiety. Changes in MACL anxiety scores were analyzed by way of a single one-tailed within group t -test. The results of this analysis revealed a significant increase in pre- to post-film anxiety $\{t(10) = 1.832 p < .05\}$. This finding confirmed the expectation that exposure to the film would induce emotional arousal (see figure 1).

Study Proper. In order to ensure that the film was arousing for every group, all subjects in the study proper also completed pre- and post-film MACLs. Once again pre- to post-film changes in anxiety were analyzed with a series of one-tailed within group t -tests. In accordance with the results of the pilot study, these contrasts revealed significant pre- to post-film increases in anxiety for all groups: group 1, $t(22) = 2.75 p < .01$; group 2, $t(19) = 2.79 p < .01$; group 3, $t(20) = 2.80 p < .01$; group 4, $t(24) = 2.70 p < .01$; group 5, $t(22) = 2.70 p < .01$ (see figure 2). Table 2 contains the descriptive statistics for these analyses and those of the pilot study.

Figure 1. Pilot study MACL scores

(Higher scores reflect greater anxiety)

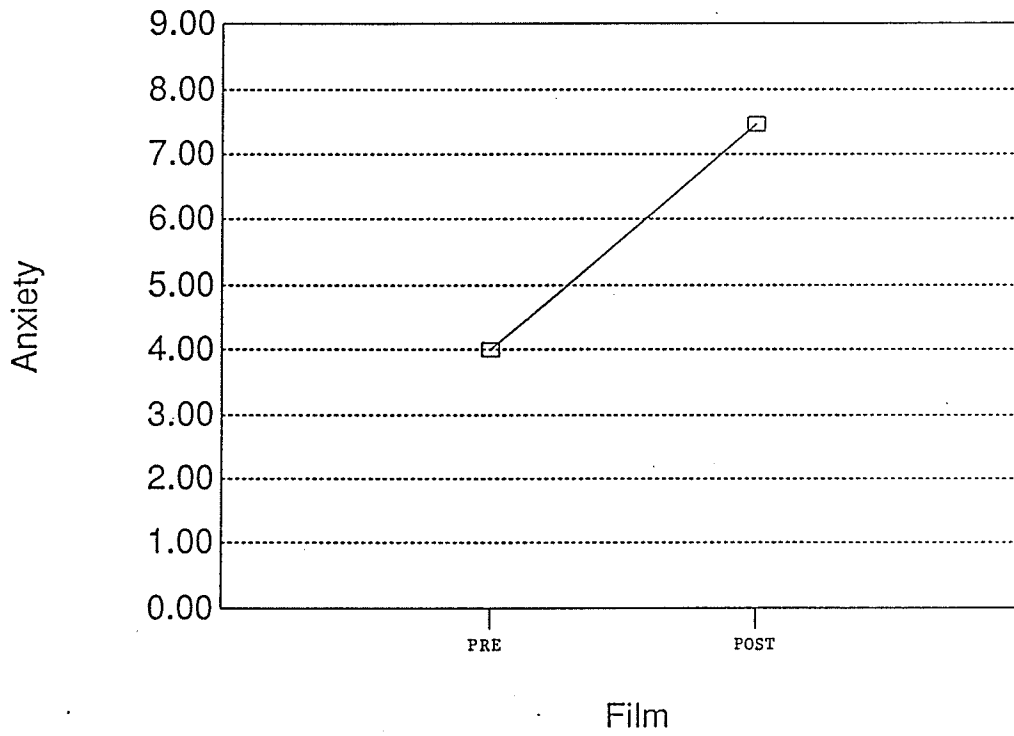


Figure 2. MACL anxiety scores

(Higher scores reflect greater anxiety)

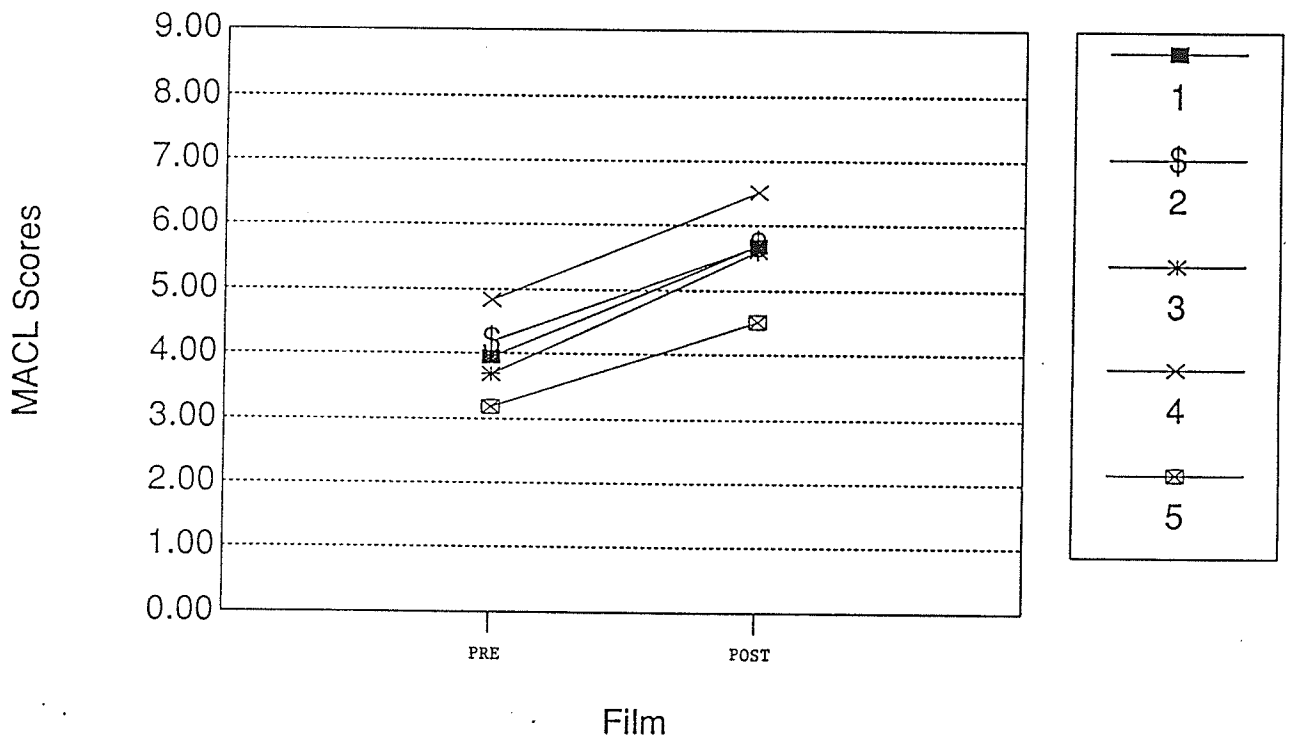


Table 2

Means and Standard Deviations () of MACL Anxiety Scores

Group	Film	
	Pre	Post
Pilot	4.00* (1.18)	7.46* (1.57)
1	3.96** (1.22)	5.70** (3.84)
2	4.20** (1.12)	5.70** (3.39)
3	3.67** (1.83)	5.62** (3.65)
4	4.84** (1.89)	6.52** (3.59)
5	3.17** (.97)	4.52** (2.17)

* p < .05

** p < .01

Recognition Accuracy.

