6-2019

Neurological Correlates of the Dunning-Kruger Effect

Alana Lauren Muller
California State University - San Bernardino, 005773335@coyote.csusb.edu

Recommended Citation

Muller, Alana Lauren, "Neurological Correlates of the Dunning-Kruger Effect" (2019). *Electronic Theses, Projects, and Dissertations*. 810.
https://scholarworks.lib.csusb.edu/etd/810

NEUROLOGICAL CORRELATES OF THE DUNNING-KRUGER EFFECT

A Thesis

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

in

Psychological Science

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by

Alana Lauren Muller

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Approved by:

Richard Addante, Committee Chair, Psychology

John Clapper, Committee Member, Psychology

Donna Garcia, Committee Member, Psychology

ABSTRACT

The Dunning-Kruger Effect is a metacognitive phenomenon in which individuals who perform poorly on a task believe they performed well, whereas individuals who performed very well believe their performance was only average. To date, this effect has only been investigated in the context of performance on mathematical, logical, or lexical tasks, but has yet to be explored for its generalizability in episodic memory task performance. We used a novel method to elicit the Dunning-Kruger Effect via a memory test of item and source recognition confidence. Participants studied 4 lists of words and were asked to make a simple decision about the words (source memory, i.e. Is it manmade? Is it alive?). They were later tested on their episodic memory and source memory for the words using a five-point recognition confidence scale, while electroencephalography (EEG) was recorded. After the test, participants were asked to estimate the percentile in which they performed compared to other students. Participants were separated into four quartiles based on their performance accuracy. Results showed that participants in all four groups estimated the same percentile for their performance. Participants in the bottom 25th percentile overestimated their percentile the most, while participants in the top 75th percentile slightly under-estimated their percentile, exhibiting the DKE and extending its phenomenon into studies of episodic memory. Groups were then re-categorized into participants that over-estimated, correctly estimated, and under-estimated their percentile estimate. Over-estimators responded significantly faster than under-estimators when estimating themselves as in the top percentile and they responded slower when evaluating themselves as in the bottom percentile. EEG first revealed generic scalp-wide differences within-subjects for all memory judgments as compared to all self-estimates of metacognition, indicating an effective sensitivity to task differences. More specific differences in late parietal sites were evident between high percentile estimates and low percentile estimates. Between-group differences were evident between over-estimators and under-estimators when collapsing across all Dunning-Kruger responses, which revealed a larger late parietal component (LPC) associated with recollection-based processing in under-estimators compared to those of over-estimators when assessing their memory judgements. These findings suggest that over- and under-estimators use differing cognitive strategies when assessing their performance and that under-estimators use less recollection when remembering episodic items, thereby revealing that episodic memory processes are playing a contributory role in the metacognitive judgments of illusory superiority that are characterized by the Dunning-Kruger Effect.

ACKNOWLEDGEMENTS

Several influential individuals should be acknowledged for their hard work and dedication on this thesis. I would like to thank my thesis committee for their impactful feedback and contributions to this project: Dr. Donna Garcia, Dr. John Clapper, and Dr. Richard Addante: Their guidance was crucial to my success.

I would also like to thank everyone in the CSUSB Cognitive Neuroscience Lab who helped collect EEG data, clean the equipment, and analyze the data: Lindsey Sirianni, Rose De Kock, Celene Gonzalez, Yoselin Canizalez, Roman Lopez, Constance Greenwood, Raechel Marino, Maynori Hinton, Kevin Benitez, Fitria Jong Martinez, Alex Burton, and Vanessa Garcia. Lindsey Sirianni deserves an extra special thank you for being the driving force behind much of the programming for all the experiments in the lab. We used her programming knowledge to learn how to code and adapt the code for each of our projects

The Office of Student Research, Office of Graduate Studies, and ASI at CSUSB have all generously contributed to supporting this project; their funding to conduct research, travel to conferences, and develop my presentation skills with this research is very much appreciated.

My family also deserves huge acknowledgement. Thank you to Emmanuel Chue, Deborah Hashimoto, Mike Muller, Cameron Yang, Lisa Muller, Mitsuko Nagaishi, Robert Nagaishi, and Gene Hashimoto for always being supportive of my academic pursuits and for instilling in me a love of learning.

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CHAPTER ONE

LITERATURE REVIEW

"…it is likely that neither of us knows anything worthwhile, but he thinks he knows something when he does not, whereas when I do not know, neither do I think I know; so I am likely to be wiser than he to this small extent, that I do not think I know what I do not know."

– Socrates from Apology by Plato, 21d

Background

Everyone has their respective strengths and weaknesses, and even the most competent expert on a given task is a relative novice on another. One's expertise is largely based upon experience and training but generalizing experiences to unfamiliar tasks can elicit overconfidence on one's performance. Overconfidence in one's skills is a common phenomenon that can happen to anyone in varying situations and can lead to an array of problems.

Overconfidence has been a topic of interest throughout recorded history as early as the time of Confucius, who said, "When you know a thing, to hold that you know it; and when you do not know a thing, to allow that you do not know it; - this is knowledge." (Confucius, trans. 1938/500). Since then, other prominent figures in history such as Shakespeare have also identified this metacognitive illusion of overconfidence ("The fool doth think he is wise, but the wise man knows himself to be a fool”) (Shakespeare, 1998/1601, 5.1.2217-2219), and Charles Darwin noted that “Ignorance more frequently begets confidence than does knowledge” (Darwin, 2009/1871). Believing oneself to possess skills or performance that one does not have is the essence of the illusory superiority bias. A corollary implied by these observations is that metacognitive illusions are bi-directional, such that more situationally-competent individuals tend to also be under-confident in estimating their respective abilities or performance. Metacognitive illusions of both overconfidence and under-confidence will be examined in the current proposal.

The consequences of exhibiting overconfidence can range from inconsequential to disastrous. Occasionally, overconfidence can be relatively harmless (though perhaps at times embarrassing), such as discovering a teammate’s lack of competence in a group project and helping them finish the work together. At other times, the consequences are devastating, such as the sinking of the Titanic. Many factors contributed to this tragic event, but a significant factor was the overconfidence of the Titanic’s manufacturers and captain that the ship was practically unsinkable; this overconfidence led down a path claiming over 1500 lives (Bartlett, 2012; Lord, 1955; Lord, 1986). Although dire consequences of overconfidence may not occur frequently, being overconfident in one’s abilities is a cognition experienced by all people at one time or another, and it is wise to minimize such illusions. It is, therefore, important to understand both how these judgments of overconfidence occur and why they occur, so that strategies can be devised to help overcome them.

Empirical studies about overconfidence have been conducted for decades. One of the earliest studies of overconfidence was conducted by (Adams & Adams, 1960) who found that participants' confidence in their ability to recognize correctly spelled words was higher than their actual accuracy at the task. Five years later, Oskamp (1965) found that when clinical psychologists were asked to make a diagnosis for a case study, their confidence in their decision increased when they were given more information about the case although their accuracy did not increase. These instances showed that confidence and accuracy were not necessarily correlated in both experimental studies and in more practical issues of clinical diagnoses – a finding that has persisted in modern research on memory as well (Hirst et al., 2015; Kvavilashvili, Mirani, Schlagman, Foley, & Kornbrot, 2009), which will be discussed below.

Throughout the years, overconfidence as a field continued to be studied in many different contexts such as social situations (Dunning, Griffin, Milojkovic, & Ross, 1990; Vallone, Griffin, Lin, & Ross, 1990), tasks of differing degrees of difficulty (Bradley, 1981; Lichtenstein & Fischhoff, 1977; Sen & Boe, 1991), and ways to reduce overconfidence (Arkes, Christensen, Lai, & Blumer, 1987; Zechmeister, Rusch, & Markell, 1986). In this research, there was a common finding of overconfidence in wrong answers (Fischhoff, Slovic, & Lichtenstein, 1977; Harvey, 1990; Howell, 1971; Lichtenstein & Fischhoff, 1977; May, 1986) and a less common finding of under-confident correct answers or top performers (Sieber, 1979) as the focus of the research at that time was not the high performers. The term “overconfidence effect” developed to describe this pattern of higher self-estimates of confidence than ability. Throughout this period, though, theoretical frameworks to account for these metacognitive illusions remained relatively sparse.

In 1999, the relationship between of over and under-confidence was further characterized by David Dunning and Justin Kruger, who explored combining the two effects under one term. In a landmark study, Dunning and Kruger conducted several studies showing that bottom performers on a logical reasoning task overestimated their task performance scores and that, conversely, top performers underestimated their task performance scores. The name “The Dunning-Kruger Effect” (DKE) became highly popularized throughout mainstream culture and society.

Generically, the DKE describes a phenomenon in which self-estimates of performance on a task and percentile ranking among others also participating in the task do not match performance accuracy and actual rank respectively. The direction of this mis-match of self-perception extends in both directions (Sieber, 1979). More specifically, the DKE describes the phenomenon in which poor performers on a task tend to overestimate their performance while high performers on a task tend to underestimate their performance, but the cognitive processes, which lead to these illusory experiences, have yet to be fully explored or understood. The goal of the current proposal is to further investigate the DKE by taking physiological measurements of metacognitive judgments at the time that DKE estimates are made, as well as to explore group-level differences in physiology during the task itself (a cognitive test of memory, see methods) to investigate differences in neural activity for performance which may account, among over and under estimators. The goal is to provide novel insight into the cognitive factors that may underlie this pervasive effect of illusory metacognition. These aims will be accomplished using electroencephalography (EEG) to record neural activity occurring at the scalp during performance on both an episodic memory task and during the estimation judgment about performance on the task. This endeavor represents a novel paradigmatic method we have developed for measuring the DKE and provides an opportunity to gain a deeper understanding of the neurocognitive processes underlying it.

The Dunning-Kruger Effect

The DKE is a psychological phenomenon described by a mismatch in one’s perceived ability and the reality of one’s objective performance on a given task, and this appears to be directionally moderated by the factor of ability. Low performers (individuals who do not earn high scores on a test using an objective scale) tend to overestimate their performance on a task while high performers (individuals who earn high scores measured on an objective scale) tend to underestimate their performance on the same task. This miscalibration is most often measured using two different questions. The first type of question asks participants to estimate their score using an objective scale (objective performance estimate). The second type of question tends to ask participants to estimate the percentile in which they rank in relation to other students/group of individuals participating in the experiment (relative performance estimate).

Researchers of the DKE generally find that low performers tend to overestimate their objective performance on a task, which then inflates their subsequent relative performance estimate (Adams & Adams, 1960; Burson, Larrick, & Klayman, 2006; Ehrlinger & Dunning, 2003; Kruger & Dunning, 1999; Oskamp, 1965; Pennycook, Ross, Koehler, & Fugelsang, 2017; Ryvkin, Krajč, & Ortmann, 2012a; C. Sanchez & Dunning, 2018). However, there are some different findings about high performers. Dunning and Kruger (1999) found that high performers tend to accurately judge their objective score on a task but underestimate their relative performance score. They argue that low performers’ and high performers’ estimates of their objective score should be rather different. Even though low performers judge their raw score to be higher than it is, their estimates are not as high as the high performers’ estimates. Because high performers perform much better on the task than low performers and they tend to estimate their score accurately, their estimates are above even the inflated estimates of the low performers. However, other studies have found that high performers still underestimate their objective score rather than gauging their score accurately (Burson et al., 2006; Pennycook et al., 2017; Schlösser, Dunning, Johnson, & Kruger, 2013) which does not fit Dunning and Kruger's explanation for high performers' metacognitive errors. Currently, this discrepancy has not been resolved.

Nevertheless, both low and high performers should have similar relative estimates of performance. Because high performers underestimate their relative score, their estimates decrease and become closer to the low performers' inflated relative estimates. Measuring the relative estimate should provide the largest difference between estimated performance and objective rank for both high and low performers. This measurement of difference between estimates and accuracy will provide the critical measure of the DKE in the current study and is why the current proposal will focus on relative performance estimates.

Most of the paradigms used to research the DKE in the extant literature follow a similar format: participants are given a task such as a series of logical reasoning problems or math problems, etc., and after they finish the task in its entirety, they are asked to estimate their overall objective score on the task itself and/or their relative performance. Thus, the data point for their metacognitive judgment is a single data point assessed at the conclusion of the study and it represents their aggregated assessment of performance across a great many of trial instances. Empirically, this paradigm has been used successfully in many different situations to elicit the DKE on such tasks as knowledge of microeconomics material on a midterm and final (Ryvkin, Krajč, & Ortmann, 2012b), knowledge about the University of Chicago (Burson et al., 2006), ability to identify humorous jokes (Kruger & Dunning, 1999), logical reasoning (Schlösser et al., 2013), cognitive reflection (Pennycook et al., 2017), size judgments (Sanchez, 2016), finance (Atir, Rosenzweig, & Dunning, 2015), and computer programming (Critcher & Dunning, 2009). More broadly, the effect has been obtained in popular culture contexts of driving (Svenson, 1981) and professors rating their own teaching skills (Cross, 1977).

Variations to the Classic Dunning-Kruger Effect Paradigm

There have been some deviations from this basic paradigm structure that have also elicited a similar effect. Simons (2013) used a priori estimates instead of the traditional post hoc estimates by asking participants to play several card games of Bridge and to predict each game's outcome in point value before the game had begun. Simons found that low performing players overestimated their point value consistently. However, higher performing players also overestimated their point value, though not as much as low performers. This experiment showed some characteristics of the DKE but differed critically in the placement of the DKE estimate questions, which came before completing the card game, whereas typical DKE research usually asks the estimate question after the task has been completed, and this could have contributed to the unique findings of high-performer-overestimation because they have lacked the insight from experience of a completed task to help inform their estimates. Nevertheless, the discrepancy between the high and low performers still remained in their overall estimates, and the question remains as to what cognitive processes are underlying this group-level difference in metacognitive assessments.

There seems to be an important difference between asking participants to make estimates before they complete a task and after they complete a task. Asking for an estimate before completing the task speaks more to one’s self-perception. Before one completes a task, the only information one can draw on is preconceived notions about one’s ability from prior experiences. However, this is not the core of what the DKE appears to refer to in its canonical form. The essence of the DKE is instead characterized by the overconfidence of individuals who inaccurately believed that they completed the task well but did not, and the inaccurate under-confidence of individuals who believed they did not perform at the top but did. These delineations are inherently retrospective in their nature and require a different type of cognition and metacognition than future predictions (Schacter, 2012; Schacter & Addis, 2007; Schacter, Benoit, De Brigard, & Szpunar, 2015). For this reason, the current work will seek to focus on data acquired by asking for estimates after the task is completed.

One beneficial innovation offered by Simons’ (2013) study is that it introduced an important novel development in paradigms, which motivated the current investigation. This paradigm introduced a repeated measures factor for the score estimate in the card game that was not present in most of the extant literature about overconfidence. Simons’ participants played several games of bridge in the same session, and provided estimates before every game. These repeated measurements allowed Simons to assess changes in participants' estimates over a relatively short amount of time. He found that participants did not correct their overestimates even after discovering by the end of the game that their estimates were in fact too high. This result inspired the repeated measures design for the current proposal by providing evidence that participants will not self-correct their overestimates even over a short period of time; the procedure allows us the flexibility to track changes in individuals' estimates as well.

