ELECTRODERMAL ACTIVITY AND METAMEMORY REPORTS AS PREDICTORS OF MEMORY RETRIEVAL

A Thesis

by

MARIE FLESCH

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree
of

MASTER OF SCIENCE

August 2004

Major Subject: Psychology

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Approved as to style and content by:

Steve Smith (Chair of Committee)	James Grau (Member)
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ABSTRACT

Electrodermal Activity and Metamemory Reports as Predictors of Memory Retrieval. (August 2004)

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Electrodermal activity (EDA), an indicator of arousal of the sympathetic nervous system, was investigated as a potential correlate of feeling-of-knowing (FOK) and tip-of-the-tongue (TOT) states. In Experiment 1, skin conductance was measured while participants answered general knowledge questions and made binary FOK and TOT judgments. Significant correlations were found between frequency of skin conductance responses (SCRs) and presence of both FOK and TOT states. In Experiment 2, warmth ratings were used and a follow-up clue session was added to offer participants the opportunity to resolve initially unanswered questions. SCR frequency during TOT states was significantly predictive of resolution during the clue period, although not as predictive as participants' warmth ratings. The potential of EDA as an on-line, non-intrusive measure of metamemory and memory retrieval is discussed.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

"Ar bharr theanga agam," "Keele otsa peal," "navonotootse'a," "tip-of-the-tongue": Whether described in Welsh, Estonian, Cheyenne, or English, people appear to have a similar experience of feeling that a word is tantalizingly close, but unavailable— stored in memory and ready for retrieval, but somehow inaccessible. Schwartz (1999) examined the universality of this experience by surveying speakers of more than fifty languages and found that nearly all languages include a word or expression describing this unsettling state. Self-estimate reports have indicated that tip-of-the-tongue states (TOTs) are experienced by most people with a frequency of about one per week (Burke, MacKay, Worthley, & Wade, 1991; Reason & Lucas, 1984). This type of blocking has been described by Schacter (2001) as ranging from a "mildly irritating curiosity" (p. 61) in some contexts to the cause of great anxiety in other contexts, as when one fails to recall the name of an acquaintance at a social gathering. Such

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This thesis follows the style and format of *Cognition*.

experiences are often accompanied by knowledge of the number of syllables in the target word (Burke, MacKay, Worthley, & Wade, 1991; Lovelace, 1987; Yarmey, 1973), first phoneme of the target word (Burke et al., 1991; Kohn, Wingfield, Menn, Goodglass, Gleason, & Hyde, 1987), syntactical knowledge of the target (Vigliocco, Vinson, Martin, & Garrett, 1999), and the retrieval of semantically related words (Reason & Lucas).

Brown & McNeill (1966) identified the TOT state as an experience during which a person feels that a target is "known, but temporarily unretrievable" and for which retrieval seems imminent. Many descriptions of TOTs have also included an emotional component. James (1893) described the presence of a "tingle with the sense of our closeness" to the target (pg. 251). Brown and McNeill compared it to an impending sneeze. In fact, some researchers have actually included emotional arousal as one of the defining features of TOTs (Gruneberg, Smith & Winfrow, 1973; Yarmey, 1973). Anecdotal data and diary studies have supported this relationship. Cohen and Faulkner (1986) found that some older participants reported more frequent TOTs when they were "tired, stressed, or unwell" (p. 189), leading the authors to suggest that

anxiety regarding memory failure may precede TOTs in elderly adults. Brown, in his comprehensive 1991 review of TOT literature, reported that 75% of undergraduate students he surveyed reported experiencing TOTs most frequently at times when they were “too nervous” (p. 206).

The emotionality of TOTs has also been examined in laboratory studies. Schwartz, Travis, Castro, and Smith (2000) explored the emotionality and strength of TOTs and found that participants could classify TOTs along these dimensions and that emotionality and strength were correlated with objective measures of performance, including recognition and later resolution of the TOT targets. They also examined imminence, a term introduced by Smith (1994) to refer to an individual’s subjective evaluation of his likelihood of immediate resolution of a TOT state. Schwartz et al. found that imminence, like emotionality and strength, was correlated with recognition and later resolution. This relationship was confirmed in a diary study conducted by Schwartz (2002) that revealed that ratings of imminence by participants experiencing naturally-occurring TOTs positively predicted resolution.

Unfortunately, as discussed by Metcalfe (1996), an empirical methodology for examining imminence has not yet

been developed. She suggested that until such a methodology is developed, progress in understanding the subprocesses of problem solving is unlikely. Metcalfe and Wiebe (1987) have investigated “warmth ratings”, a term used by to refer to subjects’ own assessments of their nearness to reaching solutions to insight problems. They asked subjects to report their feeling-of-warmth ratings every 10 seconds while attempting to solve insight problems. Although this method of quantifying imminence may be useful in some experimental settings, it is intrusive and impractical in others and raises the concern that participants may be so tasked by the reporting process that the normal retrieval process may be inhibited or altered. Therefore, a less intrusive measure than the one described by Metcalfe and Wiebe would be desirable and was sought in the present study.

Prompted by Brown’s 1991 suggestion that the role of arousal in TOTs be quantified using galvanic skin response in order to better understand the emotional component of TOTs, the current study measured electrodermal activity (EDA) while participants engaged in a prospecting task. Participants indicated moments of retrieval during the task by making small motor movements (tapping a microphone),

thereby allowing the experimenters to examine the physiological output immediately before and after the reported moment of retrieval. Participants reported the strength of their TOTs and how imminent they felt resolution was. These two components were isolated as contributors of what has been generally referred to as the "emotional arousal" of TOTs.

EDA, a continuous, peripheral measure of arousal, is controlled by the sympathetic nervous system (Raine, Venables, & Williams, 1990; Boucsein, 1992). This control has been demonstrated in studies in which "bursts" of sympathetic nerve activity, as measured by sympathetic action potentials in peripheral nerves, were correlated with skin conductance responses (SCRs) (Wallin, 1981). EDA is measured by passing a weak electrical current across two electrodes placed on the skin and recording decreases in the skin's conductivity of electricity. The tonic, or absolute, level of EDA is determined by the standing level of sweat in the sweat ducts of the epidermis (Edelber, 1972). Superimposed on the tonic level are phasic increases in conductance, referred to as skin conductance responses (SCRs), that result from increases in the standing level of sweat in the ducts. Several aspects of

EDA may be used to quantify EDA, among them frequency and amplitude. Frequency refers to the number of phasic SCRs present per minute, and amplitude to the amount of increase in conductance in an SCR as measured from the point of deflection from the tonic level to the peak of the response.[1]

Interest in the potential of EDA as an indicator of metacognitive states was aroused by findings that, although phasic increases may be spontaneous, they are also linked to cognitive stimuli (Kutas & Federmeier, 1998; Boucsein, 1992). Heightened EDA has been associated with implicit recognition of faces (Tranel & Damasio, 1988) and exposure to stimuli with strong affective valence (Bradley, Greenwald, Petry, & Lang, 1992). Aspects of EDA have been associated with readiness for information uptake (Venables, 1975), attention during information processing (Dawson & Schell, 1982), and recall of visual information (Stelmack, Plouffe, & Winogron, 1983). Distinct EDA patterns have been observed during deceptive and truthful responding, lending EDA as one measurement tool in the modern system of

[1] Consistent with recommendations by Prokasy and Kumpfer (1973), who noted that SCR frequency and amplitude do not always covary, both measures of EDA were recorded in the present study and analysis of the two were compared.

lie detection (Thackray & Orne, 1968; Raskin, 1989; Horowitz, Kircher, Honts, & Raskin, 1997).