In order to separate memory from decision the d' measure of signal detection theory was utilized as an index of recognition accuracy. D' values were calculated for each individual subject according to the following procedure. First, each correct answer on the test sheet was labeled either a hit or a correct rejection, depending on whether or not the item originally appeared on the learning list. Second, according to the same criteria, each incorrect answer was labeled either a miss or a false alarm. Thus each single response on the test sheet was assigned one of the following four labels: hit, miss, correct rejection, or false alarm. The next step involved estimating the detection and false alarm probabilities. The detection probability was calculated by dividing the number of hits by the combined sum of hits and misses. Similarly, the probability of a false alarm was derived by dividing the number of false alarms by the combined total of false alarms and correct rejections. The computed values of these two probabilities were then referred to d' tables (Swets, 1964) to determine the d' value for each subject. Finally, mean d' values were calculated for each group and used to test 3 directional hypotheses.

Comparisons between means. In accordance with recent recommendations concerning the analysis of experiments involving specific predictions, all hypotheses were tested by robust pairwise comparisons (Howell, 1987; Keppel & Zedec, 1989). All comparisons between means were conducted according to the Games and Howell (1976) procedure for planned multiple comparisons. This procedure was selected because of its robustness to variance heterogeneity and unequal sample sizes.

The first hypothesis was designed to provide a direct comparison of the rival interference and consolidation interpretations of the sleep effect. Based on the tenets of consolidation theory (Wickelgren, 1976; Eysenck & Firth, 1977) a point of sleep interpolation was predicted. More specifically, a main effect of point of sleep interpolation was predicted. Accordingly group 2 was expected to have better retention than group 1. As expected, a planned pairwise comparison revealed that group 2 did indeed report better retention than group 1 $\{t(20) = 2.09 p < .05\}$. It has been suggested that significant pairwise comparisons should be followed by a magnitude of effect procedure (Keppel & Zedec, 1989). For the purposes of this experiment, the omega squared procedure was utilized as an index of the degree of association between the dependent and independent variables. This analysis revealed that, in a 24 hour retention interval, the point of sleep

interpolation variable accounted for 13 per cent of the total variance in recognition accuracy.

The second hypothesis was designed to replicate the original Jenkins and Dallenbach (1924) study within the context of recognition memory. This replication was deemed desirable insofar as the possibility existed that previous studies may have underestimated the magnitude of the sleep effect. Based on previous research, it was predicted that subjects who slept during their retention interval (i.e. grp. 4) would report better retention than those who remained awake (i.e. grp. 3). A planned pairwise comparison involving the mean d' values of groups 3 and 4 revealed a main effect of sleep thereby confirming this expectation ($t(25) = 2.79$ $p < .01$). Thus the present experiment replicated a host of previous research indicating that subjects who sleep during a retention interval remember more than those who remain awake (e.g. Jenkins & Dallenbach, 1924; Spight, 1928; van Ormer, 1932; Ekstrand, 1967). Moreover this finding extends previous research by demonstrating that the sleep effect obtains in recognition as well as recall situations. Surprisingly, the omega squared value for this comparison indicated that sleep only accounted for 15 per cent of the variance in recognition accuracy over an 8 hour retention interval.

A third hypothesis emerged from the desire to determine whether the observed memory effects were due to

sleep per se, or circadian rhythms. To address this issue the present experiment utilized a sleep deprivation condition (i.e. grp. 5). The deprivation group learned and was tested at approximately the same times as group 4. However, while group 4 subjects slept through most of their retention interval, group 5 subjects were kept awake. Since learning and testing occurred at the same times for both groups, it was reasoned that any difference in recognition memory would be attributable to sleep itself. The specific prediction was that group 4 would exhibit superior retention than group 5. A planned pairwise comparison involving the mean d' scores of these two groups failed to confirm this prediction $\{t(45) = 1.18 p > .05\}$. Thus groups 4 and 5 did not differ in terms of recognition accuracy.

To ensure that the retention scores of group 5 were not contaminated by the effects of sleep deprivation, the retention scores from this group were compared to those of group 3. Since group 3 learned and was tested over an equivalent daytime interval, it was reasoned that this group was ideally suited to the function of controlling for sleep deprivation effects. In short, no difference between groups 3 and 5 would indicate that group 5 subjects were not adversely effected by the sleep deprivation procedure. A planned pairwise comparison involving the mean d' scores of groups 3 and 5 revealed that the two groups did not

differ significantly from each other in terms of recognition accuracy $\{t(40) = -1.06, p > .05\}$. Therefore, in accordance with previous research, this study found that a single night of sleep deprivation does not adversely effect recognition accuracy (Williams, Gieseeking, & Lubing, 1966).

Serial Position Data. For descriptive purposes, serial position graphs were constructed for each group. The graphs were constructed in the following manner. First, the percentage of subjects correctly recognizing each word was calculated. Second, the recognition values for each adjacent pair of words were averaged so that the x-axis would contain 20 rather than 40 points. This averaging procedure was designed to reduce variability and thus facilitate interpretation. The results of this procedure are depicted in figures 3 through 7.

Serial position graphs were included so as to allow the present experiment to detect the primacy effect sometimes observed in memory consolidation studies (i.e. Howarth & Eysenck, 1968). The distribution of results obtained in this study are strongly suggestive of a general consolidation effect. Accordingly, one would expect to find clear primacy effects in the consolidation groups (i.e. grps. 2, 4, & 5). Contrary to expectations, only group 4 exhibited clear primacy effects. These results are not

entirely surprising as a primacy effect has proven an elusive phenomenon where memory consolidation is concerned (Eysenck & Firth, 1977).