Theoretical Accounts and Models of the Dunning-Kruger Effect

Dunning and Kruger postulated that the reason for low performer's incorrect estimation for objective performance score is due to meta-ignorance or two-fold ignorance (Kruger & Dunning, 1999). This means that poor performers are unaware that they are ignorant of the details needed to correctly complete the task and that double ignorance bolsters feelings of false superiority (Schacter, 2012). More simply, poor performers do not have the knowledge to complete the task correctly and because they do not know their answers are incorrect, they believe they are performing well. For example, poor performers on a task of logical reasoning ability did not have the necessary knowledge to answer the questions in the test correctly. They were also unaware that their answers were incorrect providing them with false confidence that they answered correctly (Schlösser et al., 2013). While this is a very useful behavioral description, it does little to advance an understanding of the cognitive processes involved in this pervasive illusion.

Dunning and Kruger also used what they coined “reach-around-knowledge” to explain low performers’ high confidence in their abilities. The term ‘reach-around knowledge’ refers to a person’s unique knowledge gained from previously participating in a task similar to the presented task and generalizing their past experiences to the current situation (Dunning, 2011). Kruger and Dunning postulated that participants use reach-around knowledge to help achieve their estimation, though this doesn’t necessarily require that it leads them to an accurate perception. According to this view, in order to give an overestimation, one must first have knowledge about the same or similar tasks but not have the knowledge about the details of the task to complete it correctly. Having a larger store of reach-around knowledge should therefore increase the overestimation of poor performer’s scores. On the contrary, having a smaller store of reach-around knowledge should decrease the overestimation of one’s abilities resulting in a more accurate performance estimate.

Dunning and Kruger’s “reach-around-knowledge” account has not yet been operationally defined or objectively measured and lacks a substantive theoretical foundation in cognitive psychology. Nevertheless, it provides a useful platform from which to expand in investigating this phenomenon. The reach-around-knowledge account provided by Dunning and Kruger refers to changes in current behavior based upon prior experience, which is a defining feature of memory, and as such it recognizes a key role that memory processes may play in contributing to this metacognitive illusion. There is a rich and robust empirical history of memory processes being both theoretically and operationally defined and studied. Here, we will focus on the possible role of episodic memory for the DKE. Two aspects of episodic memory that may contribute to the DKE are familiarity and recollection. These processes align closely with the general concepts that Dunning and Kruger attributed to their reach-around-knowledge account, and can be drawn upon to approach the DKE in a systematic manner, as discussed in the sections below.

Memory Research

Memory Confidence and Accuracy

Memory research intersects with the DKE at the point of confidence in one's memories and the accuracy of those memories. A large collection of research is available that supports the finding that high confidence does not beget high accuracy. Brown and Kulik (1977) lead the charge in studying this lack of correlation in the late 1970's with an article about flashbulb memories. Flashbulb memories are defined by a sharp, vivid memory of one's immediate surroundings caused by a surprising, salient, often upsetting incident. Individuals who form flashbulb memories have high confidence in the accuracy of those memories, almost as if they had taken a mental picture of their environment using a camera (old cameras provided flash using a bulb, hence the term "flashbulb" memory). Since then, flashbulb memories have been studied using major traumatic events such as the 9/11 attacks (Hirst et al., 2015; Kvavilashvili et al., 2009; Shapiro, 2006; Smith, Bibi, & Sheard, 2003), the Challenger space shuttle (Bohannon & Symons, 1992; Neisser & Harsch, 1992), and the 2015 attacks on Paris (Gandolphe & El Haj, 2017). Many of these studies found that flashbulb memories were no more accurate than other memories despite the participants' high confidence in their accuracy (Neisser & Harsch, 1992). Therefore, the evidence indicates that flashbulb memories are just as susceptible to forgetting as normal memories (Hirst et al., 2015) but do not suffer from the same decrease in confidence of accuracy as normal memories (Talarico & Rubin, 2003).

Other research has shown that memories can be manipulated and distorted. Loftus, Miller, and Burns (1978) found that asking participants leading questions led them to claim they remembered information that was not actually presented to them. Another hallmark study showed evidence that participants could be induced to form rich memories of events that never occurred during their childhood simply by asking the participant's close relatives to corroborate the false memory (Loftus & Pickrell, 1995). These examples show how easily memories can be changed, formed, and manipulated.

Some of the most impactful research on memory failing to correlate with accuracy pertains to the legal system (Heaton-Armstrong, Shepherd, Gudjonsson, & Wolchover, 2006; Loftus, 1975; Loftus & Zanni, 1975; Nadel & Sinnott-Armstrong, 2012; Pena, Klemfuss, Loftus, & Mindthoff, 2017; Schacter & Loftus, 2013). Pena et al. (2017) conducted research asking participants to make judgments about their accuracy on a memory test for a mock crime observed earlier in a study. Interestingly, they found that participants who performed poorly on the memory test for details of a mock crime overestimated their memory accuracy. Their results were consistent with the results of poor performers exhibiting the DKE, suggesting that a link may exist between the two domains of memory and illusory superiority.

Memory Confidence and Familiarity

Other studies investigating the subtler and more nuanced side of memory and accuracy have been conducted using a false fame paradigm. Experiments on false fame highlight the idea that familiarity with names can lead to falsely recognizing them as famous later (Dywan & Jacoby, 1990; Jacoby, Kelley, Brown, & Jasechko, 1989; Jacoby, Woloshyn, & Kelley, 1989, 2004). In Jacoby's experiments, participants read a list of non-famous names that they were tested on either immediately after reading the list or 24 hours after reading the list. Participants who were tested one day later were more likely than participants tested immediately to mistakenly judge non-famous names from the previous list as famous.

In addition, participants were presented some non-famous names once and some four times. The non-famous names presented four times were less likely to be judged as famous due to more recollection of the context (that the list of names previously read were non-famous). The names only read once were more familiar to the participants, yet not so familiar that they remembered the context surrounding the name. However, this familiarity caused participants to believe an ordinary name was famous because they could not recollect the context in which the name was presented. These ideas of familiarity and recollection are more than just layperson’s terms for differences in memory strength; they are cognitive process subsets of episodic memory that have garnered substantial research support, and are discussed in detail below.

Familiarity and Recollection

The cognitive processes of recollection and familiarity have been featured prominently in theoretical models of episodic memory for several decades (Eichenbaum, Yonelinas, & Ranganath, 2007; Khoe, Kroll, Yonelinas, Dobbins, & Knight, 2000; Rugg & Curran, 2007; Squire, Wixted, & Clark, 2007; Yonelinas, 1999, 2002). Familiarity refers to having exposure to some material but not being able to recall the context in which it was presented. Recollection refers instead to recall of specific contextual details from prior episodic experiences.

Familiarity relates strongly to the false fame effect because seeing a non-famous name once had the effect of eliciting a similar amount of familiarity as mildly famous names that participants many have seen once before (Addante, Ranganath, & Yonelinas, 2012; Eichenbaum et al., 2007; Jacoby, Kelley, et al., 1989; Jacoby et al., 2004; Jacoby, Woloshyn, et al., 1989; Woodruff, Hayama, & Rugg, 2006; Yu & Rugg, 2010). Importantly, the participants lost the context in which the non-famous names were presented and were more likely to judge them as famous. The cognitive processes of recollection and familiarity clearly play an important role in accounting for the false fame effect, which has implications for a theoretical account of the DKE by way of the shared elements of inaccurate perceptual estimate of reality's performance.

Physiological measurements using electroencephalography (EEG) have also been recorded for familiarity and recollection. Familiarity has been associated with event-related potentials (ERP) differences in old and new memory trials during a negative-going peak at the mid-frontal scalp sites at approximately 400 milliseconds to 600 milliseconds post stimulus, called the mid-frontal old-new effect, or FN400 (for frontal-N400 effect). On the other hand, recollection has been associated with differences between memory conditions occurring at a peak in the ERP at the parietal region of the scalp from approximately 600 milliseconds to 900 milliseconds, or LPC (Addante et al., 2012; Leynes et al., 2005; for reviews see Rugg & Curran, 2007; Friedman, 2013).

Metacognition and Metamemory

Another way to study inaccurate estimates of performance is through behavioral measures of memory confidence of familiarity and recollection, for which an extensive literature of research exists (Yonelinas, 2002; Yonelinas & Parks, 2007). Deciding how much confidence one places in their own memory can only be done by thinking about one's memory processes. This term is called metacognition and it is used widely to study self-estimates of learning.

One way that researchers can study inaccurate estimations of performance in the DKE is by taking measurements of metacognition. Metacognition is often described as thinking about one's own cognitive processes to become aware of one's strengths and weaknesses in one's own thinking (Flavell, 1979). Some examples of metacognition are thinking about what presentation method most engages you in class and understanding your procrastination habits. Thinking about how likely you are to remember a learned topic at a later time is an example of a specific subset of metacognition called metamemory, described as thinking specifically about one's memory processes.

A common method used to study metamemory employs judgments of learning (JOLs) and judgments of remembering or knowing. JOLs ask participants to judge how confidently they believe they will remember a studied item during an upcoming test phase (Nelson & Dunlosky, 1991) and judgments of remembering or knowing ask participants to judge how confidently they believe their memory for that event will be accompanied by contextual details (remembering) or without contextual details (knowing). McCabe and Soderstrom (2011) gave participants a list of nouns and asked them to make either a JOL (by indicating that they would remember or not remember the word) or a judgments of remembering or knowing which they termed a "JORK" (by indicating if they believed they would recollect, know, or forget the word upon retrieval) during encoding. At retrieval, they asked participants to either give a remember/know/forget judgment or a studied/not studied judgment. They found that participants who were assigned JORKs during encoding and remember/know/forget judgments at retrieval had better accuracy than participants assigned to give JOLs and studied/not studied judgments. However, the reason these differences exist is still unknown.

While JORKs ask participants to judge how well they would remember contextual details at the time of testing (i.e. the future), it would be informative to explore why JORK differences at encoding and remember/know/forget judgment differences at retrieval emerge. One possibility is that accuracy may have improved for JORKs because the information asked of JORKs is more specific: the participant was cued to remember the context surrounding the word. JOLs do not offer as many contextual cues as JORKs due to the nature of the simplistic task of indicating if the word would be remembered or not. However, that simplicity was not guided in any way and the participant may not know what stimuli are important to remember as retrieval cues. Because of that simple yet broad judgment, JOLs may produce less accurate retrieval than JORKs. Similarly, because giving assessments for JOLs lead to less accuracy, if participants were asked to give estimates of the retrieval score, their estimates may also be less accurate because they cannot recollect the items they recognized or the ones they forgot. However, because JORKs lead to more accurate recognition, they may provide more accurate estimates. Therefore, JOLs could result in overconfidence because of the simplicity of the task compared to JORKs.

Metamemory has also been studied in conjunction with judgment heuristics. Heuristics are mental shortcuts the brain uses to make assumptions that lead to quick decisions. One heuristic relevant to metamemory is the fluency heuristic, which assumes that information that is processed more quickly has higher value, or is more appropriate and applicable to the current question or task and will hence influence the decision more heavily (Bruett & Leynes, 2015; Jacoby & Brooks, 1984; Leynes & Zish, 2012; Whittlesea & Leboe, 2000, 2003). Said more simply, information processed quickly is viewed as more important than information processed more slowly.

Students have been found to use the fluency heuristic to judge how well they learned material from a professor (Carpenter, Mickes, Rahman, & Fernandez, 2016). In (Carpenter et al., 2016) study, participants were assigned to watch one of two videos of a professor giving a lecture in a fluent or disfluent manner and then were given a test of the material they learned. In the fluent condition, the professor spoke confidently and clearly and was engaged with the students while in the disfluent condition, the professor was disengaged, hesitant, and did not confidently present the material. Students were then asked to estimate their score on the test and indicate how much they believed their learning was due to the professor, the material, and their ability to learn.

The students who rated the professor as being integral to their JOL (27% of the fluent condition) earned a significantly lower score than they had estimated while students in the disfluent condition (45% of the disfluent condition) correctly estimated their test score. Importantly, however, the amount of learning did not differ between the two groups (Carpenter et al., 2016). These findings indicate that there can be clear differences in the *perception* of our learning despite there being no differences in actual *reality* of learning, but these findings leave open and unresolved the underlying reason for *why* this distinction between perception and reality occurs in learning and in memory.

Physiological Measurements of Metacognition

In addition to studying behavioral responses for JOLs, physiological data have also been collected during JOLs using (ERPs) derived from electroencephalogram (EEG) recordings. One of the first of these recordings was done by Sommer, Heinz, Leuthold, Matt, and Schweinberger (1995). They showed participants a list of faces and asked them to make JOLs judging their perceived ability to recognize the faces upon retrieval. They found that faces that were later correctly recognized showed a positive wave from 300ms to 1000ms in the left parietal region of the scalp, much like the LPC. However, this wave did not differ between positive and negative JOL conditions (Sommer et al., 1995). The authors concluded that JOLs and recognition memory are very closely related, which provides support for our hypothesis that memory processes play a key role in judgments of self-performance (i.e.: Dunning-Kruger judgments).

Other ERP studies of JOLs and memory corroborated and expanded upon Sommer et al.'s (1995) findings. Müller et al. (2016) conducted an experiment in which participants studied pairs of pictures and were prompted to give JOLs after learning each picture pair, assessing the participant's confidence that they would remember one picture given the other picture as a cue upon retrieval. The ERPs for the JOL condition and a control condition in which participants did not make any JOLs were compared. The pattern of ERPs showed that conditions differed reliably on the medial frontal scalp sites from 300 milliseconds (ms) to 700 ms, as well as at bilateral negative occipital sites from 350 ms to 700 ms. This negative wave is reminiscent of the FN400 that is characteristic of familiarity, which will be discussed in more depth in the next section below.

Another study found evidence of ERPs consistent with recollection and familiarity in JOLs. Skavhaug, Wilding, and Donaldson (2010, 2013) asked participants to study pairs or two words and provide a JOL about later remembering one word of the pair when cued with the other. Then ERPs of items with high JOLs and low JOLs were plotted. Although a negative wave was present from 400 ms to 600 ms at the fronto-central electrode cites, the wave was not significantly different for high JOLs and low JOLs. However, the LPC was evident in the centro-parietal electrodes from 550 ms to 1000 ms when high and low JOLs were compared with high JOLs exhibiting a larger wave. This result suggests that higher JOLs elicited more recollection and that memory may also be an integral contributor to these types of self-judgment.

Together, these studies show that the FN400 and LPC are evident in the ERPs during metacognitive judgments, and importantly, also showing that ERPs are capable of capturing these sensitive memory processes in metacognitive judgements. It also gives support to the idea that familiarity and recollection may be a key cognitive process involved in the metacognitive judgments used to form Dunning-Kruger estimates by both high and low performers. Although the LPC was not evident in Sommer et al.'s study, it is possible that changes in the paradigm or analyses account for the difference.

The results of these studies support the current hypothesis that memory is heavily involved in metacognitive judgments about one's ability to perform well on a memory task. Low performers who tend to over-estimate their ability and score may do so because of familiarity with previous experiences in similar situations. High performers who tend to under-estimate their ability and score may use more recollection in their metacognitive judgments. This provides more support for the hypothesis that ERPs will be able to capture evidence of familiarity and recollection in DKE metacognitive judgements.