Of particular interest for TOT researchers is a study conducted by Bechara, Damasio, Tranel and Damasio (1997) that found that EDA was a better indicator of participants' knowledge during a decision-making task than were participants' own verbal reports of their knowledge. Bechara et al. used a gambling paradigm in which participants played a card game and were rewarded or punished according to whether their playing decisions were in accordance with a rule system that the participants had not been instructed in. This forced participants to learn the rule system and develop useful playing strategies independently. Intermittent requests for participants to report their understanding of the rules of the game revealed that participants chose advantageously in the game before they had conceptual knowledge of the rules, indicating that they may have been implicitly aware of the rules. EDA measurement during the task indicated that after participants began making advantageous game decisions, but before explicit conceptual knowledge of the game rules had developed, SCRs were present preceding risky game decisions. This finding that EDA was a more reliable

indicator of knowledge than participants' own assessments of their knowledge raises the possibility that EDA may useful in studying TOT states.

Brain imaging studies also suggest a possible EDA-TOT link. An event-related functional MRI study conducted by Kikyo, Ohki and Sekihara (2001) found heightened activation of the left dorsolateral prefrontal cortex during successful retrieval of TOT targets. This finding is of interest given that this area has been identified as an anatomical correlate of EDA (Tranel & Damasio, 1994).

Additional support for a possible relationship between EDA and metacognitive reports was found in a study that discovered systematic variation in pupil dilation, another output of the autonomic nervous system, during stages of memory retrieval (Headley, 1981). Headley measured pupil size, which increases during activation of the sympathetic system, while participants responded to general knowledge questions by either providing an answer, responding that the answer was not known (n-FOK), or that the answer was known but temporarily blocked (FOK). For each question that was not answered or was answered incorrectly, a clue of the first and last letters of the answer was provided. Pupil size was larger during FOK reports than n-FOK

reports, and during question periods answered incorrectly than during those answered correctly. Beatty's 1982 review of task-evoked pupillary responses offers further evidence of the utility of physiological measures in examining cognitive processes. Beatty concluded that pupil dilation varies systematically with mental effort, finding that dilation increases in size as greater cognitive effort is demanded of participants. More recent investigations have supported this view. Hyona, Tommola, and Alaja (1995) observed greater pupil dilation during a difficult language processing task, translating difficult-to-translate words, than during the less demanding task of translating easy-to-translate words. The authors concluded that variations in processing load are reflected in changes in pupil dilation. Given that EDA and pupil dilation are both mediated by the sympathetic nervous system, it was inferred that EDA measurement may reveal similar patterns as those observed in the pupillometry studies discussed. Specifically, more frequent SCRs were expected for those trials during which participants did not retrieve the correct answers but reported experiencing FOKs and/or TOTs than during trials when participants did not retrieve the correct answer and also not report experiencing FOKs or TOTs. This prediction

follows from Headley's finding that pupil dilation is larger during FOKs than n-FOKs, and from Beatty's studies indicating that dilation is greater during periods of greater cognitive effort, as could be assumed to be present when an individual is conducting a mental search for a target for which she believes increased effort may be fruitful than for one when she believes effort will not be productive.

The current study investigated whether EDA would be affected by the presence of knowledge of a target item when individuals reported that they were experiencing TOTs. We further investigated whether retrieval of TOT targets was better predicted by EDA or metamemory reports (feeling-of-knowing and tip-of-the-tongue states). It was predicted that more frequent SCRs would be present during response epochs when TOTs and FOKs were reported than when they were not reported, and that more frequent SCRs would be present during response epochs when participants offered answers than during those when they did not offer answers.

Metcalfe (1996) defined FOK judgments as assessments made during a period of failure to solve a problem or recall information in which the individual indicates how likely he feels he would be to reach resolution at a later

time. Metcalfe (1986) found that for routine problem solving and memory retrieval, FOK judgments were predictive of performance during later testing. Brown (1991) argued that FOK and TOT states differ in that TOTs are involuntary whereas FOK assessments are elicited by the experimenter, and in that subjects believe they will be able to *recall* the target of a TOT state whereas they only believe they will be able to *recognize* the target of an FOK. Metcalfe (1996), in contrast, argued that TOT and FOK experiences are not qualitatively different states but rather two points along a continuum of imminence, with TOT targets feeling more imminent than FOK targets. Headley's pupillometry investigation (Headley, 1981) focused on arousal during response blocks and retrieval, but did not explore the difference between blocks during which retrieval seems imminent (TOTs) and those during which it does not seem imminent (FOK). The current study explored this difference by following each omission error with two questions: 1) Would you recognize the answer? (FOK); and 2) Do you feel as if the answer is about to pop into mind at any moment? (TOT). It was predicted that if TOT reports are simply reports of strong FOK, then response epochs during which both TOT and FOK were reported would be

accompanied by more SCRs than those epochs when only FOK were reported. Experiment 2 explored the utility of using a continuum rather than binary FOK and TOT choices. Participants made warmth ratings on a 10-point scale for each omission error. A retest in which clues were provided was then administered to examine whether the metamemory reports and electrodermal activity during the first question period would predict subsequent resolution. Based on Metcalfe's (1986) findings that FOK is predictive of memory resolution, it was predicted that FOK reports would be predictive of resolution. Likewise, TOT reports were hypothesized to be predictive of resolution. A negative correlation was predicted between SCR frequency and confidence, whereas a positive correlation was predicted between SCR frequency and warmth ratings.

The predictive value of SCRs during the initial response epochs were examined to determine whether EDA may provide a means of assessing the response criterion of participants. A study by Widner, Smith and Graziano (1996) demonstrated the vulnerability of participants to demand characteristics when reporting TOTs. They informed students in a high-demand condition that a series of questions had been easy for 95% of other participants to