figure 3. Group 1 serial position graph

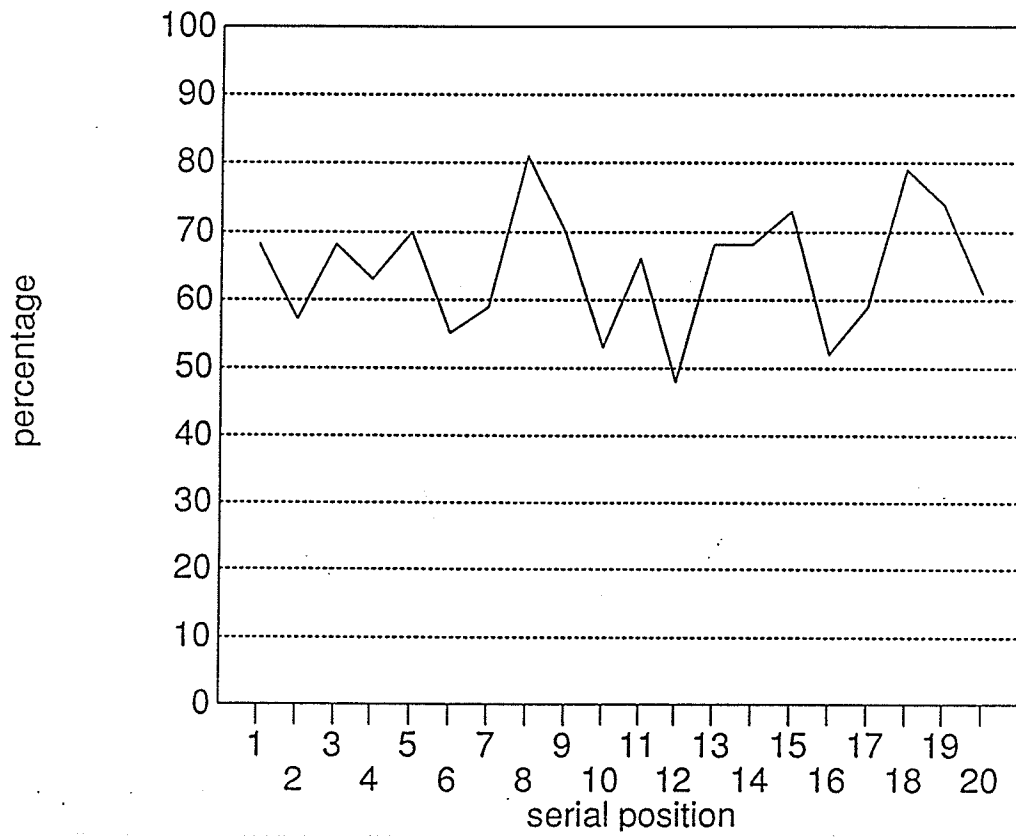


Figure 4. group 2 serial position graph

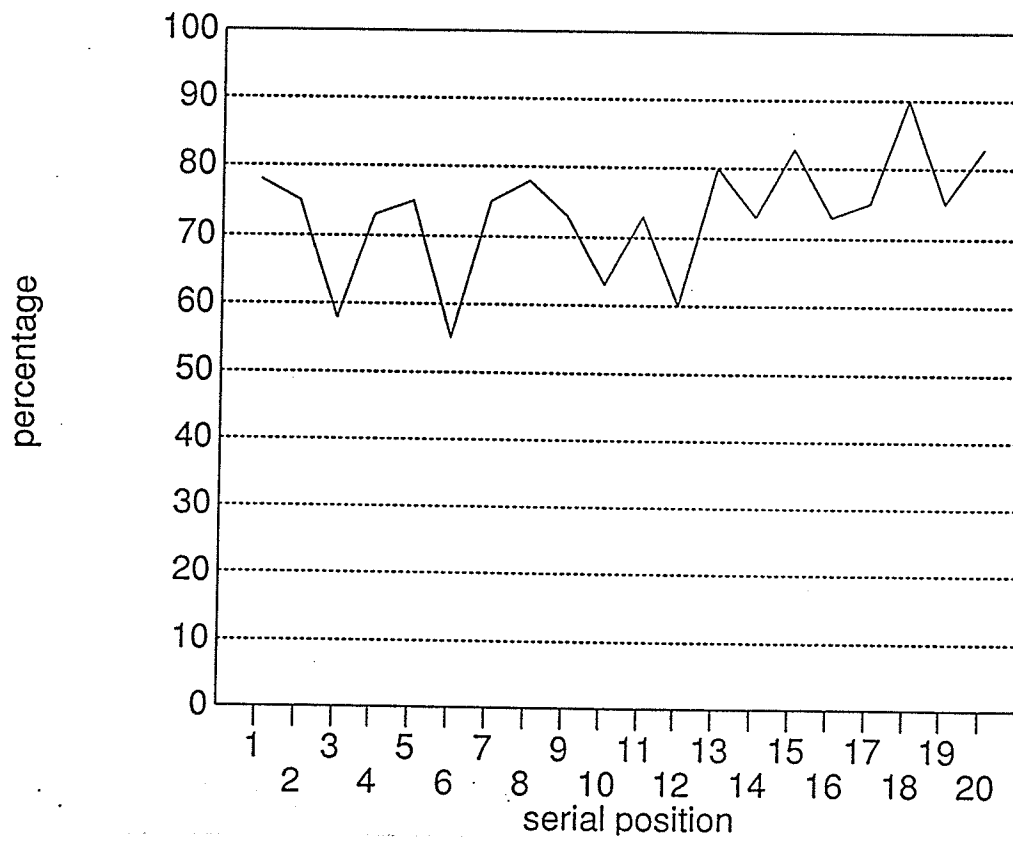


Figure 5. Group 3 serial position graph