A Memory-Based Framework for the Dunning-Kruger Effect

Many of the accounts of the DKE have focused primarily upon interpretations based upon metacognition and competency (Adams & Adams, 1960; Ehrlinger & Dunning, 2003; Kruger & Dunning, 1999; Oskamp, 1965; Pennycook et al., 2017; Ryvkin et al., 2012a; C. Sanchez & Dunning, 2018). However, it is very likely that memory experiences in one's past influencing the real-time processing of the current information- either via explicit or implicit means- could also be contributing to DKEs.

In episodic memory, theoretical models of recognition are largely governed by the dual processes of familiarity and recollection (Diana, Yonelinas, & Ranganath, 2008; Eichenbaum et al., 2007; Ranganath, 2010; Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010) (though see Wixted, 2007 and Wixted & Mickes, 2010 for nuanced alternative views), and it is possible that understanding of familiarity and recollection processes in memory may help explain a proportion of variance in the DKE.

Recollection is typically operationalized as the declarative retrieval of episodic information of both the item and context bound together into a cohesive retrieval of the episodic event (for review see Diana et al., 2008), and is usually associated with the retrieval of contextual information surrounding the item of the event (Addante et al. 2012a; for reviews see Eichenbaum et al., 2007; Yonelinas et al. 2010; Ranganath, 2010). The item may however be retrieved without recollection and via reliance upon familiarity, typically conceptualized as retrieval of an item from a prior episode but without the associated contextual information in which it occurred. Familiarity occurs, for instance, when a person can remember that someone seems familiar from the past but cannot retrieve who the person is or from where they know them. Recollection, on the other hand, would be remembering precisely who someone is and how you know them from a prior episode of one’s past experience.

These two memory phenomena have been found to be dissociable cognitive processes (Yonelinas, 2002), with dissociable neural substrates in the medial temporal lobes (Ranganath et al., 2004), neuropsychologically dissociable among patient impairments (Addante, Ranganath, Olichney, & Yonelinas, 2012; Düzel et al., 1999; Mecklinger, von Cramon, & Matthes-von Cramon, 1998), and with distinct patterns of electrophysiology at the scalp that is both spatially and temporally dissociable in event-related potentials (ERPs) (Addante et al., 2012; Curran, 2000; Friedman, 2013; Gherman & Philiastides, 2015; Rugg et al., 1998; Rugg & Curran, 2007).

Based upon the converging literatures from memory and metacognition, a viable alternative theory to explain the DKE is that the illusory superiority experience may be driven, at least in part, by familiarity from prior experience with the tested materials. This general familiarity may lead people to assume high performance despite a lack of specific retrieval of the relevant details required for real competency with the material. In this view, lacking distinct recollection but being generally familiar with material will lead people to assume that they are competent and successful, and would be associated with increased FN400 amplitudes in ERPs for inaccurate over-estimators. In this case, for example, it would be a dangerous combination to have insufficient recollection but excessive familiarity with a given topic, stimuli, or information. By contrast, under-estimators of self-performance may be marked by having had higher recollection of the study material (e.g. competency) such that these instances are associated with an LPC, while also leading people to perhaps recollect non-criterial information that could still be relatively wrong, hence lowering their estimated scores relative to other people. In this case, the excess of recollection signal would outweigh the relative noise of uncertain familiarity.

Addressing the Gap in the Current Literature

There are several gaps in the literature were addressed in this study. First, to our knowledge the traditional DKE has never before been elicited during the retrieval stage of an episodic memory confidence task. We aimed to bridge this gap and identify the DKE using a memory test paradigm in which participants are tested on their memory for the words in the test phase using a confidence gradient to indicate confidence in their answer.

Second, another gap in the literature is that to the best of our knowledge, no neurophysiological measures of the DKE have been recorded thus far. This gap will be addressed by recording EEG measures of participants during the actual metacognitive decisions underlying the DKE. Collecting physiological measures of this cognitive illusion is an important element in better understanding it and can provide insight into its underpinnings by revealing ERP effects that are reliably associated in the cognitive neuroscience literature with memory processes such as recollection and familiarity. Additionally, these EEG measures can reveal any potential contribution of implicit memory processes that could also be influencing the DKE via activation of information unavailable to conscious awareness (Addante, 2015; Leynes & Addante, 2016; Rugg et al., 1998; Wolk et al., 2004; Woodruff, Hayama, & Rugg, 2006; Yu & Rugg, 2010)

Third, an additional innovation we will bring to the field of DKE research is the paradigm of repeatedly asking participants to provide their performance estimates in relation to other students at several times during a single session of cognitive task performance. Most DKE literature to date only asks for the participants' performance estimates once, at the end of the task. Although we will still also ask for an overall estimate at the end of the study, our novel design of repeatedly asking for DKE estimates during the retrieval task will allow us to collect numerous samples of neural activity during a single participant's DKE decisions and analyze the brain activity of high and low performers while they are making their self-judgments.

Current Study

The current paradigm has been designed to study the decision-making process as it occurs in real-time during DKE relative performance estimates provided by participants throughout an item recognition memory test. The DKE is characterized in terms of two measures: self-estimates of an objective score on a test or task and a relative estimate in relation to their peers. To maintain simplicity during a lengthy memory test, the current proposal only asked relative performance estimate questions (and not the self-estimate of overall objective score) throughout the test phase of the experiment. This approach is consistent with prior work by many researchers who also ask for estimates in relation to other people (Critcher & Dunning, 2009; Ehrlinger & Dunning, 2003; Guillory &

Blankson, 2017; Kruger & Dunning, 1999; Schlösser et al., 2013). After every ten word recognition trials during the test phase, participants were asked to estimate in which percentile they believed they were performing up to that point on the task. We did not ask for repeated estimates of objective scores on the test because the more critical question for the DKE seems to concern the relative performance estimate in comparison to one's peers.

The current proposal's hypotheses are focused upon neural activity at the moment of metacognitive decisions; accordingly, the current study asked a DKE relative performance estimate once every ten slides during the item recognition memory test. One of the reasons for such repeated testing is because assessing ERPs of the DKE metacognitive decision-making process requires having sufficient trials per condition to overcome signal-to-noise ratios, usually a minimum of approximately n = 12 trials per condition in each participant contributing to group ERP effects. Presenting the Dunning-Kruger question interspersed among memory questions after every ten trials was designed as a compromise between the need to collect as many trials as possible without substantively lengthening the time of the experiment out of concern of fatigue effects.

CHAPTER TWO

METHOD

Participants

The total sample of participants consisted of 62 right-handed students free from neurological and memory problems recruited from a university in Southern California. Five participants' data were not used due to noncompliance issues and one participant did not have usable data due to technical difficulties. Two participants did not have usable EEG data but were included in behavioral analyses. The majority of our participants were women (N = 48); 56.5% were Hispanic, 22.6% were Caucasian, 11.3% were Asian, and 9.7% identified as more than one ethnicity of a different ethnicity. The average age of our participants was 23.52 years old (*SD* = 4.82). None of our participants reported any visual, medical, or physical issues that would interfere with the experiment. Most participants spoke English as their first language (N = 47) and the 15 participants who indicated speaking a different language first had been speaking English for an average of 16.73 years (*SD* = 4.74). Participants were recruited through a combination of methods including advertisements placed around campus or through an online recruitment website. Participants recruited through advertisements were paid $10 an hour for sessions that lasted approximately three hours and participants recruited the website received 8 units of credit.

Memory Test Paradigm

The paradigm used to test our hypotheses and elicit the DKE was a modified item recognition confidence test, building from similar paradigms successfully used in our lab's prior research (Addante et al., 2012; Addante, Watrous, Yonelinas, Ekstrom, & Ranganath, 2011; Addante, 2015; Addante, de Chastelaine, & Rugg, 2015; Addante, Ranganath, Olichney, & Yonelinas, 2012) and described in further detail below. This paradigm consisted of an encoding phase containing four study sessions, in which participants studied 54 words in each session, and a retrieval phase containing six test sessions in which the participant's memory was tested for 54 words in each session. They viewed a total of 324 words, 216 of which were presented in the encoding phase and 116 of which were unstudied (new) items.

Behavioral and Electrophysiological Measures

Both behavioral and physiological measurements of the DKE were recorded. The behavioral measurements consisted of participants' responses on the memory test. Participants were grouped into quartiles based on their percentile score on the test, allowing us to average each group's responses and test them against the other group's average responses to determine significant differences. They were also grouped by errors in percentile estimates; groups of over-estimators, correct-estimators, and under-estimators (also referred to as

Dunning-Kruger groups later) were constructed to investigate potential differences in cognitive strategies.

Physiological measurements of brain activity were recorded using EEG equipment from Brain Vision LLC. All EEG data was processed en masse using the ERPLAB toolbox from Matlab (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2014). The EEG data were grouped based on the above categories for each type of response, which allowed us to determine if there were significant differences in brain activity between our relevant conditions. The EEG data was first re-referenced to the average of the mastoid electrodes, passed through a high-pass filter at 0.1 hertz as a linear de-trend of drift components, and then downsampled to 256 hertz. The EEG data was epoched from 200 milliseconds prior to the onset of the stimulus to 1200 milliseconds after the stimulus was presented and then categorized based on performance group and response accuracy.

Independent components analysis (ICA) was performed using InfoMax techniques in EEGLab (Bell & Sejnowski, 1995) to accomplish artifact correction and then the resulting data was individually inspected for artifacts, rejecting trials for eye blinks and other aberrant electrode activity. During ERP averaging, trials exceeding ERP amplitudes of +/- 250 mV were excluded. Additional filtering, such as a 30hz low pass filter, was applied to group ERPs in order to make figures correspond to the similar ‘smoothing’ function that the standard process of taking the mean voltage between a given two latencies accomplishes during statistical analyses of results.

Using the ERPLAB toolbox (Lopez-Calderon & Luck, 2014), automatic artifact detection for epoched data was also used to identify trials exceeding specified voltages, in a series of sequential steps as noted below. Simple Voltage Threshold identified and removed any voltage below -100ms. The Step-Like Artifact function identified and removed changes of voltage exceeding a specified voltage (100uV in this case) within a specified window (200ms), which are characteristic of blinks and saccades. The Moving Window Peak-to-Peak function is commonly used to identify blinks by finding the difference in amplitude between the most negative and most positive points in the defined window (200ms) and compared the difference to a specified criterion (100 uV). The Blocking and Flatline function identified periods in which the voltage does not change amplitude within a specified window (848ms). An automatic blink analysis, Blink Rejection (alpha version), used a normalized cross-covariance threshold of 0.7 and a blink width of 400ms to identify and remove blinks (Luck, 2014). Maps of scalp activity were created to assess the topographic distribution of the effects.

In order to maintain sufficient signal-to-noise ratio (SNR), all comparisons relied upon including only subjects that met a criterion of having a minimum of 12 artifact-free ERP trials per condition being contrasted (Addante et al., 2012; Gruber and Otten, 2010; Kim et al., 2009; Otten et al., 2006; c.f. Luck, 2014).

Procedure

Participants arrived at the lab and completed consent paperwork and demographic information forms via voluntary self-report. The experiment consisted of three stages: 1) the encoding phase, 2) EEG set up, 3) and the retrieval phase. During the encoding phase, participants were given instructions to make a simple decision about the word presented (Figure 1). The participants were either asked to judge if the item was manmade or if the item was alive. The instructions were presented in one of two counterbalanced orders: ABBA or BAAB. The participants viewed four lists of 54 words during the encoding phase.

The stimuli were presented on a black computer screen in white letters. To begin a trial, a screen with a small white cross at the center was presented for one of three randomly chosen inter-stimuli-interval (ISI) times: 1 second, 2.5 seconds, or 3 seconds. Then, the stimulus word appeared in the middle of the screen with ‘YES’ presented to the bottom left of the word and ‘NO’ presented to the bottom right of the word. The participants indicated their answer by pressing buttons corresponding to ‘yes’ and ‘no’ with their index and middle fingers, respectively. The response for this screen was self-paced by the participant. After the participants responded, they viewed a blank black screen at a random duration of 1 second, 2.5 seconds, or 3 seconds. After the blank screen, the small white cross appeared at the center of the screen to begin the next trial. This cycle continued until all 50 words in the all four lists were presented. Between each list, participants were read the instructions for the next task to ensure they correctly switched between the animacy and the manmade decision task.

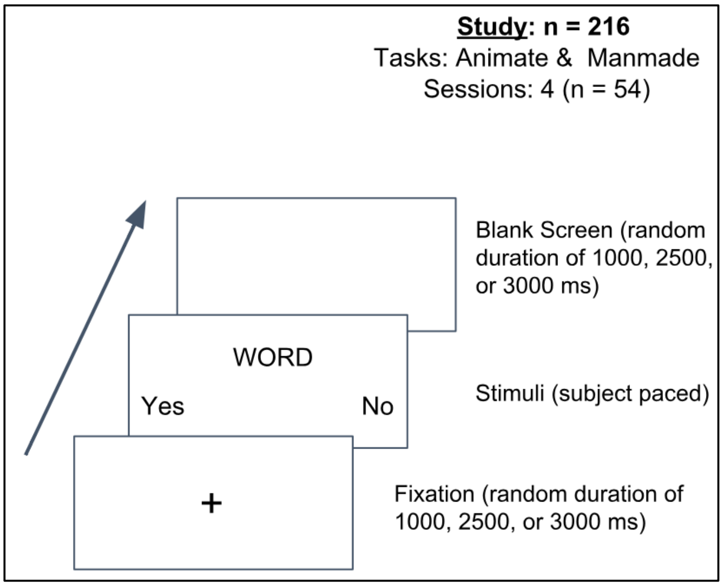

Figure 1. Encoding Paradigm**.**
Participants viewed a fixation cross for one of three randomly chosen times and then will be presented with the stimuli. After responding ‘yes’ or ‘no’ (to deciding if the word is alive or manmade), the participants viewed a blank screen for one of three randomly chosen times. After the blank screen, the fixation cross appeared again and the cycle repeated until all 54 words were presented.

After the encoding phase was complete, the EEG cap was sized while the participant’s face was wiped free of skin oil and/or makeup in preparation for attaching ocular electrodes. Five ocular electrodes were applied to the face to record electrooculograms (EOG): two above and below the left eye in line with the pupil to record electrical activity from vertical eye movements, two on each temple to record electrical activity from horizontal eye movements, and one electrode in the middle of the forehead in line horizontally with the electrode above the left eye as the ground electrode. Then the EEG cap was placed on the participant's head and prepared for electrical recording. Gel was applied to each cap site and impedances were lowered below 15 KOhms via gentle abrasion to allow the electrodes to obtain a clear electrical signal.

After the EEG cap was in place, the participant began the retrieval phase. The participants were read instructions asking them to judge if the stimulus word presented was old (studied during the encoding phase) or new (not studied before in the encoding phase; Figure 2).

As in the encoding phase, all stimulus words were presented in white font on a black screen. To begin a trial, a screen with a small white cross at the center was presented for one of three randomly chosen times: 1 second, 2.5 seconds, or 3 seconds. Then the participants were presented with a word in the middle of the screen, the numbers “1”, “2”, “3”, “4”, and “5” evenly spaced beneath the word, the word “New” on the left by the number “1”, and the word “Old” on the right under the number “5”. Participants pressed any number between “1” and “5” to indicate if they confidently believed the word was old (“5”), believe the word was old but was not confident (“4”), did not know if the word was old or new (“3”), believe the word was new but was not confident (“2”), or confidently believed the word was new (“1”). Participants were told to choose the response that gave us the most accurate reflection of their memory.