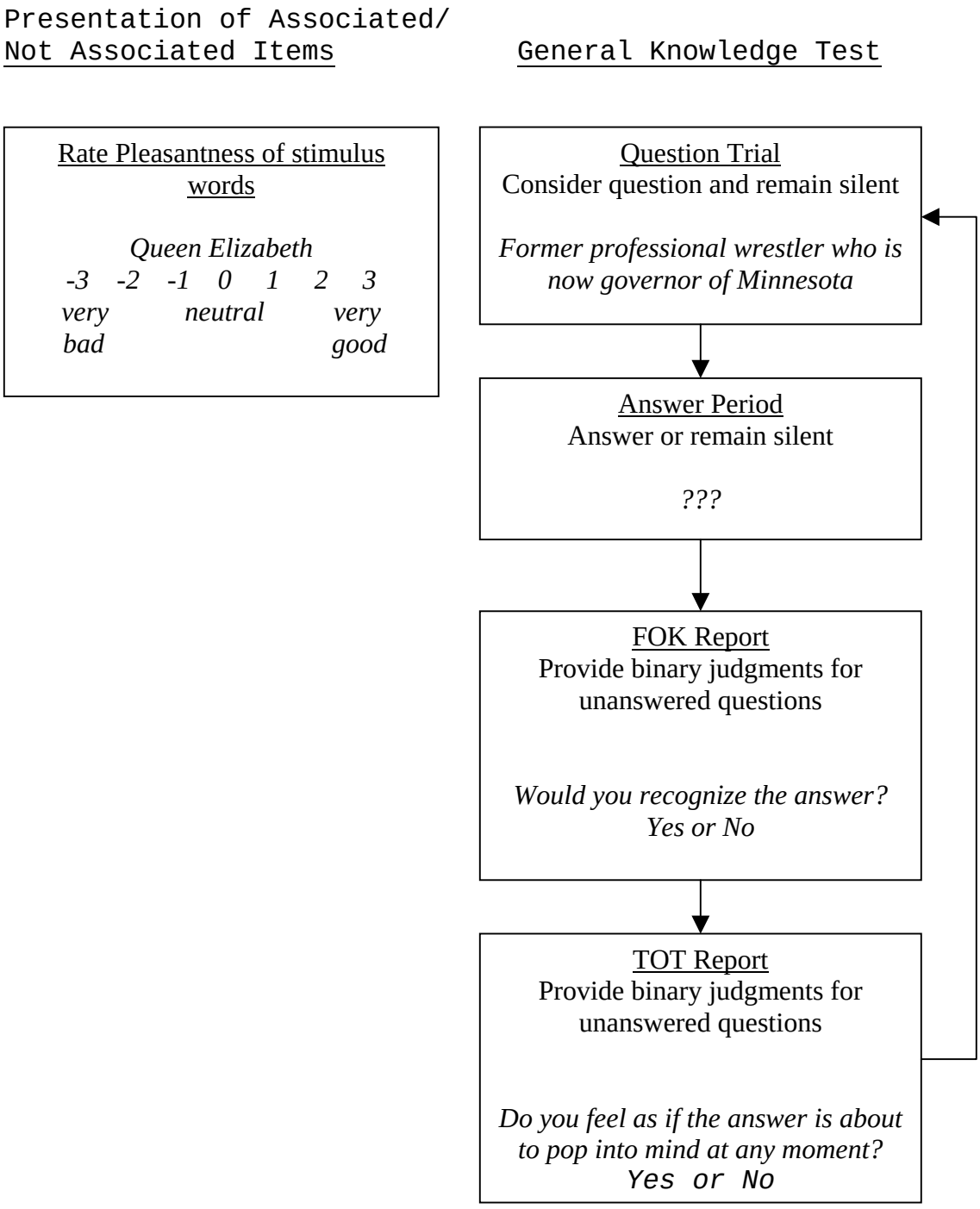
answer. In contrast, they informed students in a low-demand condition that questions had been difficult for 95% of participants to answer. Reporting of TOTs in the high-demand condition was more than twice that in the low-demand condition. This suggested that social pressure may have caused participants to adopt a less stringent criterion for reporting TOT states. The same manipulation did not result in a difference in the frequency of FOK reports, suggesting that demand characteristics did not produce a shift in response criterion for FOK reports. If the reporting of TOTs is vulnerable to demand characteristics, EDA may provide a useful tool for parsing objective TOTs (i.e., those resolved during retest), from illusory TOTs (i.e., those not resolved during retest). By using step-wise regression analyses, we examined the predictive value that would be contributed by adding frequency of SCRs to the metamemory reports. It was expected that the predictive value gained by adding EDA to TOT reports would be greater than that gained by adding EDA to FOK reports, given that Widner et al. found that FOK reports did not appear to be significantly affected by demand characteristics.

The sequence of tasks for Experiment 1 was as follows: 1) Remote Associates Priming Task; 2) Remote Associates

Test (RAT); 3) Word Fragment Priming Task; 4) Word Fragment Test; 5) TOT Priming Task; and, 6) General Knowledge Test. See Figure 1. Although the data collected during the word fragment and remote associates tests were not analyzed for inclusion in the current study, their inclusion in the experimental paradigm was beneficial in that participants gained practice in these first tests with the experimental process (delaying verbal reports, using a motor response to indicate the presence of a cognitive experience, using metacognitive scales). It was expected that this procedural practice would reduce the effort and prospective memory demands of the behaviors requested in the TOT priming task and General Knowldege Test, thereby reducing the risk that the experimental procedures would interfere with the cognitive processes being studied.

A priming task was utilized to increase the probability that participants would experience TOTs during the general knowledge test. Interlopers, also referred to as blockers, are words generated during a TOT state that are semantically or phonologically related to the target word. Research has indicated that presentation of interlopers before or during requests for retrieval of target items results in an increased frequency of TOT

Figure 1. Sequence of Presentation General Knowledge Test.



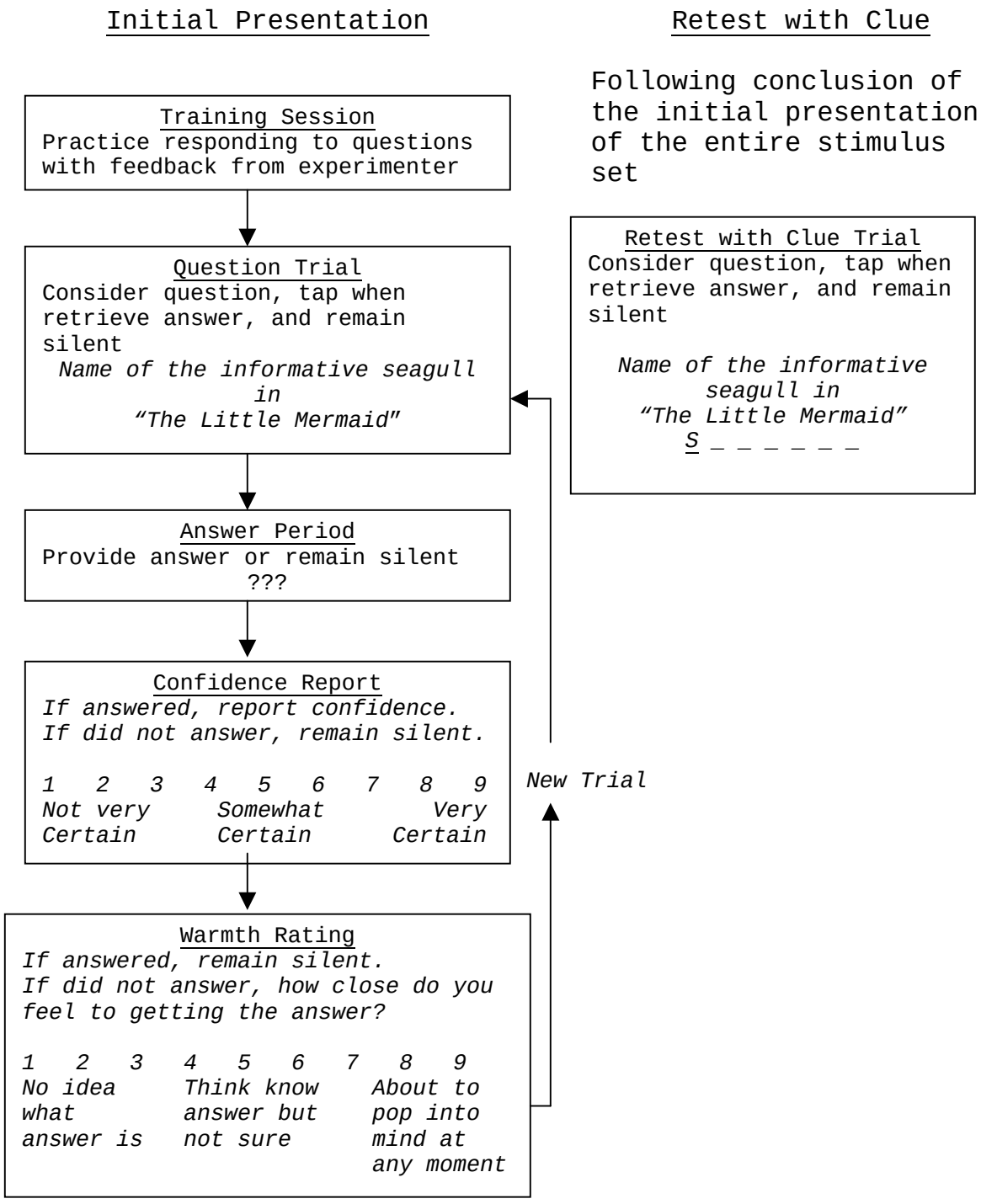
reports (Jones, 1989; Jones & Langford, 1987). The priming task utilized here required participants to assign pleasantness ratings to 28 words and names presented on the screen. Fourteen of these were unrelated to the target items and 14 were items that had been identified during the preliminary study as interlopers for the general knowledge test items. For example, Queen Elizabeth was identified as an interloper for Margaret Thatcher. Presentation of associated items was hypothesized to be positively correlated with SCR frequency and reaction time, and more TOT reports were expected for those items preceded by associated items than non-associated items.