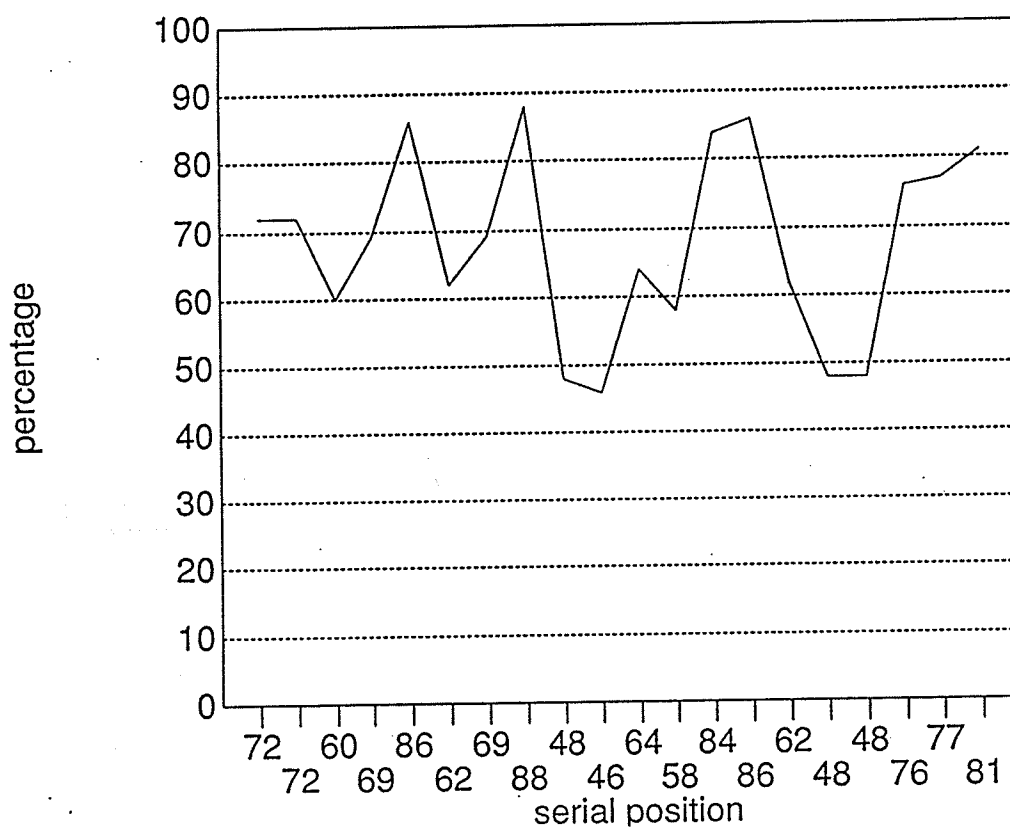


Figure 6. Group 4 serial position graph

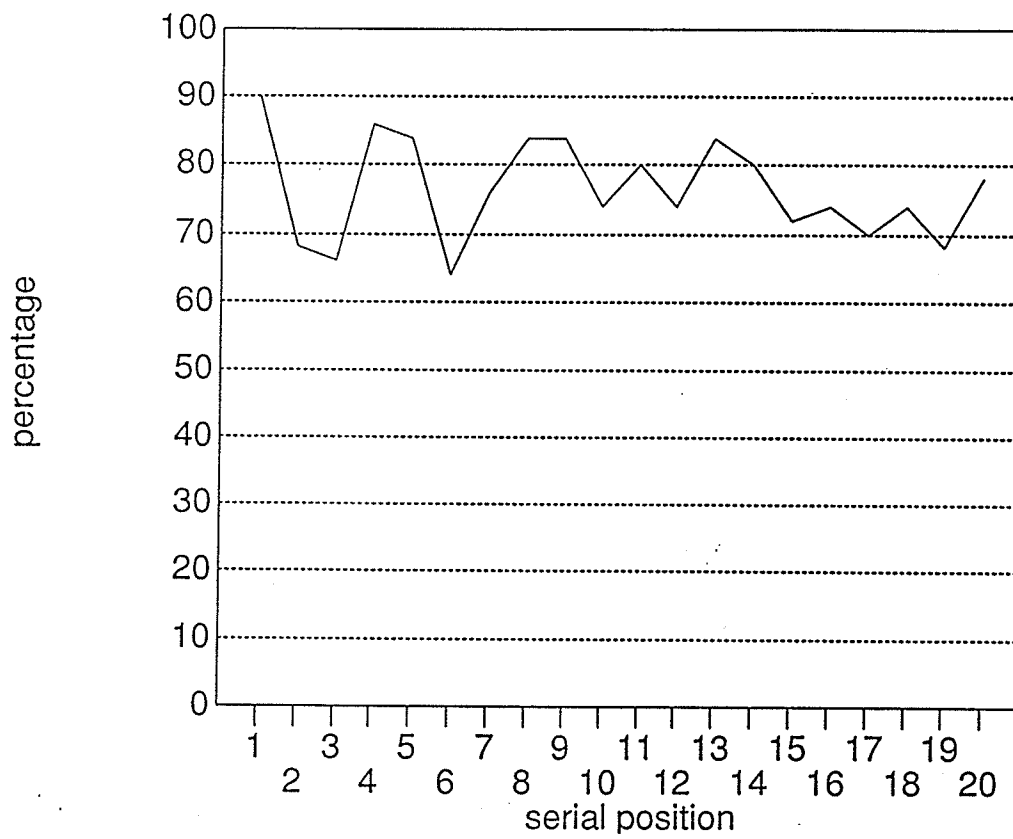
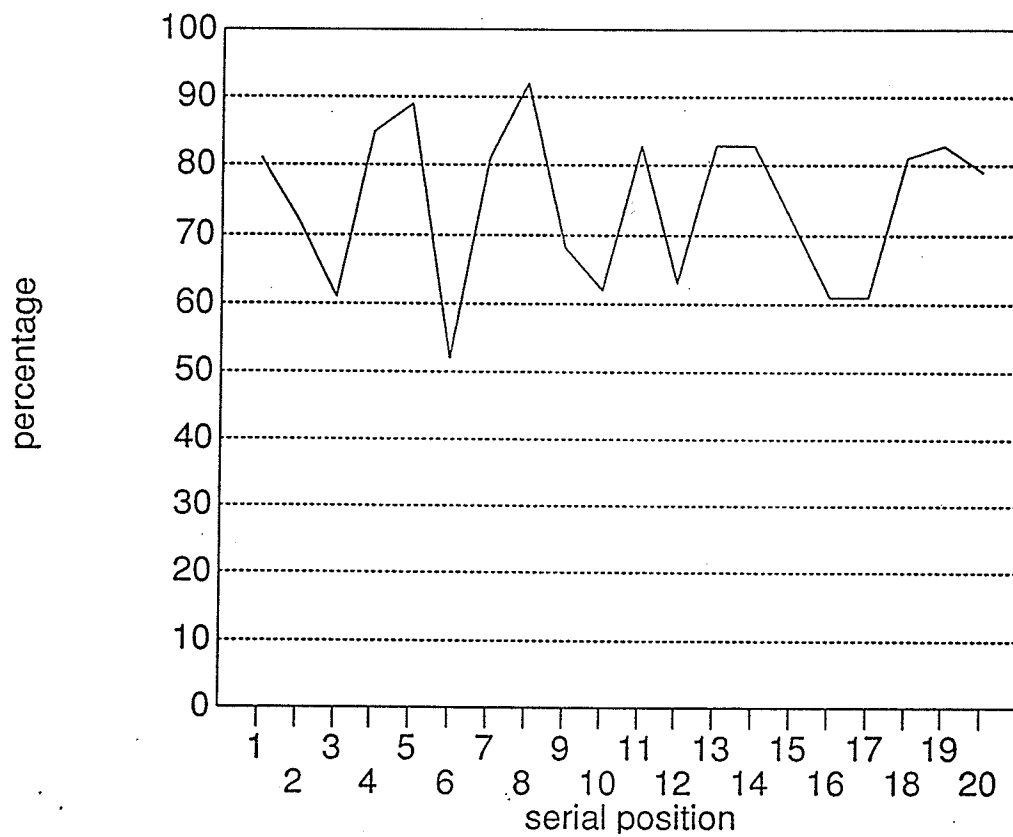


Figure 7. Group 5 serial position graph



Summary.