Immediately after that decision, they were asked to answer if the word came from the animacy decision task or the manmade decision task. The word and numbers remained on the screen but this time, word “Alive” was presented on the left by the number “1”, and the word “Manmade” was presented on the right under the number “5”. Participants were told to choose the response that gave us the most accurate reflection of their memory and could respond that they confidently believed the word was from the animacy task (“1”), believed the word was from the animacy task but were not confident (“2”), did not know the source of the word or had replied in the question directly before that the word was new (“3”), believed the word was from the manmade task but were not confident (“4”), or confidently believed the word was from the manmade task (“5”). After that, a blank black screen was presented for a randomly chosen time of 1 second, 2.5 seconds, or 3 seconds. Participants were instructed to blink only during this blank screen and avoid blinking during the screens with a small cross or stimuli. The white cross was presented after the blank screen and the cycle continued until after the 10th word has been presented.

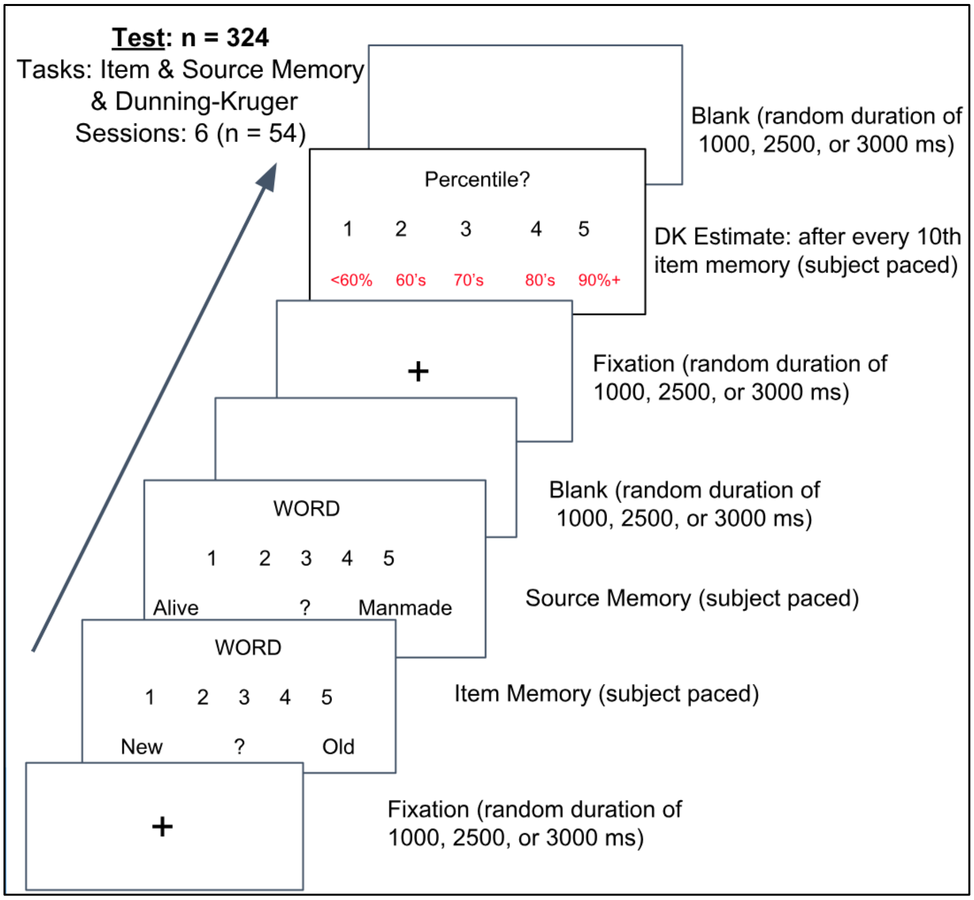

Figure 2. Retrieval Paradigm.
Participants viewed a fixation cross for one of three randomly chosen times. Then participants viewed the stimulus and indicated their confidence for the item memory and source memory. Then participants viewed a blank screen for one of three randomly chosen times and then the fixation cross appeared again continuing the cycle. For every 10th stimulus presented, the participants viewed the Dunning-Kruger Estimate asking participants to estimate the percentile in which they believed they were performing up to that point on the task in relation to other students.

After each 10th word presented, the Dunning-Kruger estimate was presented. Participants received instructions asking them to estimate the percentile in which they believed they were performing up to that point in the test compared to other students who would participate in the study. During the test phase, the word “Percentile?” was presented as a prompt for their estimate with the numbers “<60%,”, “60’s”, “70’s”, “80’s”, and “90%+” evenly spaced beneath it. The Dunning-Kruger estimate was participant-paced. After the participant responded, the blank screen was presented and the next cycle of ten words were presented.

Six lists of 54 words were presented during the retrieval phase, each with five DKE questions interspersed (after trials 10, 20, 30, 40, and 50). After the last list of 54 words was presented, participants answered four Dunning-Kruger post-test questions asking them to estimate their objective score on the whole test, their relative percentile on the whole test, how good their memory is in everyday life, and the overall difficulty of the test.

Dunning-Kruger Post-Test Questions

At the conclusion of the memory retrieval test, participants were asked two additional questions concerning the DKE (Figure 3). First, they were asked to “Estimate your score on the whole test”. Participants were prompted to respond on a 5-point scale with “1” meaning below 60%, “2” meaning between 60 and 69%, “3” meaning between 70 and 79%, “4” meaning between 80 and 89 percent, and “5” meaning above 90%. The following scale was shown evenly spaced below each prompt: “<60%,”, “60’s”, “70’s”, “80’s”, and “90%+”. The second questions they were asked was the following: “In what percentile did you perform on the whole test?”. The participants were prompted to respond on a 5-point scale with “1” meaning below the 60th percentile, “2” meaning between the 60th and 69th percentile, “3” meaning between the 70th and 79th percentile, “4” meaning between 80th and 89th percentile, and “5” meaning in the 90th percentile or above. The following scale will be shown evenly spaced below each prompt: “<60%,”, “60’s”, “70’s”, “80’s”, and “90%+”.

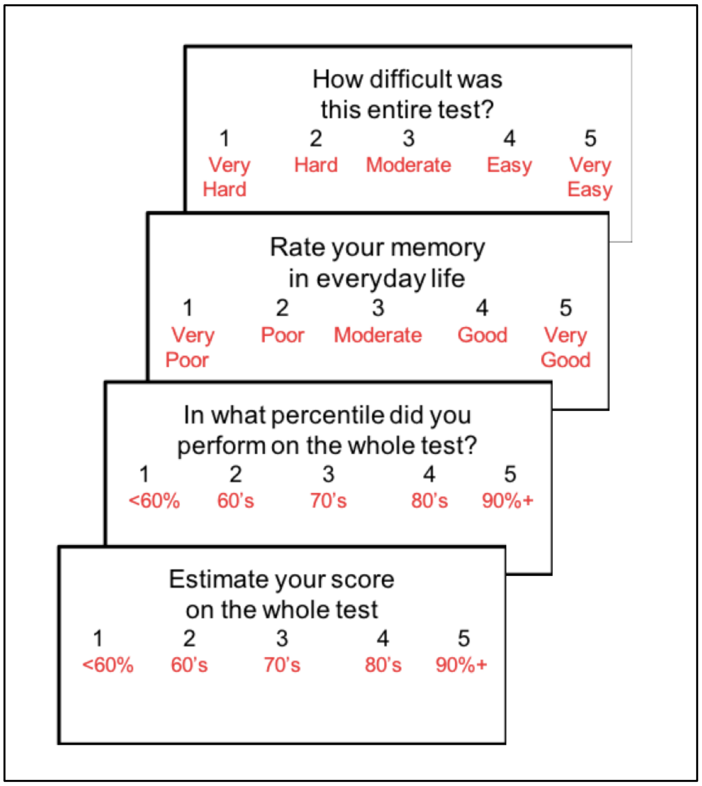

Figure 3. Post-Test Dunning-Kruger Questions.
Participants were asked four questions at the end of the study and responded on a five-point scale with the descriptions seen above.

The first questions measured perceived objective score on the entire memory test while the second question measured perceived relative score in relation to other students taking the memory test. These post-test prompts allowed us to test for the DKE at a between-subjects level to be sure the effect can be elicited using an episodic memory task.

Two additional post-test questions were also asked: 1) "Rate your memory in everyday life" and 2) "How difficult was this entire test?". For the first question, participants responded on a 5-point scale with "1" meaning very hard, "2" meaning hard, "3" meaning moderate, "4" meaning easy, and "5" meaning very easy. For the second prompt, participants responded on a 5-point scale with "1" meaning very bad, "2" meaning bad, "3" meaning moderate, "4" meaning good, and "5" meaning very good. These questions may be used as covariates in later analyses (Figure 3 above).

Hypotheses

The hypotheses for the current study are the following:

1. Low performers will significantly overestimate their relative percentile while high performers will underestimate their relative percentile on the post-test Dunning-Kruger questions.
2. A larger FN400 will be evident in the group level ERPs for low performers compared to high performers for the in-test Dunning-Kruger questions at the mid-frontal electrode sites from approximately 400 ms to 600ms.

3. A larger LPC will be evident in the group level ERPs for high performers compared to low performers for the relative post-test Dunning-Kruger questions at the left parietal electrode sites at approximately 600 ms to 900 ms.

CHAPTER THREE

RESULTS

Behavioral Results

Episodic Memory

We excluded a total of five participants from behavioral analysis. Four were excluded due to non-compliance issues while one was excluded for technical difficulties during the experiment.

Item Memory Performance. Recognition memory response distributions for recognition of old and new items are displayed in Table 1. Item recognition accuracy was calculated as the proportion of hits (*M* = .81, *SD* = .11) – proportion of false alarms (*M* = .24, *SD* = .14) (i.e. pHit-pFA). Participants performed item recognition at relatively high levels (*M* = .57, *SD* = .15) which was greater than chance, *t*(55) = 3.59, *p* < .001. In addition, participants' accuracy for high confidence item recognition trials ('5's') was significantly greater than low confidence item recognition trials ('4's'), *t*(55) = 9.04, *p* < .001.

Table 1. Distribution of Responses for Each Item Response as a Proportion of All Memory Responses

Item Recognition Confidence	1	2	3	4	5
All Old Items	.09	.07	.04	.21	.60
All New Items	.43	.23	.10	.15	.08
Animacy Task	.13	.06	.04	.16	.60
Manmade Task	.08	.04	.03	.14	.71

Source Memory Performance. Source memory response distributions for recognition of old and new items are displayed in Table 2. Source memory accuracy values were collapsed to include high and low source confidence responses which were then divided by the sum of items receiving a correct and incorrect source response to calculate the proportion. (Addante et al., 2012a, 2012b; Roberts et al., 2018). Mean accuracy for source memory was .30 (*SD* = .19) and was reliably greater than chance, *t*(55) = 11.78, *p* < .001.

Table 2. Distribution of Responses for Each Source Response as a Proportion of All Memory Responses

Source Recognition Confidence	1	2	3	4	5
All Old Items	.14	.14	.22	.17	.33
All New Items	.05	.08	.70	.09	.08
Animacy Task	.24	.17	.27	.16	.16
Manmade Task	.11	.11	.17	.2	.41

We also assessed the extent to which the current results could replicate and extend source memory findings for differences among high and low confidence item judgements that were reported by Addante et al., 2012a, since that was a novel phenomenon which benefits from external validity of the literature. When assessing source memory for each level of item hit responses, participants' accuracy for low confidence item recognition trials ('4's') (*M* = .51, *SD* = .24), *t*(55) = 15.78, *p* < .001) and high confidence item recognition trials

(‘5’s’) (*M* = .68, *SD* = .10), *t*(55) = 50.54, *p* < .001) were each significantly greater than chance, and reliably different from each other (*t*(55) = 5.33, *p* < .001). Of note for this finding is that it replicated the prior findings of these unique condition comparisons, extends this with a data set that was double the sample size of the preceding work, and in a paradigm which permits assessing reaction times associated with the cognitive processes supporting these source memory judgements (see results below).

Accuracy for Item and Source Memory Combinations. The current memory paradigm was adapted from prior work that reported uniquely different response accuracies for correct source judgements that were preceded by high and low levels of item recognition confidence hits (Addante et al., 2012). In order to assess the extent to which those novel findings could be replicated with a larger sample size and extended by assessing response time differences, the same analysis was performed on the current data. Accuracy for high confidence item judgments with low confidence source judgments (*M* = 0.68, *SD* = .10) was more accurate than low confidence item judgments with low confidence source judgments (*M* = 0.51, *SD* = 0.24), *t*(55) = 5.33, *p* < .001. The accuracy for both the high confidence item judgments with low confidence source judgments and the low confidence item judgments with low confidence source judgments were each significantly greater than chance (*t*(55) = 50.54, *p* < .001; *t*(55) = 15.78, *p* < .001, respectively).

Response Speed for Episodic Memory Judgments

Reaction times for each item response are shown in Table 3 while reaction times for each source response are shown in Table 4. Because paired t-test were conducted to investigate differences in response speeds within each individual, participants were excluded from analysis if they did not have responses in both of the comparisons. Participants responded significantly faster when identifying hits than misses, $t(55) = -6.23$, $p < .001$, false alarms, $t(55) = -4.43$, $p < .001$, and correct rejections, $t(55) = -3.52$, $p < .001$. They also responded significantly faster when identifying correct rejections than misses, $t(55) = 3.40$, $p = .001$, and misses to false alarms, $t(55) = 2.24$, $p = .03$. There were no significant differences between the reaction times for false alarms and correct rejections, $t(55) = 0.93$, $p = .35$.

Table 3. Average Reaction Times for Each Item Memory Response

Item Reaction Times	1	2	3	4	5
All Old Items	2547 (1067)	3295 (1534)	3151 (1678)	2682 (752)	1852 (394)
All New Items	2205 (671)	3014 (1200)	2897 (1858)	2999 (868)	2085 (820)
Animacy Task	2451 (990)	3355 (1128)	3376 (1352)	2732 (976)	1853 (378)
Manmade Task	2470 (782)	3425 (1369)	3254 (1391)	2947 (1174)	1765 (339)

Note. Values are in milliseconds with standard deviations in parentheses.

Table 4. Average Reaction Times for Each Source Memory Response

Source Reaction Times	1	2	3	4	5
All Old Items	2168 (1193)	2258 (1084)	1589 (802)	2189 (1066)	1776 (827)
All New Items	1615 (1106)	2295 (1135)	913 (516)	2043 (1034)	1488 (998)
Animacy Task	1791 (742)	2428 (1084)	1366 (1039)	2274 (1194)	1744 (967
Manmade Task	1961 (951)	2477 (1089)	1405 (1079)	2216 (981)	1635 (785)

Note. Values are in milliseconds with standard deviations in parentheses.