Experiment 2 differed in that the task was not preceded by the Remote Associate Test or Word Fragment Test sessions nor was the general knowledge test preceded by the presentation of interlopers. The procedure was varied in that participants rated their likelihood of resolutions and confidence using scales rather than binary choices. After participants responded to all stimuli, the stimuli were presented a second time and were accompanied by clues. Clues provided were the first letter of the answer, or in cases of names, the first letters of the first and last names, along with blanks to indicate the number of letters

in the answer. For presentation order in Experiment 2, see Figure 2. Numerous studies (Brown & McNeill, 1966; Yarmey, 1973) have found that the first phonemes of targets are accessible at greater than chance levels during TOTs for both rare-word definitions and famous people. Providing the first letter of the target was therefore expected to heighten the response rate for TOTs more so than for targets for which the answers were not known.

To investigate the possibility that the motor response of tapping (to indicate retrieval of answers) may have created a motor artifact that confounded the results, SCRs were compared for three types of responses: 1) Those not answered during either the first presentation or the clue period; 2) Those not answered during the first presentation but then resolved during the clue period; and, 3) Those answered during both presentations. If a motor artifact confounded the electrodermal measurements, similar levels of SCRs should have been present during both the first and second presentations of a question that a participant initially solved, given that motor responses would be present during both presentations. In contrast, if SCRs are indicators of the effort of retrieval, then questions answered correctly the first time should be accompanied by

Figure 2. Sequence of Presentation During Experiment 2.



fewer or no electrodermal responses when presented again during the clue period, given that only a motor response and not retrieval effort would be present during this measurement period.

EXPERIMENT 1

METHOD

Participants

Thirty-three introductory psychology students voluntarily participated in the experiment in partial fulfillment of their course requirements. Data from 1 subject were excluded due to persistent coughing that interfered with the measurement of electrodermal responses. Data from 2 participants were excluded due to failure to follow instructions. Analyses were conducted on data obtained from the remaining thirty participants, whom included 22 men and 8 women. Participants were tested individually in sessions that were approximately 1 1/2 hours, including time required for attachment of physiological recording devices.

Apparatus and Recording Procedure

Skin conductance responses (SCRs) were recorded from the thenar and hypothenar eminences of the left hand. After hands were cleansed and thoroughly dried, Grass 32mm diameter collars and Grass EC33 electrode paste with 0.5% saline in neutral base were used to attach two silver chloride biosensors. An electrode clipped to the left

earlobe served as the ground. Electrical signals from the electrodes were relayed to a Grass Model 8 polygraph, processed by a Coulbourn Instruments bioamplifier, and recorded on a strip chart recorder running at a speed of 10.6 mm/s. Stimuli were presented on a Dell computer monitor with screen size of 16 inches. Participants indicated the moment at which they retrieved answers by tapping a Labtec AM-22 microphone, which transmitted a signal that was also recorded on the strip chart recorder. A Coulbourn bio-system calibrator was utilized.

Using standard procedures (Fridlund & Cacioppo, 1986), biosensors were attached to the left shoulder and forehead to obtain EMG recordings of the trapezius and corrugator supercilii. A photoelectric plethysmograph was attached to the second finger of the left hand to measure heart rate. EMG and heart rate results are not reported in the current paper.

Data Quantification and Analysis

A criterion for the smallest scorable response was established at 0.05 μS (microSiemens), a conservative criterion consistent with common standards (Dawson, Schell, & Fillion, 1990), and necessary due to the pen limitations

of the strip chart recorder. Given the average latency of 1-3 seconds from stimulus onset to the onset of SCR (Dawson, et al.), SCRs were assumed to be elicited by the stimulus if they fell within the latency window between 1 s after stimulus presentation to 1 s after either the taps used to indicate resolution in cases in which answers were offered, or until 1 s after the end of the stimulus presentation in cases in which no answers was offered. For both types of responses, this limited analysis of SCRs to the period during which consideration of the question was assumed to be occurring. Fowles (1988) argued that changes in EDA can be reliably detected within this short period. Adopting the stringent criteria of 1 s rather than 3 s has been recommended as a means of reducing noise in physiological data, such that nonspecific SCRs do not contaminate the measurement of event-related SCRs (Dawson et al).

Materials and Test Procedure

Participants were seated on the opposite side of a moveable dividing wall from the experimenter, amplifier and strip chart recorder. This placement insured that they could see neither the activity of the strip chart recorder nor the experimenter. They were asked to remain quiet

during any answer periods when they were not able to produce an answer or solution. Participants were also asked to avoid moving the hand that the biosensors were attached to (left hands), and to generally try to avoid unnecessary movements.

Items for the General Knowledge Test included landmarks and names of famous people used by Brennan, Baguley, Bright and Bruce (1990) as well as definitions of low-frequency words used by Jones (1989), Perfect and Hanley (1992) and Yaniv and Meyer (1987). Additional stimuli were developed in two preliminary studies in which participants were asked to record TOTs and partial retrieval information during the presentation of clues for proper names. Names used included political figures (Nelson Mandela, Margaret Thatcher) and other persons who had received attention in the popular media during the 10 years prior to the experiment(Ted Kazcynski), as identified by examining a review of the top news stories of that decade (National Geographic Society, 1999). Those items for which participants responded with both moderate TOT rates and moderate correct rates were selected for the experiment. Several items were also selected that had very high correct response rates (Who performed opposite Julia

Roberts in Pretty Woman? Richard Gere) to maintain participant motivation and to ensure that most participants would have at least a few correct responses to allow for comparison to commission and omission errors.

The priming task for the General Knowledge Test was presented as a pleasantness rating task. Twelve of the words used in the task had been identified as effective interlopers for the stimuli words in a study by Balfour (1992), or had been rated by participants in the preliminary study as words highly associated with the targets. For example, Queen Elizabeth was identified as a name highly associated with Margaret Thatcher. The remaining 12 words in the priming task were matched with the targets by stimulus type but were not related. For example, Jane Fonda was included as a match for Evander Holyfield because both are famous names, even though the two were not found in the preliminary studies to be associated. Participants were asked to rate each word or name that appeared on the screen with a number from –3 to +3, -3 indicating items they felt were “very bad”, +3 indicating “very good”, and 0 neutral. The scale was presented on the screen below each presentation stimulus. Participants were instructed to respond to items as they

saw them, rather than waiting until the end of the period. Each stimulus appeared for 5 seconds.