MACL anxiety scores from both the pilot study and the study proper confirmed the expectation that exposure to the film would generate emotional arousal. Thus it can be stated with some certainty that, in the present experiment, learning occurred under conditions of emotional arousal.

Table 3 contains the summary statistics involved in the testing of the hypotheses generated by this study. Based on the tenets of consolidation theory (Wickelgren, 1976; Eysenck & Frith, 1977) hypothesis one predicted that sleep would be most beneficial when it closely followed learning. A robust pairwise comparison involving the mean d' values of groups 1 and 2 confirmed this prediction. The comparison between groups 1 and 2 was designed to provide a direct contrast of the rival interference and consolidation interpretations of the sleep effect. The validity of this contrast depended entirely on both groups being equated in terms of overall time awake and hence overall exposure to interference. Failure to control for overall exposure to interference would have effectively invalidated this comparison by introducing an extraneous source of variation. To ensure that this was not the case self report measures of bedtime and wake-up time were collected from all subjects. These measures indicated that, on average, group 1 subjects received 6.80 hours of sleep, while group 2 subjects received 6.75 hours of sleep (see table 3).

Table 3

Summary Statistics for Hypotheses testing.

[Means and standard deviations ()]

GRP.	N	TST	d'	Omega Squared
1	23	6.80 (1.27)	.91 _a * (.21)	.13
2	20	6.75 (1.29)	1.43 _a * (.67)	
3	21	----	1.13 _b ** (.14)	.15
4	25	6.25 (.74)	1.51 _b ** (.23)	
5	23	----	1.31 (.49)	

* p < .05

** p < .01

Notes: 1. means with same subscripts differ significantly from each other.

2. TST values measured in hours.

The virtually identical total sleep time (TST) obtained by these two groups effectively equated them in terms of overall exposure to interference. Thus, it appears reasonable to conclude that the observed effect was due to a point of sleep interpolation and not differential exposure to interference.

Hypothesis 2 sought to establish the sleep effect within the context of recognition memory. In accordance with the original work of Jenkins & Dallenbach (1924), one group (grp. 3) learned in the morning and was tested in the early evening, while another group (grp. 4) learned in the late evening and was tested in the early morning. The present experiment differed from previous studies in that recognition rather than recall memory was assessed. The change from recall to recognition memory was implemented in response to evidence suggesting that recall measures may underestimate the magnitude of the sleep effect (i.e. Ekstrand, 1967). The specific prediction was that group 4 subjects would exhibit superior retention by virtue of having slept through most of their retention interval. This prediction was confirmed thus revealing that the commonly observed effect of sleep on memory generalizes to the domain of recognition memory. With regard to the magnitude of the effect, sleep was only found to account for 15% of the total variation in recognition accuracy (table 3).

Finally, self report measures of total sleep time indicated a mean TST value of 6.25 hours for group 4, thus confirming the expectation that group 4 subjects would spend most of their retention interval asleep.

The third and final hypothesis stated that group 4 would exhibit better retention than group 5. This prediction emerged from the belief that the observed effects of sleep on memory are due to sleep per se rather than overnight biological rhythms. The results of group 5 were compared to those of group 3 to ensure that group 5 scores had not been effected by the sleep deprivation. Group 3 was deemed suitable for the task of controlling for sleep deprivation effects because its members learned and were tested over an equivalent daytime interval. As expected the retention scores of groups 3 and 5 did not differ suggesting that group 5 subjects had not been adversely effected by the single night of sleep deprivation. Having established that group 5 subjects were not suffering from sleep deprivation effects, the results from this group were then compared to those of group 4. It was reasoned that comparing the retention scores of groups 4 and 5 would isolate the effects of sleep per se on memory because these groups differed only in terms of their immediate post-learning environment. Therefore, any difference between the two groups could be attributed to the effects of sleep per se. Contrary to expectations, the

mean d' values of groups 4 and 5 did not differ (table 3). This suggests that the well documented effect of sleep on memory may be more precisely described as an overnight circadian effect.

Discussion

This experiment was designed to examine three salient issues surrounding the sleep effect. First, the source of the sleep effect was examined. That is, this study sought to determine whether the facilitating effect of sleep on memory is due to a post-learning reduction in cognitive interference, or to a consolidation of the memory trace. Second, this study attempted to separate the effects of sleep per se on memory from those of circadian rhythms. Finally, this experiment tried to replicate and extend previous work in this area by examining the sleep effect within the context of recognition memory. In this section each issue is summarized and discussed in light of the interference and consolidation models of forgetting. This section also includes a discussion of the weaknesses inherent in this design, and some suggestions for future research.

The Source of the Sleep Effect.

The primary goal of this study was to examine the source of the sleep effect. At present there exist two different explanations of how sleep exerts its facilitating effect on memory. The most widely held belief is that sleep exerts its influence by passively protecting the memory

trace from the noxious interference which is generated by all waking activity (Keppel, 1968; 1972). The belief that changes to the structure of the trace only occur in response to waking activity is an important corollary of this position. The second position, that of consolidation theory, simply states that sleep exerts its influence by promoting the consolidation of recently acquired information. Consequently the consolidation process should be most effective when sleep closely follows learning.

In this study, the interference and consolidation models of forgetting were compared by contrasting the retention scores of groups 1 and 2. For this contrast, the point of sleep interpolation was manipulated while all other variables, including exposure to interference and circadian variables, were held constant. Circadian variables were controlled by having the groups learn and be tested at precisely the same times. Exposure to interference was controlled as a result of the fixed 24 hour retention interval. More specifically, table 3 reveals that groups 1 and 2 slept for a virtually identical amount of time. Therefore, given the fixed interval, it follows logically that the groups were also awake for an equal amount of time. Insofar as the occurrence of nonspecific interference is linked directly to waking activity, it can be stated with confidence that the groups were equated in terms of exposure to interference. Equal exposure to

interference was of paramount importance for this contrast because interference theory maintains that the rate of forgetting is determined entirely by the amount of interference to which subjects are exposed. As a result of this exclusive reliance on cognitive interference as the sole mechanism of forgetting, the significant difference which emerged between groups 1 and 2 is very difficult to explain in interference terms. For this reason these results are interpreted as providing strong support for the notion of memory consolidation.