In addition, participants responded significantly faster to high confidence item recognition trials (*M* = 1897 ms, *SD* = 397 ms) than low confidence item recognition trials (*M* = 2834 ms, *SD* = 1032 ms), *t*(49) = -8.10, *p* < .001. This finding persisted even when source memory was held constant, comparing low confidence item judgments with low confidence source judgments (*M* = 2833 ms, *SD* = 1109 ms) to high confidence item judgments with low confidence source judgments (*M* = 1950 ms, *SD* = 617 ms), *t*(47) = 6.96, *p* < .001 (Figure 4). Differences observed in reaction time for items in which the source was correct (*M* = 2322 ms, *SD* = 589 ms) and items for which the source was incorrect (*M* = 2475 ms, *SD* = 654 ms) approached significance but did not reach the threshold of significance, *t*(54) = -1.77, *p* = .08 (Figure 4).

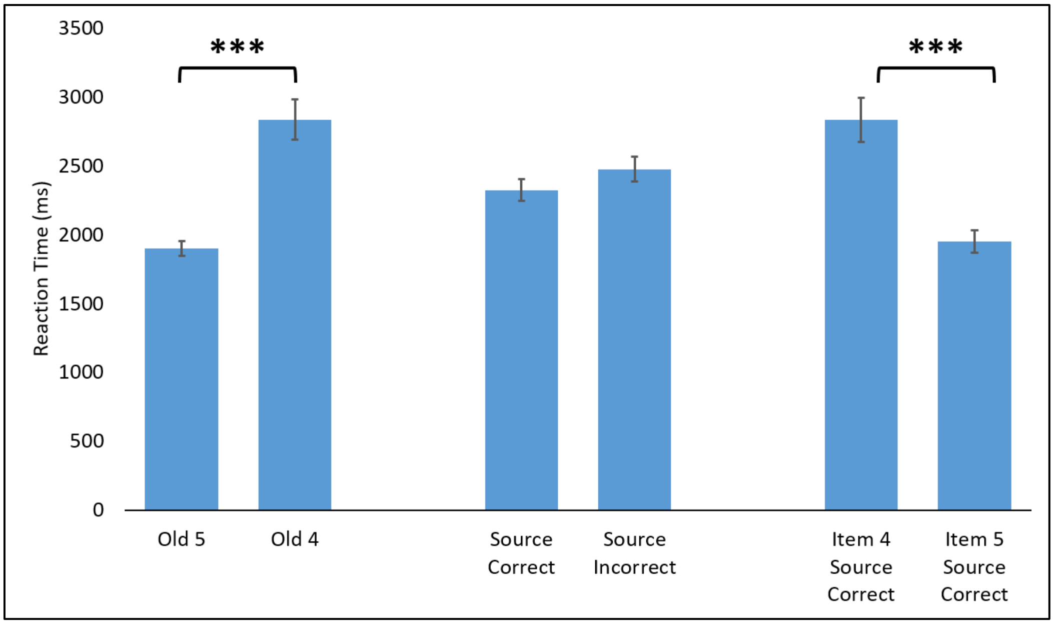

Figure 4. Response Times for Item Recognition Judgments for Specific Item and Source Memory Conditions.
* *p* < .05, ** *p* < .01, *** *p* < .001.

Dunning-Kruger Response Judgments

The distribution of responses for each Dunning-Kruger response category for the post-test and in-test Dunning-Kruger responses are shown in Table 5. When plotted against actual performance, results from subjects' reported performance estimates revealed that the canonical Dunning-Kruger Effect was evident in the dataset, thereby replicating the DKE and extending it to our episodic memory paradigm (Figure 5).

Table 5. Distribution of Responses for Each Dunning-Kruger Response, as a Proportion of All Dunning-Kruger Responses

DKE Type	<60%	60-69%	70-79%	80-89%	>90%
In-Test DK Responses	.05	.20	.39	.29	.07
Post-Test DK Responses	.02	.11	.54	.30	.04

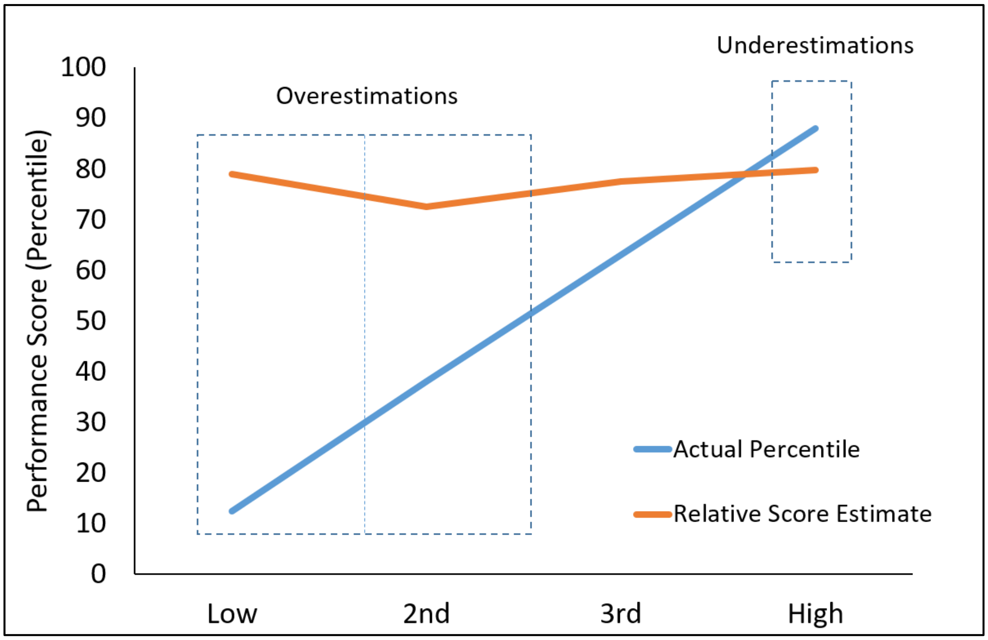

Figure 5. Actual Percentile and Estimated Percentile by Quartile. Participants were separated by their actual percentile ranking. The low group consists of those in the first quartile (less than or equal to 25%), the second group consists of those in the second quartile (>25% and <=50%), the third group consists of those in the third quartile (>50% and <=75%), and the high group consists of those in fourth quartile (>75%). Participants who performed in the first quartile showed the most overestimation while participants who performed in the fourth quartile showed underestimation of their actual percentile.

First, the participants were split into quartiles based on memory accuracy. Average memory test accuracy by quartile and each quartile's average post-test Dunning-Kruger response is listed in Table 6.

Table 6. Average Recognition Memory Test Accuracy and Average Post-Test and In-Test Dunning-Kruger Relative Response by Quartile

Quartile	Accuracy	Average Post-Test DK Relative Response	Average In-Test DK Relative Response
Top (N = 14)	.74 (.06)	3.50 (0.65)	3.26 (0.73)
3rd (N = 14)	.62 (.02)	3.29 (0.99)	3.33 (1.01)
2nd (N = 14)	.55 (.04)	2.79 (0.80)	2.79 (0.81)
Bottom (N = 14)	.38 (.08)	3.43 (0.51)	3.17 (0.62)

Note. Standard deviations are in parentheses.

In order to be able to directly compare participants' post-test relative Dunning-Kruger estimate and their actual percentile, participants' percentile ranking made from their accuracy on the memory test was converted to the 5-point scale of percentile estimates that were used both in-test during the retrieval task and at the end of the experiment. A difference score for each participant's percentile ranking was calculated by subtracting their post-test relative Dunning-Kruger estimate from their converted percentile ranking mentioned above. The bottom quartile (M = 2.43, SD = 0.51, $t(26)$ = 17.69, p < .001), 2nd quartile (M =

1.79, *SD* = 0.80, *t*(26) = 8.33, *p* < .001), and 3rd quartile (*M* = 1.43, *SD* = 1.28, *t*(26) = 4.16, *p* < .001) significantly overestimated their percentile ranking while the top quartile significantly underestimated their percentile ranking (*M* = -0.79, *SD* = 0.89, *t*(26) = -3.29, *p* = .003) (Figure 6).

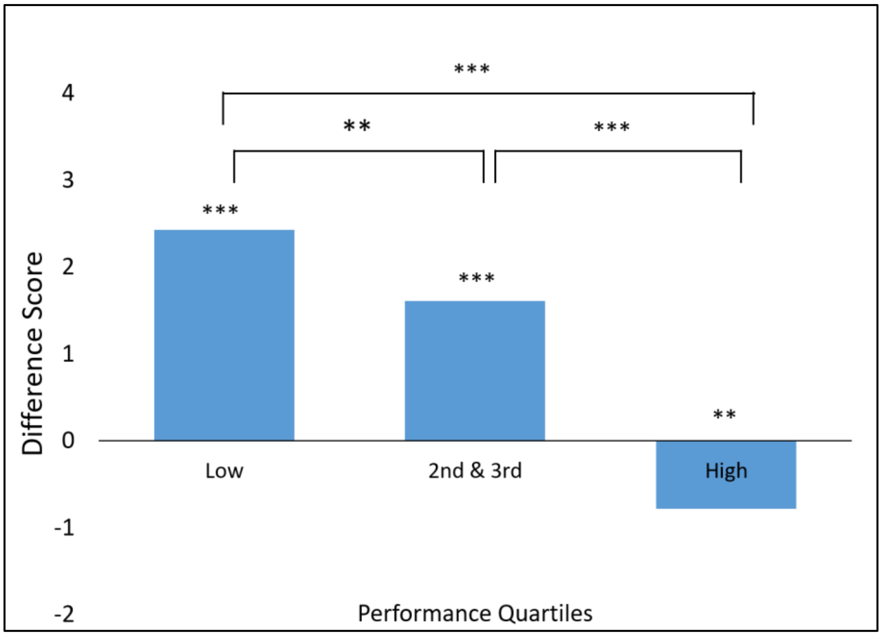

Figure 6. Average Difference Score by Quartile.
Difference score is calculated by subtracting the converted percentile ranking from the estimated post-test relative score. The bars show the magnitude of overestimation above the x-axis and underestimation below the x-axis for each of the groups. The 2nd and 3rd quartile groups were combined because the groups were not significantly different. Participants in the first quartile and the 2nd & 3rd quartile both overestimated their percentile significantly and were significantly different from each other. Participants in the fourth quartile underestimated their percentile significantly and were significantly different than the low percentile and the 2nd & 3rd percentile. * *p* < .05, ** *p* < .01, *** *p* < .001, † = *p* < .10.

However, a t-test revealed that the difference scores of the 2nd quartile and the 3rd quartile were not significantly different, *t*(26) = 0.88, *p* = .39, and so these were combined. The combined 2nd and 3rd quartile group was still significantly overestimated their percentile ranking (*M* = 1.61, *SD* = 1.07, *t*(54) = 7.98, *p* < .001). On average, the difference score for the top quartile was significantly different than the score for the bottom quartile (*t*(26) = 11.68, *p* < .001) and the combined 2nd+3rd quartiles (*t*(340) = 7.22, *p* < .001). The difference score for the bottom quartile was also significantly different than the score for the 2nd and 3rd quartiles (*t*(38) = 2.93, *p* = .01).The magnitude of the errors made by each group decreased as percentile increased: the bottom quartile overestimated their percentile by 62.56%, the 2nd quartile overestimated by 37.95%, the 3rd quartile overestimated by 14.56%, and the top quartile underestimated by 8.30% (Figure 5). This basic finding provides evidence that the DKE was elicited by our memory paradigm in a way that has not been shown before to our knowledge. This result extends the DKE to episodic memory.

In order to better investigate differences in cognitive strategies, participants were separated into groups based on estimation accuracy instead of percentile ranking based upon their post-test estimates of their relative performance on the memory test.[1]

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[1] We used the post-test relative Dunning-Kruger estimate to create groups of over-estimators (N = 38), correct-estimators (N = 8), and under-estimators (N = 10), although we also conducted a paired t-test between the average of the in-test Dunning-Kruger responses (*M* = 3.14, *SD* = 0.81) for each person to the post-test relative Dunning-Kruger response (*M* = 3.16, *SD* = 0.78) and found that the two scores did not differ, *t*(55) = 1.30, *p* = .20, justifying the decision to use the post-test relative Dunning-Kruger response to separate our groups.

Response Speeds for Dunning-Kruger Judgments

Differences in reaction times for each Dunning-Kruger response were also analyzed, using a t-test between groups. There were no significant differences in reaction times collapsed across all Dunning-Kruger responses between the three estimator groups (over-estimators vs under-estimators: *t*(44) = 0.17, *p* = .87, over-estimators vs correct-estimator: *t*(42) = -0.81, *p* = .42, under-estimators vs correct-estimators: *t*(16) = -0.76, *p* = .46).

Reaction times were then analyzed by response number to investigate any differences in specific responses. Over-estimators' reaction times when rating themselves in the 90th percentile or above (response of '5', N = 13) were found to be significantly faster (*M* = 1656 ms, *SD* = 544 ms) than under-estimators' reaction times (*M* = 2578 ms, *SD* = 827 ms) of the same judgement, *t*(14) = -2.43, *p* = .03 (Figure 7). That is, people who over-estimated their abilities were also responding faster when they believed they were doing the best, as opposed to the slower responding of people who were under-estimating their abilities.

Our sample size for the under-estimator group contained only three people, and though the current paradigm has been previously established as being sensitive to small sample sizes of three for memory and EEG related effects (Addante et al, 2012; Addante, 2015) we still wanted to be conscientious of possible issues related to small sample sizes in the DKE measure. Therefore, we also collapsed that group with the additional group of correct-estimators (N =

2) to create a more generic larger group (N=5). Over-estimators were still significantly faster than our collapsed generic group (*M* = 2457 ms, *SD* = 634 ms; *t*(18) = -2.56, *p* = .02) when responding that they thought they were doing the best (i.e. in the 90th percentile or above). The reaction times for over-estimators (N = 10) when rating themselves less than the 60th percentile (response ‘1’; *M* = 2204 ms, *SD* = 628 ms) were significantly slower than when over-estimators rated themselves in 90th percentile or above (DK response of ‘5’; *M* = 1656 ms, *SD* = 544 ms, N = 13), *t*(21) = 2.24, *p* = .04.

We next conducted a t-test between over-estimators (*M* = 2178 ms, *SD* = 602 ms, N = 11) and the combined group of correct- and under-estimators (*M* = 1604 ms, *SD* = 330 ms, N = 3) rating themselves in the 59th percentile or lower but there were no significant differences between their reaction times, *t*(12) = 1.56, *p* = .15, very possibly due to low sample size. Every other comparison of reaction times for responses of ‘1’, ‘2’, ‘3’, ‘4’, and ‘5’ were not significantly different between under-estimators and over-estimators (Table 7 for data).

One other effect involving reaction time emerged that was marginally significant based upon standard thresholds. The combined group of correct + under-estimators exhibited reaction times with the opposite pattern showing a slower average response time when rating themselves in the 90th percentile or above (*M* = 2457 ms, *SD* = 634 ms, N = 5) and a faster mean reaction time when rating themselves less than the 60th percentile (*M* = 1604 ms, *SD* = 329 ms, N =

3; *t*(6) = -2.12, *p* = .08). These marginal effects may be due to the low sample size in these groups (Figure 7).