The general knowledge test consisted of 30 questions. Participants were asked to tap as soon as they thought of the answer, to answer aloud when the response screen appeared and then, only for those questions they were not able to answer, to answer “yes” or “no” to two questions that would follow the response period. The first question asked whether the participant would recognize the answer (feeling-of-knowing report), the second whether he/she felt the answer was “about to pop into mind at any moment” (a tip-of-the-tongue report). Each clue was presented for 15 s. Screens requesting the answer and responses to the two questions were each 5 s. Again, a 2 s *ready* screen prepared participants for each clue. Before beginning the task, the experimenter distinguished a feeling-of-knowing state from recall and encouraged the participants not to tap until full recall had occurred. The distinction offered was that a feeling-of-knowing state is present when an individual knows that he possesses the requested information, whereas recall has occurred at the moment when he would be able to verbalize the answer if the experimental setting allowed spontaneous responses.

Participants were given an example in which a biology major sees a question about fish and immediately realize that it is an answer she will recall once she searches her memory. They were instructed, however, that the subject should not tap until the moment when she has completed that search and actually has recalled the answer. This distinction was an effort to minimize premature responding. Upon completion of the General Knowledge Test, biosensors and the photoplethysmograph were removed and participants were debriefed.

RESULTS

A significance level of $p < .05$ was adopted for reported effects in both experiments. All planned comparisons were two-tailed.

Percentages of general knowledge questions that participants answered correctly were calculated, as were those that were answered incorrectly (commission errors). Response periods during which participants were unable produce an answer (omission errors) were further organized into three categories: 1) those accompanied by reports of feeling-of-knowing (FOK), 2) those accompanied by feeling-of-knowing (FOK) *and* tip-of-the-tongue (TOT), and 3) those

for which neither FOK nor TOT was reported. Distribution of these verbal responses is illustrated in Table 1.

Table 1

Verbal Responses in Experiment 1

Correct responses	34%
Incorrect responses	6%
FOK without TOT	19%
FOK with TOT	23%
Answer unknown	18%

One-way analyses of variance (ANOVAs) were used to analyze the effect of associated item presentation in the priming task (associated, not associated) on the number of skin conductance responses per second (RPS). No significant differences were found between epochs preceded by associated and not associated items for either frequency of SCRs, $F(1, 837) = .84$, or average amplitude of SCRs, $F(1,$

576) = 1.78. ANOVAs were also used to examine the effect of associated item presentation (associated, not associated) on reaction time between presentation of questions and participants' indication (by motor response) that they had retrieved the answers. Analysis indicated that participants did not take significantly longer to respond during epochs preceded by associated items than not associated items, $\underline{F}(1, 796) = .75$. A Chi-Square analysis was used to investigate the effect of associated item presentation (associated, not associated) on five possible verbal responses to questions (correct answer; incorrect answer; FOK *and* TOT; FOK, but no TOT; neither FOK nor TOT. This analysis failed to reveal differences in the verbal responses made following associated and unassociated items, $X^2(4, \underline{N} = 798)$.

An ANOVA was used to analyze the effect of FOK presence (FOK present, FOK absent) on frequency of SCRs. Response epochs when participants reported FOKs, regardless of the presence or absence of TOTs, were compared with response epochs when they did not report FOKs (n-FOKs). Results indicated a significant effect of presence of FOK for RPS, $\underline{F}(1, 486) = 10.14$, with higher RPS present when participants reported that they would recognize the answer,

(M=.08, SD=.08) than when they reported that they would not recognize the answer (M=.06, SD=.06). An ANOVA was used to analyze the effect of TOT presence (TOT present, TOT absent) on the frequency of SCRs. Response epochs when participants reported TOTs, regardless of FOK reports, were compared with those when they did not report TOTs (n-TOTs). Results indicated a significant effect of TOT presence for RPS, F(1, 486) = 10.34, with higher RPS during TOT reports, (M=.09, SD=.09) than no-TOT reports, (M=.07, SD=.07).

An ANOVA was used to analyze the effect of resolution (item resolved, item unresolved) on frequency of SCRs (RPS). Response epochs when participants offered answers, regardless of the accuracy of those answers, were compared with those in which they did not offer answers. A significant difference was found, F(1, 796) = 116.60, with more than twice as many RPS being recorded during resolved question periods, (M=.17, SD=.15) than unresolved question periods, (M=.08, SD=.08).

Those questions that participants answered were isolated and ANOVAs were used to analyze the effect of response accuracy (accurate response, inaccurate response) on SCR frequency and response time (time from presentation of stimulus until motor indication of retrieval). Although

a significant difference was not found in RPS, $F(1, 308) = 1.93$, a significant difference was found in the response time of correct versus incorrect responses, $F(1, 308) = 20.88$, with a faster response time for correct responses, ($M = 3.80$, $SD = 3.25$), than for incorrect responses, ($M = 8.10$, $SD = 2.71$). Pearson's correlation coefficient between the RPS and AVEAMP measures was significant, $r(587) = .23$. Partial correlation, controlling for subject, also revealed a significant relationship, $r(575) = .17$

DISCUSSION

Distribution of verbal responses was examined to determine whether the stimulus set had been effective in producing sufficient variability in metamemory states to correlate with physiological responses. Participants reported experiencing TOTs for a mean of 23% of stimuli, with one participant reporting TOTs for only 2 stimuli (6.7%) and another for 14 stimuli (46.7%). This mean is greater than the 13% reported by Brown and McNeill (1966) and the 11% reported by Koriat and Lieblich (1974). The high rate of TOTs may have been the result of the design decision to include mostly questions that had produced high TOT rates in the pilot study and in other experiments. Furthermore, self-presentation demand may be particularly

high when participants are tested individually and responses are reported aloud as was the case in the current study. If this factor caused an inflation in the number of TOTs reported by participants in this experiment, an attenuation in the correlations with the physiological measurements may have occurred. In Experiment 2, a second opportunity to answer questions during a clue session was introduced as an attempt to address this concern by comparing resolved TOTs with those that remained unresolved.

EXPERIMENT 2

METHOD

Participants

Twenty-two introductory psychology students voluntarily participated in the experiment in partial fulfillment of their course requirements. Data from two participants were excluded due to failure to follow instructions. The remaining twenty participants included 14 men and 6 women. Participants were tested individually during 90 minute sessions.

Apparatus and Recording Procedure

Recording procedures and equipment used in Experiment 1 to measure EDA and heart rate were used again in Experiment 2. EMG was not recorded.