As previously mentioned, the d' measure of signal detection theory provides a relatively unbiased index of recognition accuracy. The d' measure also enjoys a second, very important characteristic: Namely, d' values are believed to provide a measure of the average strength of the "old" items (Murdock, 1982). This characteristic is directly relevant to the comparison of the interference and consolidation models of forgetting since the consolidation process itself is believed to have a direct impact on trace strength. That is, a consolidated memory trace is believed to enjoy an enhanced resistance to degradation (Wickelgren, 1976; Eysenck & Frith, 1977). This virtue is believed to occur as a function of changes in trace strength. It therefore stands to reason that a more efficiently consolidated memory trace should be "stronger" than a less efficiently consolidated one. Since the

consolidation process is believed to be most efficient when it closely follows learning, one would expect group 2 to exhibit "stronger" memory traces. Insofar as d' provides a measure of the relative strength of the old items (Murdock, 1982), this expectation is confirmed by this experiment (see Table 3). In other words, group 2 which slept shortly after learning, exhibited a "stronger" memory for the old items than did group 1. Although interference theory does not concern itself directly with the issue of trace strength, one can reasonably speculate that the theory would have to predict that these groups would exhibit equal trace strengths, since they were strictly equated in terms of exposure to interference.

Isolating the Effects of Sleep Itself.

This study also sought to separate the effects of sleep itself on memory from those of circadian rhythms. This seemed desirable insofar as some circadian variations are entirely dependent on sleep, while others are completely independent of sleep but tend to occupy the same time interval (Idzikowski, 1984). The present experiment examined this issue by comparing the retention scores of two groups of subjects who differed only in terms of their immediate post-learning environment. Both groups learned late in the evening and were tested early in the morning,

thereby equating them in terms of exposure to circadian variables. However, one group was sleep deprived for the entire retention interval, while the other was allowed to sleep. It was reasoned that comparing the retention scores of these two groups would isolate the effects of sleep because the groups differed systematically only in that one group slept while the other did not. To ensure that the performance of the deprivation subjects was not contaminated by the loss of sleep, their scores were compared to that of a group which learned and was tested over an equivalent daytime interval. In accordance with previous research this study found that a single night of sleep deprivation did not adversely effect recognition memory (Williams, Geiseking, & Lubing, 1966).

Based on the belief that the observed memory effects were indeed due to sleep, the present experiment predicted that subjects in the sleep condition would exhibit better retention than those in the deprivation condition. Contrary to expectation no significant difference emerged between the two conditions. Since the two groups were treated identically except for the inclusion or exclusion of sleep, this finding strongly suggests that the sleep effect is actually a circadian rhythm effect. This position is consistent with previous research which shows that memory is influenced by a number of biological variables which are largely independent of sleep. For example, vasopressin,

which has been implicated as a positive component of the consolidation process, is at its highest level during the night (George et al. 1975). Similarly, plasma cortisol levels, which inhibit protein synthesis and are therefore expected to have a negative impact on memory consolidation, are relatively low during most of the night (Idzikowski, 1984). Moreover, catecholamines, which also inhibit protein synthesis, are higher during the day in both human plasma (Prinz et al., 1974), and human cerebro-spinal fluid (Ziegler et al., 1976).

These findings, along with the results of the present experiment, seem to suggest that circadian variables alone are sufficient to promote the consolidation of recently acquired memory traces. However, logic suggests that this conclusion be viewed with caution. For instance, if the sleep effect is due solely to circadian rhythms then one would expect group 5, which was exposed to these circadian changes, to report better retention than group 3 which was not. That groups 3 and 5 did not differ raises the possibility that the sleep effect may be due to an interaction between sleep and circadian rhythms. Accepting this possibility would lead one to expect a hierarchy of performance among the eight hour groups. That is, one would expect that group 4, which received both sleep and overnight circadian rhythms, would exhibit the best retention, while group 3, which received neither would

exhibit the worst retention. Group 5, which was exposed only to the overnight circadian rhythms, would be expected to occupy the median position in this hierarchy. Although this is consistent with the results of this study, these differences did not reach statistical significance.

Therefore, statistically speaking, these results only allow for the conclusion that the facilitative effect of sleep on memory is actually due to circadian rhythms. Nonetheless, the fact that such a hierarchy did emerge does seem to suggest that sleep does exert some sort of a facilitative effect on memory.

The fact that the differences in retention between groups 4 and 5 did not reach significance also bears directly on the interference model of forgetting. With regard to this specific contrast, interference theory predicts that group 4 should exhibit superior retention because it was only awake (i.e. exposed to interference) for one third of the time that group 5 was. In fact, since interference theory predicts no circadian effect on forgetting, this contrast is functionally equivalent to that involving groups 3 and 4. More specifically, since groups 3 and 5 were both tested after eight hours of waking activity, and since single-list forgetting is thought to depend entirely on exposure to waking activity (Keppel, 1968), these two groups should, according to interference theory, represent identical conditions. Yet groups 3 and 4

differed significantly from each other, while groups 4 and 5 did not. These results appear impossible to explain from an interference standpoint. To illustrate, if the difference between groups 3 and 4 is ascribed to the fact that group 3 was awake for 8 hours while group 4 was awake only 2.25 hours, then the same difference would be expected to emerge between groups 4 and 5 since the exact same conditions once again apply. In short, identical conditions should reasonably be expected to produce identical results. The fact that this did not occur suggests that, at the very least, interference theory provides an inchoate explanation of the sleep effect.

Extending the Sleep Effect.

A third and final goal of this investigation was to replicate the original Jenkins and Dallenbach (1924) study within the context of recognition memory. This replication was prompted by the desire to assess the sleep effect using a more appropriate measure of item availability. More precisely, it is now widely accepted that free recall tests are too sensitive to recall interference to be used as an index of total response availability (e.g. Wickelgren, 1976; Spear, 1978; Tilley, 1981). Since the sleep effect is believed to be a storage phenomenon, it stands to reason that it should be measured by tests which adequately

address the total contents of memory. In this regard, there is a growing consensus that storage issues, that is issues which are concerned with the total amount of information in store, are best addressed by recognition tests (e.g. Tulving & Pearlstone, 1966; Wolford, 1971; Loftus & Loftus, 1976; Wickelgren, 1976; Eysenck & Frith, 1977). Based on this reasoning it was deemed desirable to replicate the earlier work in this area within the context of recognition memory.

In accordance with previous work, this study found that subjects who sleep during a retention interval remember more than those who remain awake (e.g. Jenkins & Dallenbach, 1924; Spight, 1928; van Ormer, 1932; Graves, 1937; Ekstrand, 1967; Idzikowski, 1984). The fact that this replication occurred within the context of recognition memory is notable in that it emphasizes the robustness and generalizability of the sleep effect. However, the observed effect was found to account for only 15% of the variation in recognition accuracy over an eight hour interval. Unfortunately, since previous studies did not include a magnitude of effect measure, it is impossible to say whether the magnitude of the effect obtained with recognition tests differs from that obtained with the more commonly employed free recall tests.