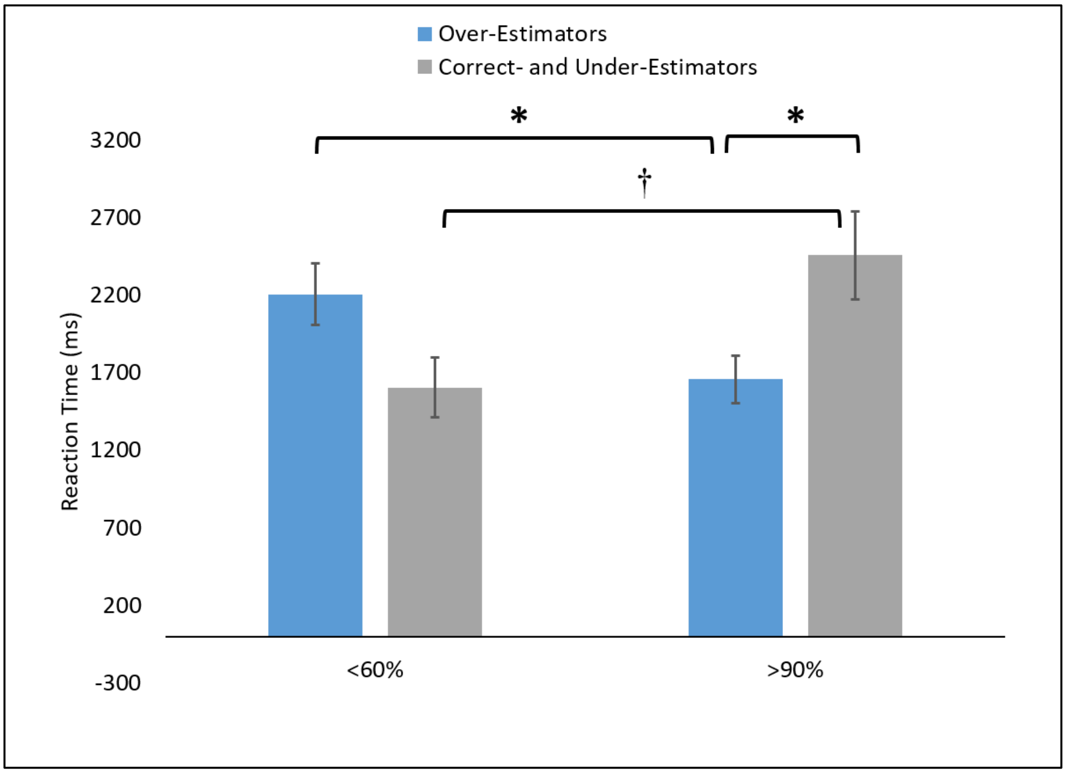

Figure 7. Mean Reaction Times of High and Low Percentile Estimation by Dunning-Kruger Groups.
Performing in the 59th percentile or below corresponds to response 1 on the task and performing in the 90th percentile or above corresponds to response 5. The reaction times are separated by over-estimators and the combined group of correct- and under-estimators. Mean reaction times are reported in ms. * = *p* < .05., † = *p* < .10.

Table 7. Response Distribution Proportions of Dunning-Kruger Responses and Mean Reaction Times, Standard Deviations, and Sample Size for In-Test Dunning-Kruger Judgments by Estimator Group

Group	Dunning-Kruger Judgments	1	2	3	4	5
Over-Estimators	Response Distribution	.05	.19	.39	.28	.09
(n = 36)	Reaction Time	2204	2064	1948	2044	1656
	SD	628	641	644	860	544
	N per Response	10	23	33	27	13
Correct-Estimators	Response Distribution	.09	.28	.33	.25	.05
(n = 8)	Reaction Time	1447	2323	2018	1920	2275
	SD	263	987	890	733	360
	N per Response	2	6	7	5	2
Under-Estimators	Response Distribution	.01	.21	.35	.38	.05
(n = 10)	Reaction Time	1918	2074	2166	1996	2579
	SD	--	1249	543	770	478
	N per Response	1	5	9	9	3
Combined Correct- and Under-Estimators	Response Distribution	.04	.24	.34	.32	.05
(n = 18)	Reaction Time	1604	2209	2101	1969	2457
	SD	330	1062	693	729	635
	N per Response	3	11	16	14	5

Note. Means and SD are in milliseconds.

Electrophysiological Results

Recognition Memory

Recognition memory was analyzed by comparing the physiology of ERPs for correctly identified old items (hits: responses of ‘4’ and ‘5’) to correctly identified new items (correct rejections: responses of ‘1’ and ‘2’). The scalp topographic maps for the item recognition difference wave (Hits - Correct Rejections) for every 200 ms are shown in Figure 8. A central positive effect (shown by warmers colors on the map) is evident beginning at 400-600ms. To establish the consistency of the current study’s effects with those of prior studies using the same memory paradigm, we analyzed this FN400 effect at the same Cz site as reported in Addante et al. (2012a); it was found to be a reliable effect at Cz ($t(54) = 3.80$, $p < .001$) but was also significant at several adjacent electrode sites, such as Pz ($t(54) = 3.41$, $p = .001$).

Consistent with prior findings on ERPs of recognition memory, this FN400 effect was then found to then shift towards the left parietal region during later latencies of 600-800ms, exhibiting maximal effects at the same left parietal site of CP5 reported in Addante et al., (2012a) (i.e. demonstrating the LPC effect, for reviews see Rugg & Curran, 2007; Friedman, 2013).

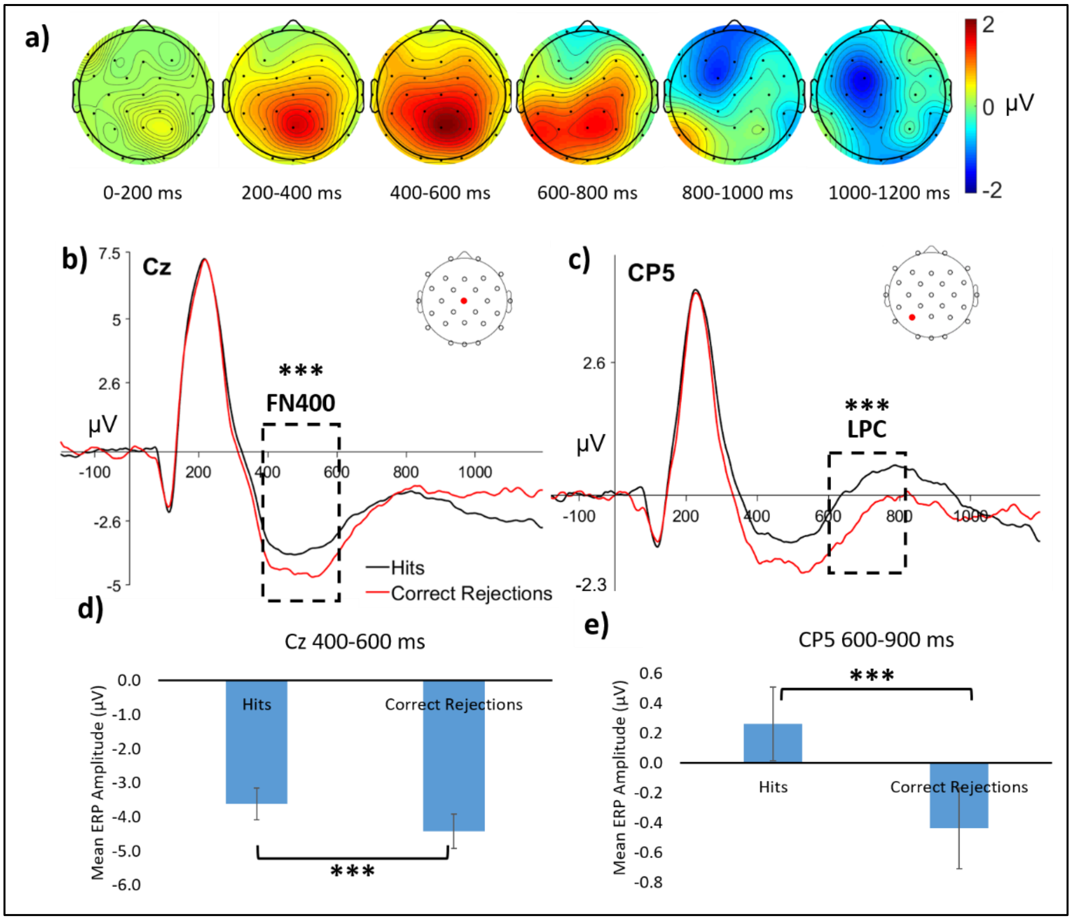

Figure 8. Event-Related Potentials for Recognition Memory.
a) Topographic maps of hits compared to correct rejections for every 200 ms interval. b) Cz shows an FN400 from 400ms to 600ms. c) CP5 shows an LPC from 600ms to 800ms, consistent with replicating prior findings in this memory paradigm (Addante et al., 2012a, 2012b). Mean ERP amplitudes for hits compared to correct rejection from d) 400-600 ms and e) 600-800ms. Compare to Addante et al., (2012), *Neuroimage*. * $p < .05$, ** $p < .01$, *** $p < .001$.

To assess the consistency with and replicability of similar neuropsychological findings reported of small samples (N = 3 and N = 6) while with the same paradigm (Addante et al., 2012b) we also compared item hits that were successfully recognized with low confidence (item response of ‘4’; *M* = -

5.13, *SD* = 0.66) to those hits that were recognized with high confidence (response ‘5’; *M* = -4.28, *SD* = 0.64). This revealed the same pattern of FN400 effects at mid-frontal sites (Fc1) from 400-600 ms (*t*(34) = 2.69, *p* = .01) and LPC effects at left parietal site (P3) from 600-900ms as was reported among hippocampal amnesia patients and controls by Addante et al., (2012b) *t*(34) = 3.21, *p* = .003 (low confidence hits: *M* = 0.59, *SD* = 0.48; high confidence hits: *M* = -0.41, *SD* = 0.42; Figure 9).

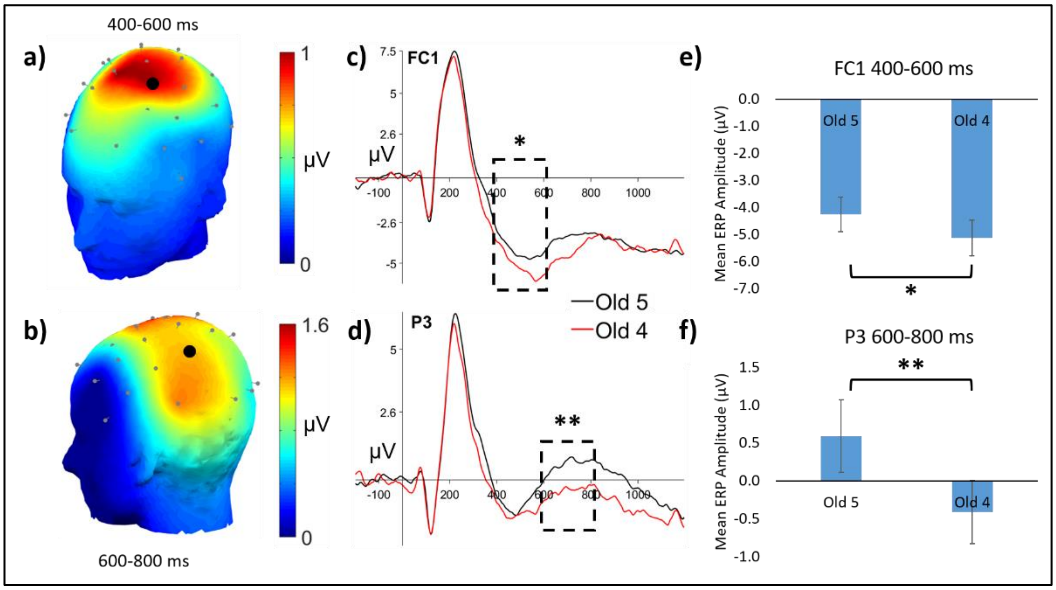

Figure 9. Event-Related Potentials for High Confidence Recognition and Low Confidence Recognition.
Topographic maps of high confidence item hits compared to low confidence item hits from a) 400-600 ms and b) 600-800 ms. Maps are range normalized with warmer colors indicating more positive differences in voltage. ERPs of high and low confidence recognition items at electrode sites c) FC1 and d) P3. The dashed box indicates latencies that represent significant differences in ERP amplitude. Mean ERP amplitude differences are shown at electrode site e) FC1 from 400-600 ms and f) P3 from 600-900ms. Compare to prior findings of Addante, et al., (2012), *Neuropsychologia*. * *p* < .05, ** *p* < .01, *** *p* < .001.

Source Memory

ERPs for source memory were analyzed by comparing judgments of both correct and incorrect source memory responses as compared to correct rejections. For source correct judgments, an FN400 effect was evident from 400-600 ms at Cz, again replicating findings from prior studies (Addante et al., 2012), *t*(54) = 3.97, *p* < .001. During later latencies of 600-800 ms, correct source judgments elicited the canonical LPC effect of recollection (Addante et al., 2012a,b, Rugg & Curran, 2007) maximal over left parietal site CP5, *t*(54) = 4.05, *p* < .001. For source incorrect judgements, an FN400 effect was evident from 400-600 ms at fronto-central site of Cz (*t*(54) = 2.85, *p* = .01), but there was no evidence of a reliable LPC effect at left parietal site of CP5 during the later latencies of 600-800 ms, as the source incorrect ERPs were not significantly different than correct rejections (*t*(54) = 1.98, *p* = .053) (Figure 10).

The prior analyses established the viability for the current paradigm in successfully eliciting the standard, canonical ERP effects of familiarity and recollection (the FN400, and LPC, respectively), but because our goal of assessing ERPs for the Dunning Kruger Effect will require assessing effects that are non-traditional and otherwise relatively novel and unexplored, we also wanted to first establish that the current paradigm would be an effective platform from which to detect those kinds of effects.