Materials and Test Procedure

The procedure used was identical to that in the General Knowledge Test of Experiment 1 in all but four respects: 1) The Word Fragment Test and Remote Associates Test were not used. A substitute for the practice that participants gained during these tests was provided by adding a training session in which the experimenter watched the participants respond to 3 questions and reminded him/her when to tap and how to respond to the metamemory

prompts; 2) Given the apparent inefficacy of the priming task in generating TOTs in Experiment 1, the priming task was not included in Experiment 2; 3) 40 rather than 28 questions were used; and 4) Participants responded to a warmth scale after each stimulus rather than the 2 binary FOK/TOT assessments used in Experiment 1. The experimenter explained, “You will see 2 scales like this [displayed screen] after each clue. If you answer the question, please rate how sure you are of your answer, with a 10 meaning very certain, a 5 meaning somewhat certain, and a 1 meaning not very certain. If you are not able to answer the question, please wait and respond to the next scale. On that scale, please rate how close you feel to getting the answer. A 1 means you have no idea what the answer is, a 5 means you think you know the answer but aren’t sure and a 10 means you feel as if the answer is about to pop into your mind at any moment.” Participants were instructed to respond to the scale as soon as it came up on the screen and were reminded that they would only respond to one of the two scales. The screen was headed with the instruction to respond to the scale if the participant either had or had not answered the question to avoid confusion about when they should respond. The anchor points on the scale were

clearly labeled. As in Experiment 1, stimuli were presented for 15 seconds and were followed by a 5 second reporting period. Each scale was presented for 8 seconds. A 2 second “ready” screen was presented before each stimulus.

Immediately following the General Knowledge Test, participants were given a retest that included clue presentations. Presented on the screen for 15 seconds were the questions accompanied by the first letter of the answer and blank spaces to indicate the number of letters in the answer. For example, appearing below the question ‘The medieval forerunner of chemistry’ was the clue ‘A_ _ _ _ _ _’ as a clue to the answer ‘alchemy’. Those answers that included two words, such as names, included the first letters of each word or name. As in the first presentation, participants were instructed that they would have 15 seconds to consider the question and that they should tap the microphone at the moment the answer occurred to them, then wait to report until the prompt screen. Participants were not asked to make metamemory reports during the retest session.

RESULTS

Analysis failed to reveal a significant correlation between RPS and confidence in correct answers $r(346) = .09$ or incorrect answers $r(29) = .30$. A significant correlation was found between warmth ratings and RPS for questions for which no answer was offered $r(394) = .08$. A significant negative correlation was found between response time and confidence for those items answered $r(394)=-.54$, $p<.01$, indicating that participants more quickly resolved items for which they reported more confidence in their answers than those items for which they reported less confidence in their answers.

Questions not answered during the first presentation period were isolated and regression analyses were conducted to determine whether resolution during the clue presentation was reliably predicted by either warmth ratings or SCR frequency during the first presentation. Step-wise regression analyses were used to examine the variance in resolution uniquely accounted for by each of these factors, as well as their predictive value when combined. Results indicated that average amplitude of SCRs did not predict response during the clue period ($\beta=.025$),

however both RPS (β =.18, p<.001) and the metacognitive reports (β =.35, p<.001) did predict resolution. Stepwise regression analysis indicated that RPS and metacognitive reports accounted uniquely for 3%, (β = .03, p<.001), and 12%, (β =.12, p<.001), of the variance respectively, with the two measures combined most reliably predicting resolution, (β =.14, p<.001). Regression anyalyses were conducted on data contributed by each participant individually, to identify whether the predictive value of EDA varied between subjects. Analysis revealed significant prediction of EDR for recall during retest for only one subject, (β .45, p<.o1).

A comparison was made between three types of responses: those not answered during either the first presentation or the clue period, those not answered during the first presentation but then resolved during the clue period, and those answered during both presentations. A significant simple effect for RPS between presentation time, F(1, 222) = 45.89, p<.001, was found for responses that participants failed to answer during either period, with more than twice as many SCRs being recorded during the first response period, (M=.06, SD=.07) than during the clue

period, (M=.03, SD=.05. Among responses that were answered during the clue session after having been missed during the first presentation, a small but significant increase in RPS was observed, F(1, 137) = 9.96, p<.01, with a mean during the second presentation (M = 0.14, SD = 0.16) slightly larger than during the first presentation (M=.10, SD=.08). Analysis of the third group of responses, those answered during both presentations, indicated that significantly fewer RPS were present during the second presentation, (M=.14, SD=.24) than during the first presentation (M=.23, SD=.32), F(1,376) = 25.37, p<.001.

DISCUSSION

Metacognitive reports offered by participants when they were unable to answer during the first presentation of stimuli were reliable predictors (β =.35) of responses during the subsequent clue period, indicating that participants were fairly accurate in judging their knowledge.

Comparison of the EDA during the first and second presentations of questions that participants initially solved revealed that no significant artifact was present from the motor activity required during the task. The

lower RPS during the second presentation of questions that were not answered either time may indicate that participants did not persist in their resolution efforts. Slightly more RPS were recorded during the clue periods for questions answered for the first time during the clue period than for questions answered during both the initial presentation and again during the clue period. Although a larger difference may have been expected in these two response periods, this may indicate that the resolution of some of these questions may have occurred during the interim between presentations rather than during the actual clue period. Finally, the lower RPS during the clue period of those questions initially solved supports that the pattern of SCR reported in the current paper was due to psychological factors rather than motor artifact.

Inferences drawn from the second experiment should be interpreted with caution given that the period that was allowed for resolution between the first and second presentations was no more than 25 minutes for any question, with resolution for some items being even less depending on their placement within the initial and clue presentation sessions. Given that resolution of TOT targets may occur several minutes to several days after initial recall

failure, participants in the current study may not have been allowed sufficient time to demonstrate their knowledge. Numerous studies have demonstrated the broad range of resolution times for TOTs. Approximately 50% of targets are retrieved in the first 1 to 2 minutes following TOTs (Burke, MacKay, Worthley, & Wade, 1991; Gruneberg, Smith, & Winfrow, 1973; Yarmey, 1973). However, retrieval remains likely for several days following initial failure to retrieve the target of a TOT. Read and Bruce (1982) found that 74% of initially unresolved TOTs were resolved in the 2 days following their occurrence; Burke et al. found that 96% of naturally occurring TOTs were eventually resolved. Therefore, although a clue for each stimulus was provided to promote recovery, failure to provide answers for items identified by subjects as TOTs may indicate insufficient resolution time rather than the occurrence of a false alarm in identifying a TOT. If the resolution period allowed was insufficient, the estimated relationship between the physiological and metamemory measures may have been attenuated. Future studies may probe this possibility by allowing longer resolution periods, or by using a diary method following the initial laboratory presentation to investigate the relationship

between arousal and metacognitive judgments in these later retrievals.

GENERAL DISCUSSION AND CONCLUSIONS

Results indicated metamemory reports were a strong predictor of resolution. In Experiment 2, warmth ratings made by participants during the first presentation of targets which they were unable to answer predicted subsequent retrieval of the target during the retest session. The predictive value of metamemory reports in the current study is an encouragement that when this measurement approach is more practical than a physiological approach, and when an intrusive measurement does not cause interference in the cognitive process being studied, metamemory reports are likely to be a useful and valid means of assessing knowledge.

Results indicated that frequency of SCRs was correlated with metamemory reports, with higher frequency of SCRs during reports of tip-of-the-tongue as well as during reports of feeling-of-knowing. A positive correlation was also found between SCR frequency and warmth ratings. This suggests that EDA may be an effective on-line, non-intrusive measurement of metamemory. Furthermore, results obtained by retesting with clues in Experiment 2 indicated that EDA was predictive of resolution, a finding that brings some encouragement that

this method may provide a means of separating real and illusory TOTs and in so doing reduce the interference of demand characteristics on the empirical study of retrieval.