The small size of the observed effect is most plausibly ascribed to the general lack of control over the

total amount of sleep received by the sleep group (i.e. group 4). Table 3 reveals that, on average, subjects in this group only slept for six and one quarter hours of their retention interval; with the remaining time being spent awake and probably in transit between their homes and the experimental site. To be sure this problem could have been avoided by having the subjects sleep in a sleep laboratory. However, logistical considerations precluded this option. The same constraints effectively added one half hour to the retention interval of the sleep group (see Appendix A, group 4). This additional time was added when it became apparent that less than half of the subjects were in place and ready to begin testing within the originally allotted time. In essence then, the subjects in the sleep group were operating under a dual disadvantage. First, they only slept for approximately two thirds of their retention interval. Second, their retention interval was one half hour longer than that of the awake subjects (i.e. group 3). Given these conditions it is not surprising that sleep only accounted for a relatively small amount of the total variation in recognition accuracy. Indeed, that the sleep effect emerged at all under these conditions may be taken as a testament to the robustness of this phenomenon. In a related vein, it is interesting to note that, despite the adverse conditions, group 4 subjects still exhibited the highest overall d' value.

Suggestions for Future Research.

The results of this study provide support for the notion of memory consolidation. As is often the case, work on one specific project generates ideas for future work. This section will outline some of these ideas.

The most obvious extension of this study would involve determining whether arousal is a necessary part of this procedure. Since all groups in this study learned under conditions of emotional arousal the present design cannot speak to this issue. The present design also provides no information on the theoretically expected differences between recall and recognition. These issues could easily be addressed with a single experiment. For example, a 2 (arousal/no arousal) x 2 (recall/recognition) design would address both issues. Such an experiment would probably work best by having all subjects learn at night and then be tested in the morning. Conversely the retention interval could also be varied thus expanding the experiment to a three way design.

The circadian variable finding certainly requires replication. Ideally such a replication would involve polysomnographic monitoring in a sleep laboratory. These added measures would provide more precise information as to the amount and quality of sleep obtained by the subjects.

Consequently, future research could avoid the heavy reliance on self-report measures which characterized the present investigation.

Finally the original studies by Jenkins and Dallenbach (1924) and van Ormer (1932) demand replication. These studies remain the only available studies to have charted the course of the memory trace over the entire night. Both studies obtained an identical pattern of results. However, replications involving modern polysomnographic techniques would enhance the validity of these studies while simultaneously providing additional physiological data. Depending on the specifics of the design, such a study could also provide valuable information about the relative contributions of each sleep stage to the process of memory consolidation.

Concluding Remarks.

This experiment obtained results which are believed to provide strong and unequivocal support for the notion of memory consolidation. More specifically, in accordance with a prediction derived from the tenets of consolidation theory, this study found that the point of sleep interpolation has a direct effect on the strength of the memory trace and hence overall retention. In fact the point of sleep interpolation was found to account for 13% of the

total variation in recognition accuracy over a 24 hour interval. This study also found evidence which suggests that the sleep effect is actually a circadian rhythm effect. This finding is important in that, should it prove replicable, it provides direction for future research into the biology of memory processes. That is, a robust circadian effect on memory would logically suggest that the changes associated specifically with the last third of the circadian cycle are actively involved in the retention of recently acquired information. Such a finding could reasonably be expected to produce significant theoretical and practical developments.

Recall that, according to interference theory, the rate of extra-experimental (i.e. single-list) forgetting depends solely on the amount of RI to which one is exposed (Keppel, 1968; 1972). To the extent that the occurrence of RI is tied directly to waking activity, one can say that the forgetting of a single list is determined entirely by the amount of waking activity which intervenes between learning and testing. This assumption was added to classical interference theory when it became apparent that the model could not convincingly explain extra-experimental forgetting. The result of this study suggest that this assumption is no longer tenable. For example, this position clearly predicts that, all things being equal, memory performance should not vary as long as subjects are equated

in terms of overall time awake. Insofar as group 2 subjects exhibited better retention than group 1 subjects, despite being awake for the same amount of time, this study provides evidence which directly contravenes this prediction. Moreover, the finding that the robust and well documented sleep effect is, at least in part, due to simple circadian rhythms also undermines the interference position because all waking activity is assumed to be detrimental to retention --- regardless of its temporal location. Most damaging perhaps, is the finding that two theoretically identical situations (i.e. grp. 3 vs. grp. 4; grp. 4 vs. grp. 5) produce statistically different results. Taken together these results strongly suggest that the widely accepted model of interference is in need of reworking. This is not meant to deny the importance or existence of cognitive interference. On the contrary, the truly voluminous literature documenting the existence and effects of cognitive interference clearly establish the phenomenon as valid. The belief that the interference position has been overstated appears more reasonable. In this regard, Ekstrand (1972) has argued that interference effects appear to be restricted to retrieval situations and therefore interference theory may not be applicable to storage issues. He goes on to add that storage issues appear to be most readily interpreted from a consolidation theory standpoint. Insofar as the sleep effect is thought to be a

storage phenomenon, the results and conclusions drawn from this study are in complete harmony with Ekstrand's position.

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Appendix A

Experimental Design

Groups

1. learn 10am ----- wake ----- sleep ----- test 10am
2. learn 11:30pm ---- sleep ----- wake ----- test 11:30pm
3. learn 8:30am ----- wake ----- test 4:30pm
4. learn 12am ----- sleep ----- test 8:30pm
5. learn 12am ----- sleep dep. ----- test 8am

Notes:

- 1) Comparing groups 1 and 2 provides a direct contrast of the interference and consolidation predictions.
- 2) Groups 3 and 4 replicate Jenkins and Dallenbach (1924).
- 3) Comparing groups 5 and 4 isolates the effects of circadian rhythms on memory. With regard to this contrast, group 3 functions as a control group for non-specific sleep deprivation effects.

Appendix B

Screening Questionnaire No. 1

Please answer the following questions as honestly and accurately as you can. Your responses will be kept strictly confidential.