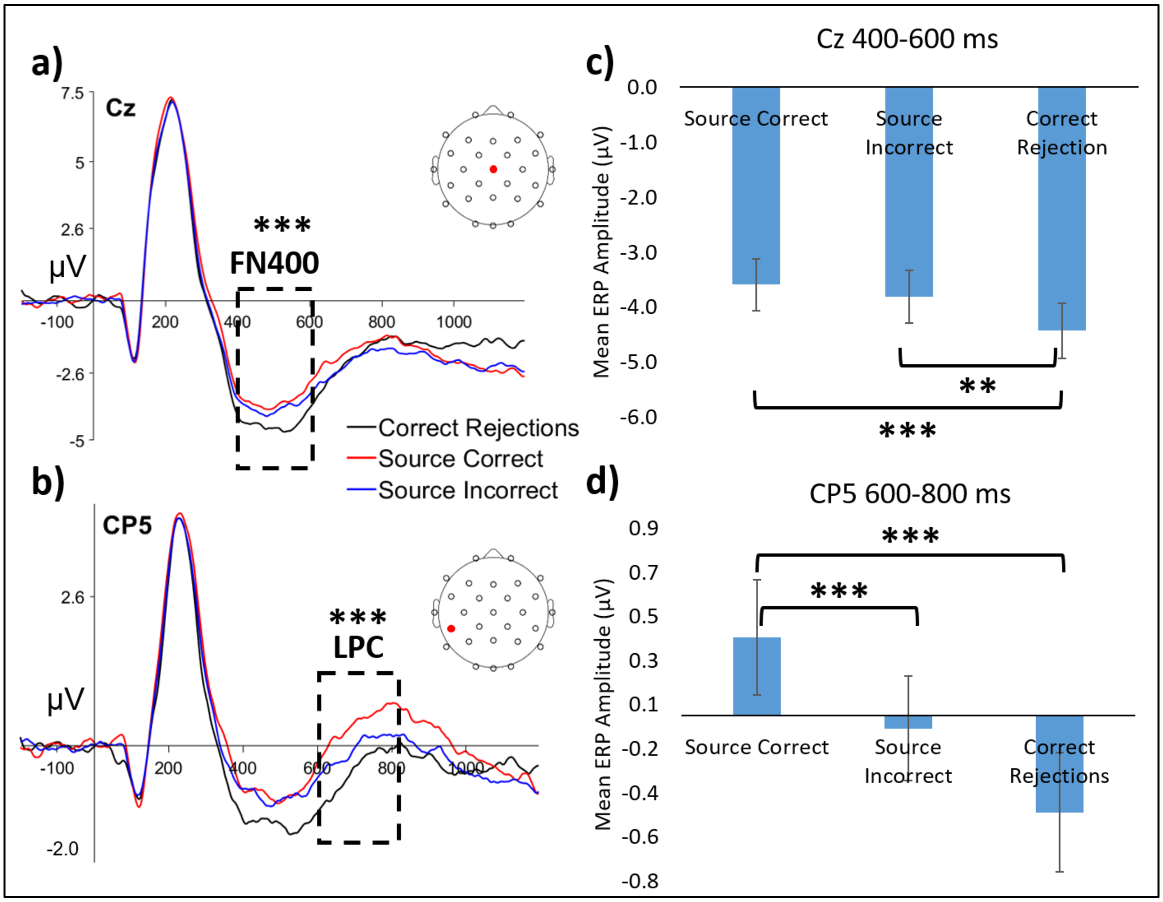

Figure 10. Event-Related Potentials for Source Memory.
ERPs of source correct judgements and source incorrect judgements compared to correct rejections at electrode site a) Cz and b) CP5. Bar graphs show the mean ERP amplitudes of source memory judgments for c) site Cz from 400-600 ms and for d) site CP5 from 600-800ms. Compare to Addante et al., (2012), Neuroimage. * $p < .05$, ** $p < .01$, *** $p < .001$.

For this reason, we also assessed the extent to which we could identify relatively novel ERP effects that were not the traditional ones for a memory task, and hence we analyzed a rare memory condition referred to as ‘context familiarity’, which has been reported earlier by Addante et al (2012a) for combinations of item+source memory responses that varied for high and low item confidence while holding source memory accuracy constant.

We assessed these conditions as compared to correct rejections, from 400-600ms for item familiarity, from 600-800ms at Cp5 for recollection, and from 800-1000ms at left frontal for context familiarity, as reported previously by Addante et al., (2012a). First, we replicated that high confidence item hits with correct source memory did elicit an LPC at a-priori electrode sites CP5, *t*(17) = 2.40, *p* = .03, and post-hoc visual inspection of the data revealed that these differences were evident maximally at P4, *t*(17) = 3.32, *p* = .004. Next, we found evidence of a significant negative-going effect from 800-1000 ms at left frontal and frontal-central electrode sites that had been previously reported by Addante et al. (2012a) for context familiarity processing, thereby replicating those findings with a larger sample size in the current study. This effect was maximal at left-frontal site F7, *t*(17) = -2.36, *p* = .03, and marginally significant at adjacent sites (Fc1, Fc5, and C3; representative site of Fc1: *t*(17) = -2.08, *p* = .053 (Figure 11)[2]. These results converge to replicate prior finding and give credence to the current paradigm's ability to detect reliable ERPs effects for novel cognitive processes.

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[2] Similar to Addante et al (2012a), low confidence hits with correct source memory judgments did not exhibit an FN400 for item familiarity at any electrode site from 400-600 ms, nor exhibit any evidence of an LPC for recollection-related processing at CP5 from 600-800 ms, *t*(17) = 0.09, *p* = .93.

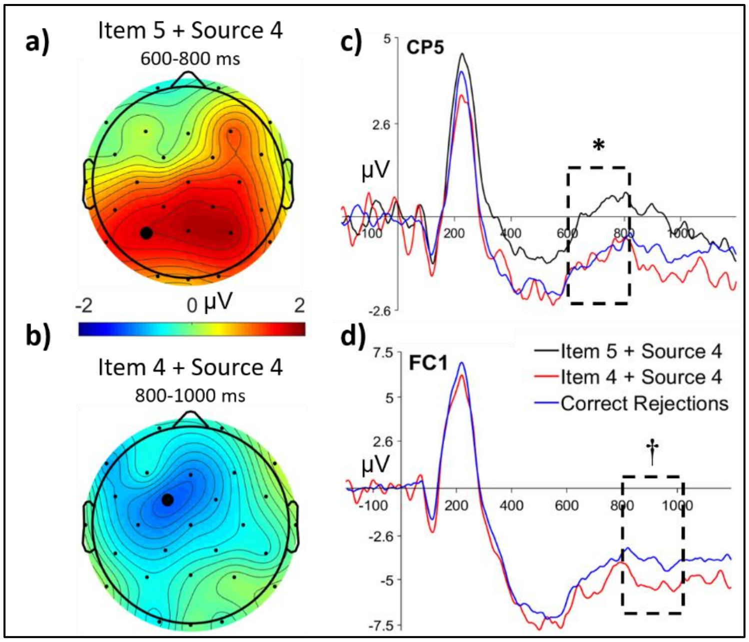


Figure 11. Event-Related Potentials for Contextual Familiarity.
Topographic maps show a) high confidence item recognition with low confidence source judgments (Item 5 + Source 4) compared to correct rejections from 600-800 ms and b) low confidence item recognition with low confidence source judgments compared to correct rejections from 800-1000 ms. The black dot in panel a indicates site P3 while the black dot in panel b indicates site FC1. c) ERPs show that an LPC effect is evident for Item 5 + Source 4 but not for Item 4 + Source 4 at CP5 from 600-800 ms. d) ERPs show that a negative-going effect is evident at FC1 from 800-1000 ms. The dashed box indicates the latencies of the ERP that represent statistically significant effects. The cross indicates latencies that are marginally significant. Compare to Addante et al., (2012), Neuroimage. * $p < .05$, ** $p < .01$, *** $p < .001$, † = $p < .10$.

Dunning-Kruger Effect

Because investigation into the electrophysiology of the DKE is novel and exploratory, the data were analyzed in several ways to probe several possible differences between judgements and cognitive strategies. First, we assessed for general differences that could be identified between the tasks of memory and metacognition. To do this, we compared the ERPs for all memory judgements collapsed together and compared that to ERPs for decisions in all of the Dunning-Kruger related judgments (Figure 12).

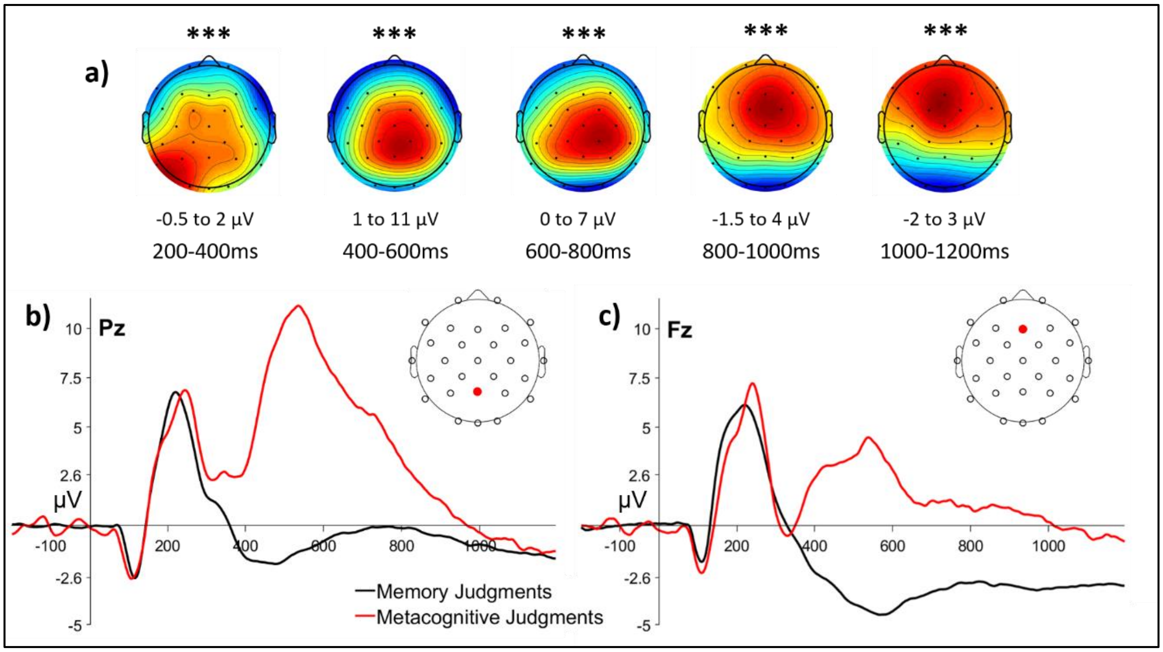


Figure 12. Comparison of Event-Related Potentials for Memory Judgments and Metacognitive Judgments Estimating Performance.
a) Topographic maps of ERPs for all memory judgments compared to all Dunning-Kruger judgments. Each topographic map is range normalized according to their mean latencies. Warmer colors represent more positive-going voltage differences. b) ERPs for memory and metacognition tasks at central parietal site Pz. c) ERPs for memory and metacognition tasks at mid-frontal site Fz. * $p < .05$, ** $p < .01$, *** $p < .001$.

This comparison revealed that activity for the metacognitive DKE decisions was significantly greater than those for memory judgements, starting from approximately 300 ms and continuing through 1000 ms at almost every electrode site. These effects were maximal at the central parietal site of Pz through 800ms (300-500 ms: $t(54) = 10.69$, $p < .001$; 400-600 ms: $t(54) = 15.19$, $p < .001$; 600-900 ms: $t(54) = 9.79$, $p < .001$.), upon which time the effects became evident as maximal at mid-frontal site Fz from 900-1200 ms ($t(54) = 6.46$, $p < .001$). This comparison was further examined by estimator group but no significant differences were found.

Are there differences in how different DKE groups were making their memory judgements? We next investigated physiological differences in memory as a function of the different DK groups (over-estimators, under-estimators, correct-estimators). Memory-related ERP effects (hits minus correct rejections, Figure 8 above) were analyzed as a function of DK group. At the 600 ms to 900 ms latency that characterizes the LPC of recollection-related memory processing, five electrodes in the left parietal region (CP5, CP1, Pz, P3, and P7: P3 is reported as a representative electrode) had a significantly higher amplitude for the under-estimator group ($M = 1.96$, $SD = 1.35$) than the over-estimator group ($M = 0.30$, $SD = 1.72$), $t(44)= 2.81$; $p = .01$ (Figure 13).

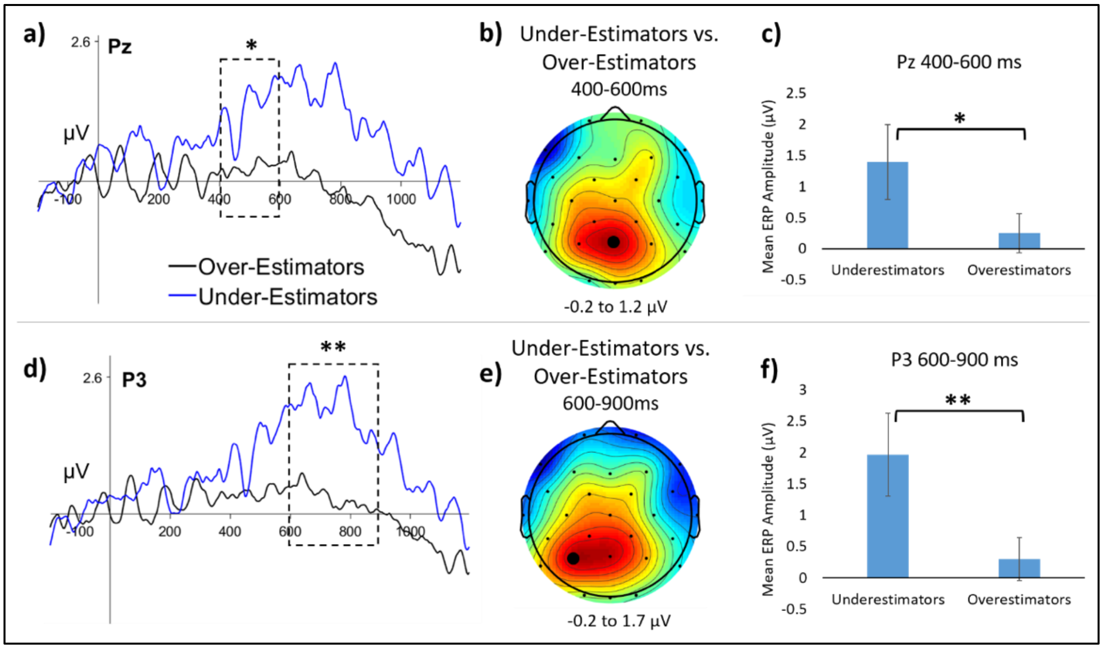


Figure 13. Difference Waves of Recognition Memory Event-Related Potential Effects for Dunning-Kruger Groups.
Difference waves for memory effects (hits - correct rejections, e.g. Figure 7) for Dunning-Kruger groups of Over- and Under-Estimators at electrode a) Pz and d) P3. The dashed box indicates the latency that represents statistically significant effects. Topographic maps show differences in memory effects at a) Pz from 400-600 ms and e) P3 from 600-900 ms. Each topographic map is range normalized according to their mean latencies. Warmer colors represent more positive-going voltage differences. Bar graphs show significant differences in mean ERP amplitude c) Pz from 400-600 ms and f) P3 from 600-900 ms. * $p < .05$, ** $p < .01$, *** $p < .001$.

This finding suggests that the under-estimator group, which consists of the highest performing individuals, relied on using more recollection than the over-estimator group in making memory judgments. Since the over-estimators constituted the lowest performing individuals, it is possible that one reason why they performed lower was because of lacking in recollection of those particular trials. We also found that under-estimators had a significantly higher amplitude (*M* = 1.39, *SD* = 1.59) than over-estimators (*M* = 0.25, *SD* = 1.38) maximally at Pz, *t*(44)= 2.24; *p* = .03, but also significant at P3, *t*(44)= 2.18; *p* = .03, from 400ms to 600ms. The difference was evident in the parietal region instead of the expected left frontal region characteristic of the FN400 (Figure 13).

Next, we investigated differences in physiology for the respective DK metacognitive judgments estimating how one thought they were doing on the task (this comparison is with the total group, not split by estimator group). ERPs of self-estimates in the 69th percentile or less (responses of ‘1’ and ‘2’) were collapsed together as a general metric of low self-estimates and were found to be significantly different than the high self-estimate category that ranged from self-estimates in the 80th percentile or above (responses of ‘4’ and ‘5’), maximally over electrode F8 from 600-900 ms, *t*(32) = -2.97, *p* = .006, but also significant at several adjacent electrode sites such as F4, *t*(32) = -2.54, *p* = .02.