Despite that these experiments demonstrated that EDA was significantly correlated with metamemory reports and that EDA was a significant predictor of clued resolution, the modest sizes of these effects are concerning. Whereas warmth rating accounted uniquely for 12% of variance in response during retest, EDA accounted uniquely for only 3% of variance. Although the significant correlations discovered between electrodermal activity and both TOT and FOK reports are of theoretical interest, the effect sizes cause concern as to the practical contribution that this physiological measurement offers.

Several factors may have contributed to an attenuation of the effects and should be considered in determining the value of continuing to pursue EDA as a tool for measuring retrieval. First, the current study utilized manual measurement of strip chart recordings, rather than digital recordings. Numerous aspects of EDA can be measured in addition to SCR frequency and amplitude, including SCR latency, rise time, recovery time, and magnitude. Correlations among these components are not high, generally

less than .5 (Dawson, Schell & Filion, 1990). Specific components have been identified as correlates with different psychological phenomenon. This raises concern that measurement of only two components of EDA may not have been adequate in investigating a possible relationship between EDA and the psychological phenomena of interest. Indeed, the current study found significant results using frequency, but not amplitude of SCRs. To more fully explore possible patterns in EDA during retrieval, digital recording of EDA would be most practical, allowing for analysis of more components of EDA and of a larger volume of data. An additional concern regarding the utilization of manual measurements of strip chart recordings is described by Boucsein (1992). He explains that the wide range of the EDA signal is problematic for such measurement given that if the experimenter uses high amplifier gain, large SCRs will exceed the upper limit and such data will be lost, whereas with lower amplification small SCRs will not be identifiable and data will be lost. The current study varied amplification during preparation with each participant to meet the range estimated to be most appropriate for that individual. Despite this adjustement, some responses exceeded the upper limit and others were not

captured due to inadequate amplification. Additionally, due to pen limitations of the strip chart recorder, the criterion for a scorable SCR was established at 0.05 μS (microSiemens), a stringent criteria given that SCRs range from .01 to 5 μS (Venables & Christie, 1973). Digital recording with the capacity to examine a broader range of SCR amplitudes may be worthwhile in pursuing the utility of EDA as a measure of retrieval processes.

A second problematic factor in the current study was that the paradigm imposed a temporal limit on retrieval. This restriction may have interfered with the function of impasse and thereby attenuated the relationship between heightened arousal during impasse and subsequent retrieval. Participants were allowed 15 seconds to consider a test item. At the end of that period, they were asked to assess whether they were experiencing a TOT and then were instructed to move on to the next test item. Consideration of the opportunistic-assimilation hypothesis offered by Seifert et al. (1995), suggests that interrupting participants during their retrieval attempt may have interfered with the effect of physiological arousal on TOT resolution during retest. Seifert and her colleagues

suggested that information-processing attempts that end in impasses generate failure indices in long-term memory. These indices guide later return to elements of the unresolved problem, increasing the probability that resolution will be reached. The authors suggest that interrupting an experimental subject during an attempt to reach a resolution, rather than allowing him to reach full impasse, may interfere with the process of forming failure indices and thereby reduce the probability of later resolution. If so, the method in the study reported here may have interfered with the very process it sought to examine. Future research could address this potential flaw by allowing participants to consider questions until they determine that they have reached impasse.

A final concern from the current study that may warrant further investigation was the informal observation that SCRs were of the greatest amplitude when subjects failed to recall items that were particularly important to them and for which they felt embarrassment and frustration during the failure, as identified by discussion between the experimenter and participants after the experimental sessions was concluded. For example, failure to recall a movie director who had directed several of one’s favorite

films, and facts elementary to one's college major were failures associated with more marked EDA responses. This raises questions as to whether there may be different EDA patterns during those TOT states that are identified as unimportant to the individual and those TOT states when recall failure is perceived as detrimental, as may be the case of failing to remember a key term during a lecture. This observation suggests that emotionality ratings of TOTs may have been more highly correlated with EDA measures than were the strength and imminence features used to subclassify TOT states in the current study. Studies examining the predictive value of emotionality have yielded mixed results. Schwartz, Travis, Castro, and Smith (2000), using an experimental methodology, found that emotionality of TOTs was more predictive of recognition and later resolution than imminence or strength. In contrast, Schwartz (2002), using a diary method to investigate naturally-occurring TOTs, found that emotionality was actually associated with failure to resolve TOTs. Alternatively, these failures may have been distinctive in that they were related to greater effort, or cognitive load, in which case heightened EDA would confirm Beatty's (1982) findings that greater processing load was associated

with greater pupil dilation. Further EDA study including emotionality and effort ratings may be useful in investigating whether this informal observation reflected an idiosyncrasy of the participants in the current study or a key component of the TOT phenomenon.

Results of the two experiments in this study indicated a positive correlation between frequency of electrodermal responses and metacognitive reports, and significant predition of resolution by electrodermal responses. Although the small effect sizes observed may indicate that this measure will not be an efficient means of examining TOTs, the small effect sizes may also have been the result of correctable limitations and flaws in the study. Studies that have used fMRI and pupillometry to examine retrieval strongly indicate that EDA may systematically vary during stages of TOT, and encourage the authors that further pursuit of this method may be fruitful. With refinement of the experimental approach, EDA may be an effective means of inexpensively monitoring retrieval processes on-line without interfering with the cognitive processes under investigation.

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APPENDIX A

EXPERIMENT 1 GENERAL KNOWLEDGE TEST ITEMS

Answers appear in parentheses below the questions. If a distractor associate was used in the priming task, the distractor appears within the parentheses after the answer.

Former professional wrestler who is now governor of Minnesota

(Jesse Ventura)

In a Disney film, the actress who played the musical governess of the VonTrapp children

(Julie Andrews)

The mountainside in the Black Hills of South Dakota that has been sculpted

(Mount Rushmore/ Mount Everest)

The medieval forerunner of chemistry

(alchemy)

Woman who served as Britain’s Prime Minister for 11 years

(Margaret Thatcher/ Queen Elizabeth)

Actor who played opposite Julia Roberts in “Pretty Woman”

(Richard Gere)

Woman convicted of killing her 2 children by rolling a car carrying them into a lake

(Susan Smith)

A mixture of metals, usually one of higher quality with a poorer one

(alloy/ compound)

Famous tennis player who died of AIDS in 1993

(Arthur Ashe/ Andre Agassi)

High school teacher killed in the Challenger space shuttle explosion

(Christa McAuliffe)

Actress who played the mother of Forrest Gump

(Sally Field/ Susan Sarandon)

Expert in children’s diseases

(pediatrician)

Name of the informative seagull in “The Little Mermaid”

(Scuttle/ Sebastian)

A person overly concerned about their health

(hypochondriac/ hysteria)

Florence’s most famous statue, sculpted by Michelangelo

(Statue of David)

To search for provisions

(forage)

A goblet or wine cup, used especially in church for communion

(chalice)

Sediment deposited by a river or other running water

(silt/ sand)

The marble building in Italy that will fall over by the year 2020, it is said

(Leaning Tower of Pisa)

False testimony under oath

(perjury/ lying)

Former employee of Clarence Thomas who accused him of sexual harassment

(Anita Hill/ Paula Jones)

Criminal played by Anthony Hopkins in “Silence of the Lambs”

(Hannibal the Cannibal)

Impenetrable by light

(opaque/ diffraction)

France’s largest archway, located in Paris

(Arc de Triomphe/ Eiffel Tower)