1. When you awaken in the morning, how often can you recall experiencing at least one dream during the night?

1	2	3	4	5	6	7
Never			Sometimes			Always

2. When you awaken in the morning, how often can you describe all or part of a dream experienced before awakening?

1	2	3	4	5	6	7
Never			Sometimes			Always

3. On the average, how many mornings a week can you recall all or part of a dream when you awaken?

0	1	2	3	4	5	6	7
---	---	---	---	---	---	---	---

4. In general, how often do you have trouble falling asleep at night?

1	2	3	4	5	6	7
Never			Sometimes			Always

10. Are you currently being treated for any medical problems?
Yes _____ No _____

If yes, what are you currently being treated for? _____

11. What prescription and/or over-the-counter medications are you currently taking?

Drug:	Dosage/day:	Purpose:
_____	_____	_____
_____	_____	_____
_____	_____	_____

12. On the average how many days per week do you drink alcohol?

0 1 2 3 4 5 6 7

13. Are you currently taking any other drugs? Yes ___ No ___

If so, what? _____ (answer is optional)

How often? _____ (answer is optional)

14. What time do you normally go to bed? _____ Get up? _____

15. In general, how many times per night do you usually wake up?

0 1 2 3 4 5 6 7

16. How long does it usually take you to fall asleep?

15 minutes or less _____ 30 mins. _____

more than 30 mins. _____ more than 1 hour _____

17. In general, how would you rate your sleep?

0 1 2 3 4 5 6 7

very
poor

average

very
good

Appendix C

Learning List

1 - 40 (in order)

- | | |
|-------------|-------------|
| 1. silence | 21. custom |
| 2. daylight | 22. palace |
| 3. amount | 23. letter |
| 4. weapon | 24. cellar |
| 5. clothing | 25. humor |
| 6. kindness | 26. devil |
| 7. metal | 27. prison |
| 8. river | 28. poet |
| 9. village | 29. money |
| 10. arrow | 30. picture |
| 11. effort | 31. honor |
| 12. meadow | 32. butter |
| 13. teacher | 33. dollar |
| 14. artist | 34. sugar |
| 15. shadow | 35. justice |
| 16. patent | 36. glory |
| 17. kettle | 37. barrel |
| 18. duty | 38. anger |
| 19. costume | 39. women |
| 20. rattle | 40. boulder |

Appendix D

Distractors

- | | |
|--------------|----------------|
| 41. twilight | 61. cotton |
| 42. insect | 62. lemon |
| 43. blossom | 63. paper |
| 44. owner | 64. ticket |
| 45. valley | 65. belief |
| 46. scarlet | 66. baker |
| 47. fortune | 67. garments |
| 48. friend | 68. odor |
| 49. flower | 69. victim |
| 50. science | 70. vision |
| 51. impulse | 71. background |
| 52. answer | 72. pupil |
| 53. beggar | 73. murder |
| 54. college | 74. exhaust |
| 55. marriage | 75. doctor |
| 56. salad | 76. event |
| 57. coffee | 77. knowledge |
| 58. jury | 78. garden |
| 59. prairie | 79. steamer |
| 60. freedom | 80. maiden |

Appendix E

Test List

Test List (in order).

- | | |
|--------------|--------------|
| 1. honor | 41. clothing |
| 2. daylight | 42. insect |
| 3. maiden | 43. humor |
| 4. steamer | 44. beggar |
| 5. palace | 45. garden |
| 6. butter | 46. lemon |
| 7. meadow | 47. owner |
| 8. devil | 48. blossom |
| 9. murder | 49. scarlet |
| 10. anger | 50. silence |
| 11. garments | 51. prairie |
| 12. baker | 52. friend |
| 13. cellar | 53. money |
| 14. patent | 54. river |
| 15. paper | 55. belief |
| 16. coffee | 56. teacher |
| 17. jury | 57. kindness |
| 18. freedom | 58. rattle |
| 19. poet | 59. amount |
| 20. cotton | 60. boulder |
| 21. letter | 61. victim |
| 22. science | 62. kettle |

- | | |
|----------------|---------------|
| 23. prison | 63. effort |
| 24. salad | 64. vision |
| 25. costume | 65. pupil |
| 26. sugar | 66. dollar |
| 27. valley | 67. shadow |
| 28. metal | 68. event |
| 29. answer | 69. custom |
| 30. duty | 70. ticket |
| 31. background | 71. odor |
| 32. weapon | 72. knowledge |
| 33. justice | 73. barrel |
| 34. arrow | 74. flower |
| 35. artist | 75. glory |
| 36. impulse | 76. village |
| 37. fortune | 77. doctor |
| 38. college | 78. picture |
| 39. exhaust | 79. marriage |
| 40. women | 80. twilight |

Appendix F

Test Form

Name _____

Student number _____

1.	OLD	NEW	21.	OLD	NEW
2.	OLD	NEW	22.	OLD	NEW
3.	OLD	NEW	23.	OLD	NEW
4.	OLD	NEW	24.	OLD	NEW
5.	OLD	NEW	25.	OLD	NEW
6.	OLD	NEW	26.	OLD	NEW
7.	OLD	NEW	27.	OLD	NEW
8.	OLD	NEW	28.	OLD	NEW
9.	OLD	NEW	29.	OLD	NEW
10.	OLD	NEW	30.	OLD	NEW
11.	OLD	NEW	31.	OLD	NEW
12.	OLD	NEW	32.	OLD	NEW
13.	OLD	NEW	33.	OLD	NEW
14.	OLD	NEW	34.	OLD	NEW
15.	OLD	NEW	35.	OLD	NEW
16.	OLD	NEW	36.	OLD	NEW
17.	OLD	NEW	37.	OLD	NEW
18.	OLD	NEW	38.	OLD	NEW
19.	OLD	NEW	39.	OLD	NEW
20.	OLD	NEW	40.	OLD	NEW

41.	OLD	NEW	61.	OLD	NEW
42.	OLD	NEW	62.	OLD	NEW
43.	OLD	NEW	63.	OLD	NEW
44.	OLD	NEW	64.	OLD	NEW
45.	OLD	NEW	65.	OLD	NEW
46.	OLD	NEW	66.	OLD	NEW
47.	OLD	NEW	67.	OLD	NEW
48.	OLD	NEW	68.	OLD	NEW
49.	OLD	NEW	69.	OLD	NEW
50.	OLD	NEW	70.	OLD	NEW
51.	OLD	NEW	71.	OLD	NEW
52.	OLD	NEW	72.	OLD	NEW
53.	OLD	NEW	73.	OLD	NEW
54.	OLD	NEW	74.	OLD	NEW
55.	OLD	NEW	75.	OLD	NEW
56.	OLD	NEW	76.	OLD	NEW
57.	OLD	NEW	77.	OLD	NEW
58.	OLD	NEW	78.	OLD	NEW
59.	OLD	NEW	79.	OLD	NEW
60.	OLD	NEW	80.	OLD	NEW

Appendix G

Screening Questionnaire No. 2

Name _____

Student number _____

1. What time did you go to bed last night? _____

2. What time did you wake up this morning? _____

3. How would you rate last night's sleep?

0 1 2 3 4 5 6 7

very
poor

average

very
good

4. How long did it take you to fall asleep last night?

15 minutes or less _____ 30 mins. _____

more than 30 mins. _____ more than 1 hour _____

5. How many times did you wake up last night?

0 1 2 3 4 5 6 7

6. Do you remember a dream from last night? Yes___ No___

If so, could you please describe it in as much detail as possible (use the back of this sheet if necessary).