Name of the Unibomber

(Ted Kazcynski)

Actress who played the flight instructor and love interest of Tom Cruise’s character in Top Gun

(Kelly McGillis/ Nicole Kidman)

Branch of zoology dealing with birds

(ornithology)

This actor is best known as Captain James T. Kirk

(William Shatner/ Jean luc Picard)

APPENDIX B

EXPERIMENT 2 GENERAL KNOWLEDGE TEST ITEMS

Former professional wrestler who is now governor of Minnesota

(Jesse Ventura)

To heat milk below its boiling point to kill bacteria

(pasteurize)

In a Disney film, the actress who played the musical governess of the VonTrapp children

(Julie Andrews)

The mountainside in the Black Hills of South Dakota that has been sculpted

(Mount Rushmore)

The medieval forerunner of chemistry

(alchemy)

Woman who served as Britain’s Prime Minister for 11 years

(Margaret Thatcher)

A person who does not practice what he preaches

(hypochondriac)

Actor who played opposite Julia Roberts in “Pretty Woman”

(Richard Gere)

A type of animal that feeds off the flesh of dead animals

(scavenger)

Woman convicted of killing her 2 children by rolling a car carrying them into a lake

(Susan Smith)

A mixture of metals, usually one of higher quality with a poorer one

(alloy)

Famous tennis player who died of AIDS in 1993

(Arthur Ashe)

A famous piece of rock in Ireland that is said to bring good luck to those who kiss it

(Blarney Stone)

High school teacher killed in the Challenger space shuttle explosion

(Christa Christa McAuliffe)

Actress who played the mother of Forrest Gump

(Sally Field)

Field of medicine specializing in children’s diseases

(pediatrician)

A light and strong wood used in modeling

(balsa)

Washington, D. C. mayor arrested for smoking crack

(Marion Barry)

Name of the informative seagull in “The Little Mermaid”

(Scuttle)

A person overly concerned about their health

(hypochondriac)

Writer and director of “Pulp Fiction”

(Quentin Tarantino)

Florence’s most famous statue, sculpted by Michelangelo

(Statue of David)

The escape of blood from vessels, including internal as well as external bleeding

(hemorrhage)

Voluntarily refraining from indulgence

(abstinence)

Sediment deposited by a river or other running water

(silt)

The marble building in Italy that will fall over by the year 2020, it is said

(Leaning Tower of Pisa)

False testimony under oath

(perjury)

Former employee of Clarence Thomas who accused him of sexual harassment

(Anita Hill)

Criminal played by Anthony Hopkins in “Silence of the Lambs”

(Hannibal the Cannibal)

Impenetrable by light

(opaque)

After 27 years of imprisonment, he was elected President of South Africa

(Nelson Mandela)

France’s largest archway, located in Paris

(Arc de Triomphe)

Boxer whose ear was bitten off by Mike Tyson

(Evander Holyfield)

A famous ancient temple overlooking Athens

(Parthenon)

Name of the Unibomber

(Ted Kazcynski)

Actress who played the flight instructor and love interest of Tom Cruise’s character in Top Gun

(Kelly McGillis)

To keep eggs warm until they hatch

(incubate)

Branch of zoology dealing with birds

(ornithology)

This actor is best known as Captain James T. Kirk

(William Shatner)

Ship that wrecked off the coast of Alaska in 1989, contaminating the shoreline with oil

(Exxon Valdez)

APPENDIX C

EXPERIMENT 2 GENERAL KNOWLEDGE CLUES

Former professional wrestler who is now governor of Minnesota

J_ _ _ _ V_ _ _ _ _ _

To heat milk below its boiling point to kill bacteria

P_ _ _ _ _ _ _ _ _

In a Disney film, the actress who played the musical governess of the VonTrapp children

J_ _ _ _ A _ _ _ _ _ _

The mountainside in the Black Hills of South Dakota that has been sculpted

M_ R_ _ _ _ _ _ _

The medieval forerunner of chemistry

A_ _ _ _ _ _

Woman who served as Britain’s Prime Minister for 11 years

M_ _ _ _ _ _ _ T _ _ _ _ _ _ _

A person who does not practice what he/she preaches

H _ _ _ _ _ _ _ _

Actor who played opposite Julia Roberts in “Pretty Woman”

R _ _ _ _ _ _ G _ _ _

A type of animal that feeds off the flesh of dead animals

S_ _ _ _ _ _ _

Woman convicted of killing her 2 children by rolling a car carrying them into a lake

S _ _ _ _ S _ _ _ _

A mixture of metals, usually one of higher quality with a poorer one

A _ _ _ _

Famous tennis player who died of AIDS in 1993

A _ _ _ _ _ A _ _ _

A famous piece of rock in Ireland that is said to bring good luck to those who kiss it

B _ _ _ _ _ _ S _ _ _ _

High school teacher killed in the Challenger space shuttle explosion

C _ _ _ _ _ _ M _ _ _ _ _ _ _ _

Actress who played the mother of Forrest Gump

S _ _ _ _ F _ _ _ _

Field of medicine specializing in children’s diseases

P _ _ _ _ _ _ _ _ _

A light and strong wood used in modeling

B _ _ _ _

Washington, D. C. mayor arrested for smoking crack

M _ _ _ _ _ B _ _ _ _

Name of the informative seagull in “The Little Mermaid”

S _ _ _ _ _ _

A person overly concerned about their health

H _ _ _ _ _ _ _ _ _ _ _ _ _

Writer and director of “Pulp Fiction”

Q _ _ _ _ _ _ T _ _ _ _ _ _ _ _

Florence’s most famous statue, sculpted by Michelangelo

D _ _ _ _

The escape of blood from vessels, including internal as well as external bleeding

H _ _ _ _ _ _ _ _ _

Voluntarily refraining from indulgence

A _ _ _ _ _ _ _ _ _

Sediment deposited by a river or other running water

S _ _ _

The marble building in Italy that will fall over by the year 2020,

it is said

L _ _ _ _ _ _ T _ _ _ _ _ _ P _ _ _

False testimony under oath

P _ _ _ _ _ _

Former employee of Clarence Thomas who accused him of sexual harassment

A _ _ _ _ H _ _ _

Criminal played by Anthony Hopkins in “Silence of the Lambs”

H _ _ _ _ _ _ _ L _ _ _ _ _

Impenetrable by light

O _ _ _ _ _

After 27 years of imprisonment, he was elected President of South Africa

N _ _ _ _ _ M _ _ _ _ _ _

France’s largest archway, located in Paris

A _ _ _ _ T _ _ _ _ _ _ _

Boxer whose ear was bitten off by Mike Tyson

E _ _ _ _ _ _ H _ _ _ _ _ _ _ _

A famous ancient temple overlooking Athens

P _ _ _ _ _ _ _ _

Name of the Unibomber

T_ _ K _ _ _ _ _ _ _ _

Actress who played the flight instructor and love interest of Tom Cruise’s character in Top Gun

K _ _ _ _ M _ _ _ _ _ _

To keep eggs warm until they hatch

I _ _ _ _ _ _ _

Branch of zoology dealing with birds

O _ _ _ _ _ _ _ _ _

This actor is best known as Captain James T. Kirk

W _ _ _ _ _ _ S _ _ _ _ _ _

Ship that wrecked off the coast of Alaska in 1989,

contaminating the shoreline with oil

E _ _ _ _ V _ _ _ _ _

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