We probed the effect further to investigate the contributions of particular responses. We could not compare the highest self-estimates (judgments of ‘5’) to the lowest self-estimates (judgments of ‘1’) due to low sample size in both categories (N = 3 for responses of ‘1’, N = 2 for responses of ‘5’). Thus, we compared 80-89th percentile self-estimates (judgments of ‘4’, N = 19) to 60-69th percentile judgments (judgments of ‘2’, N = 10) and found that the significant difference persisted maximally over the right frontal electrode F8, *t*(27) = -3.02, *p*

= .01, but was also significant at several frontal sites such as F4, *t*(27) = -2.59, *p* = .02 (Figure 14). These effects did not differ when analyzed by estimator group.

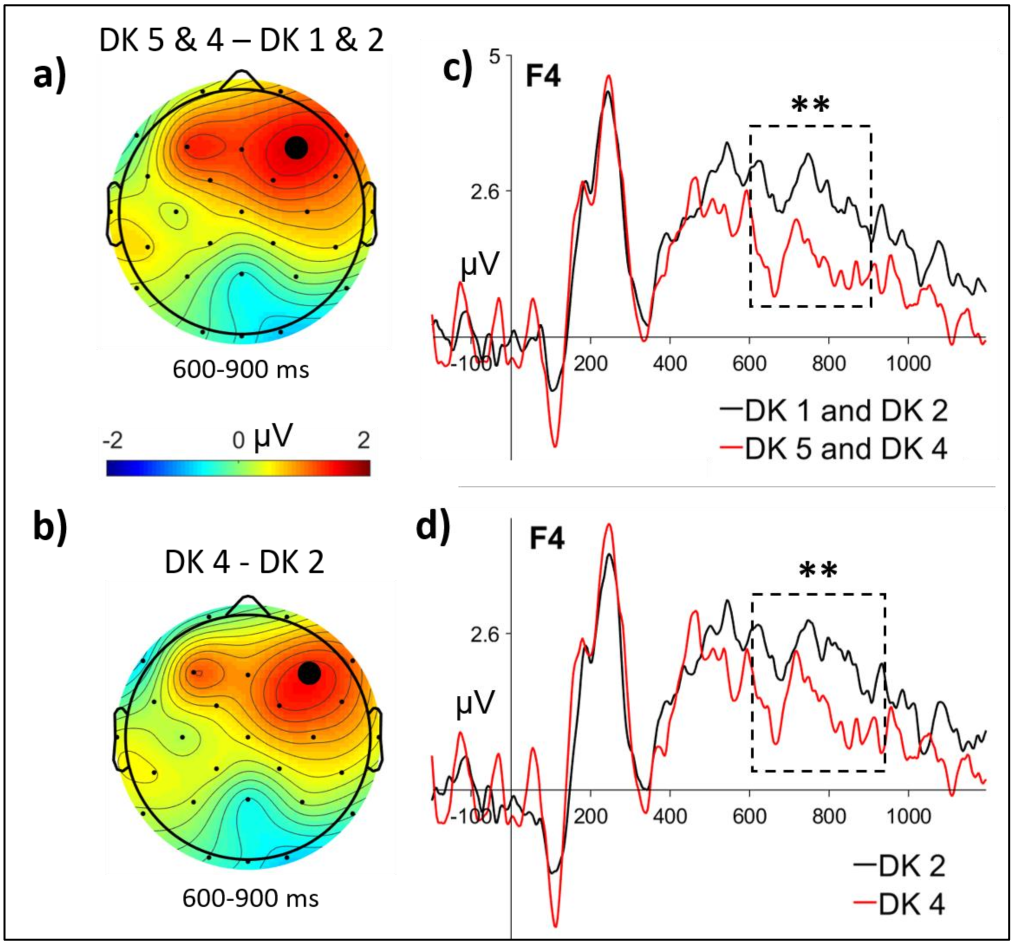


Figure 14. Event-Related Potentials Comparing High and Low Dunning-Kruger Self-Estimates.
a) Topographic maps of Dunning-Kruger responses of ‘5’ and ‘4’ for all subjects compared to Dunning-Kruger responses of ‘1’ and ‘2’ and b) Dunning-Kruger response of ‘4’ compared to Dunning-Kruger responses of ‘2’ separately at 600-900 ms. The black dot identifies electrode site F4 (where ERPs shown in panel b represent). c) and d) ERPs corresponding to each of the topographic maps are displayed directly to the right of their respective topography maps. The dashed box indicates the latency of the topographic map that represents statistically significant effects. * *p* < .05, ** *p* < .01, *** *p* < .001.

How do metacognitive judgments differ among good and bad, over- and under- estimators? To investigate this question, we analyzed group level differences in ERPs between the over-, correct-, and under-estimators by DKE response (all responses collapsed together). There were significant differences in ERP amplitude between the under-estimators and over-estimators at left-frontal electrode F3 from 150-250 ms ($M_{Over\text{-}Estimators}$ = 5.09, *SD* = 3.08; $M_{Under\text{-}Estimators}$ = 2.93, *SD* = 2.18; *t*(44) = -2.07, *p* = .04) and at mid-frontal electrode Fz from 400-600 ms ($M_{Over\text{-}Estimators}$ = 4.16, *SD* = 5.09; $M_{Under\text{-}Estimators}$ = 0.55, *SD* = 4.40; *t*(44) = -2.03, *p* = .048), such that ERPs for over-estimators/under-performers were far more positive than that of the under-estimators/over-performers. Mean ERP amplitude was also significantly different between Correct-Estimators (*M* = -1.30, *SD* = 2.92) and Under-Estimators (*M* = 1.64, *SD* = 2.33) at central electrode Cz from 800-1200 ms, *t*(16) = 2.38, *p* = .03.

This frontal effect at 400-600 ms may be characteristic of the FN400 ERP effect related to familiarity-based processing, in that over-estimators may be under-performing because they are relying on the less-specific memory process of familiarity to make their metacognitive judgments reflecting upon their past performance, instead of the recollection-related processes that appear to be supporting those who were found to be over-performing/under-estimating (Figure 15).

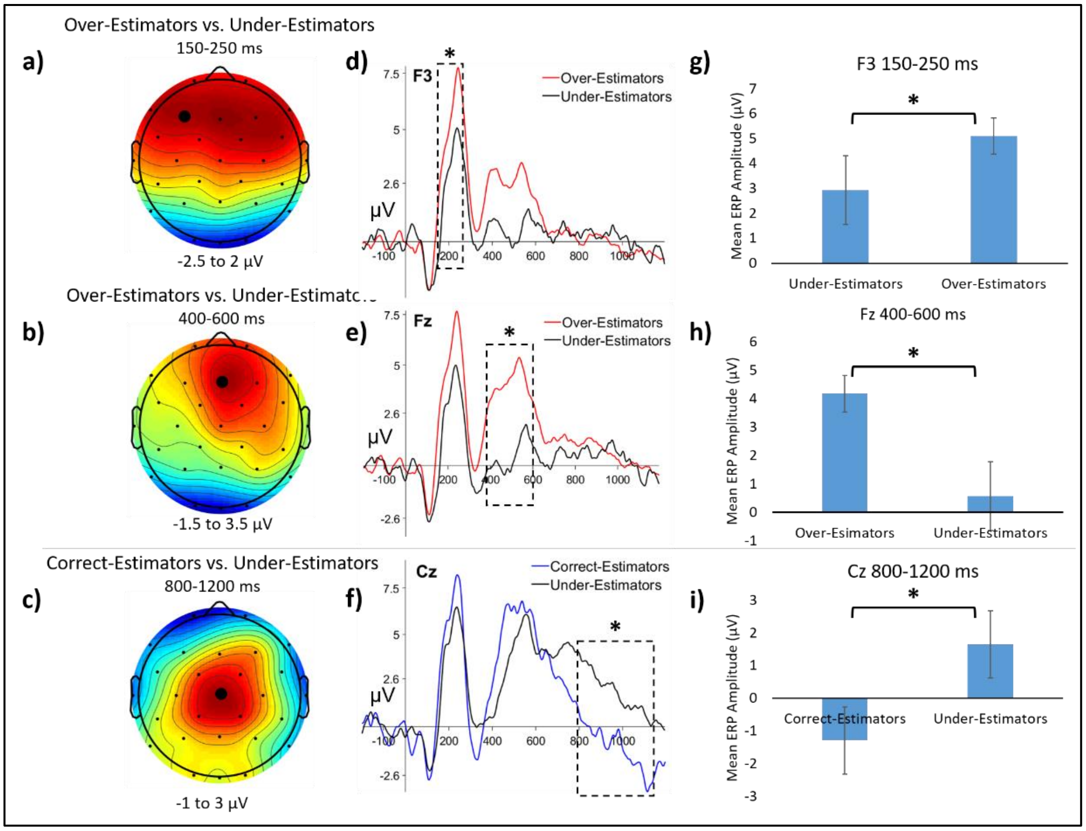


Figure 15. Event-Related Potentials of Collapsed Dunning-Kruger Responses by Dunning-Kruger Group.

Topographic maps show ERPs of collapsed Dunning-Kruger responses (Dunning-Kruger judgments 1, 2, 3, 4, and 5 combined) for Over-Estimators compared to Under-Estimators from a) 150-250 ms and b) 400-600 ms and c) for Correct-Estimators compared to Under-Estimators from 800-1200 ms. Each topographic map is range normalized according to their mean latencies. Warmer colors represent more positive-going voltage differences. d), e), and f) show ERPs corresponding to each topographic map to left. g), h), and i) show bar graphs displaying the mean ERP amplitudes corresponding to each ERP and topographic map on the left. The dashed line indicates the time differences that ERPs are significantly different between the groups compared. * $p < .05$, ** $p < .01$, *** $p < .001$.

CHAPTER FOUR

DISCUSSION

Recognition and Source Memory Results

The primary goal of this experiment was to investigate the physiology of the DKE by using EEG to record brain activity during self-estimates of performance in an episodic memory task. However, to help establish the reliability of our physiological effects for the DKE (which is rather new and exploratory), it was important to show that our behavioral and physiological findings for memory were consistent with past research. We first review the results of the current study for measures of episodic memory, and then review the results for the Dunning-Kruger judgments.

By using a well-established memory paradigm (Addante et al, 2011, 2012a, 2012b; Addante, 2015; Roberts et al., 2018), we were able to replicate several memory effects in the literature. We first identified basic memory effects ubiquitous in the literature that old items are remembered better and responded to faster than new items (Tables 1 and 2), and that ERPs for these items were associated with the canonical effects of the FN400 and LPC that are traditionally viewed as the putative neural correlates of familiarity- and recollection-based memory processing (Figures 8 and 9) (e.g. Addante et al., 2012b; for reviews see Sanquist, 1980; Curran, 2000; Rugg & Curran, 2007; Friedman, 2013). We also identified behavioral and physiological effects for source memory, revealing that an FN400 effect was evident for both conditions of source correct and source incorrect trials, but that the LPC was evident only for the source correct trials (Figure 10) consistent with earlier findings from this paradigm (Addante et al., 2012a, b) and also consistent with theoretical models positing recollection and familiarity as dual processes of episodic memory (Yonelinas, 1999; 2002; Yonelinas et al., 2004; 2010).

The current study was also able to extend several recently-reported ERP effects of memory that have remained relatively unexplored in the field, and hence benefiting replication and extension in order to further understand these phenomena. In particular, Addante et al. (2012a) reported a novel late front-parietal ERP effects described as “context familiarity” for instances in which participants provided low-confidence item memory hits that still had accurate source memory judgments for their studied task’s context. Our results replicated these findings, and did so with a larger sample size, in a different laboratory, and using a different subject population (Figure 10). The current study extended those physiological findings by also reporting behavioral measures of reaction times for the conditions of context familiarity, and contrasted that with recollection-related responses. This revealed reliable differences in how subjects were responding in these instances: participants responded faster to the high confidence recognized items than low confidence recognized items (Figure 4). This extends the ERP findings by demonstrating that they are not epiphenomenal and reflecting distinct cognitive processes retrieving memories of context that are independent of those with recollection (Addante et al., 2012a).

Together, these ERP and behavioral results replicating traditional memory-related effects in the data provide convergent evidence that our study was effective at eliciting the neural-correlates of memory processes such as recollection and familiarity. More importantly, they establish that our dataset can be used for novel explorations into metacognition-related physiology for which there is a much sparser ERP literature from which to draw comparisons. These findings give us confidence that the data set is reasonably uncontaminated by artifacts (such as blinking, eye saccades, and muscle activity), and is otherwise acceptable for further exploration in new domains.

The Dunning-Kruger Effect

Dunning-Kruger Behavioral Results

To assess the DKE, we first sought to establish the viability of the adapted episodic memory paradigm for eliciting the canonical Dunning-Kruger pattern of results, which is a necessary and critical step. To our knowledge, the DKE has not been previously explored in episodic memory tasks, nor in other tasks using repeated self-estimate trials rather than a one-time post-test self-estimate (e.g. Dunning & Kruger, 1999). Our task employed Dunning-Kruger estimates interspersed throughout an on-going episodic memory test, which was an innovation in integrating these methodologies into behavioral tasks. The current study's paradigm also permitted the collection of reaction times for Dunning-

Kruger judgments that could be analyzed at a group level, which prior studies of the DKE had not been able to investigate due to their use of one-time measures.

The results from our behavioral measures revealed that the memory paradigm was indeed successful at eliciting the DKE. Participants were separated into quartiles and their actual percentile ranking in the group was plotted alongside their estimated percentile ranking (Figure 5). The lowest performing participants in the bottom quartile were found to have drastically overestimated how highly they ranked in their groups while the highest performing participants underestimated their actual ranking. This basic finding was important to identify, and its establishment permitted us to continue to explore the data in more specific ways in both behavioral and electrophysiological domains.

For measures of reaction time, over-estimators were discernably faster than under-estimators in judging themselves to be in the top percentile, but they were slower to judge themselves as being in the bottom percentile. There are three theoretical accounts that can be used to explain the reaction times for under- and over-estimators: cognition, social interactions, and the traditional Dunning-Kruger account of double ignorance (1999).

The first account uses cognition for prototypes to explain the reaction time patterns. Kruger and Dunning's (1999) results suggest that over-estimators do not understand that they are performing poorly and so they believe they are performing well and placing well within their participant group. This could lead to them having a very positive perception about their ability to perform well on certain types of tasks. Research on prototypes has shown that answers to questions that are very obviously true (closest to one's prototype) are answered faster (for example, the question, "Is a robin a bird?" will elicit a faster "yes" response than the questions "Is an ostrich a bird?" even though both are true) (Rosch, 1974; Collins & Quillian, 1969). Therefore, if a person's perception of oneself (or prototype of themselves) includes that they perform well on tasks, they will be more likely to give a fast response when rating themselves well as opposed to rating themselves poorly. On the other hand, if they believe they are performing poorly, this perception would oppose the prototype that they have formed causing them to react slower to rating their performance negatively. The same may be true If under-estimators have formed a perception about themselves that they are only average or even below average. It would then be logical that they would be slow to rate themselves as being the best and quick to rate themselves as being less than the best.

The second account by which the current findings for DKE reaction times could be viewed is the need to belong theory proposed by Baumeister and Leary (1995). The need to belong theory states that individuals have a need to form social attachments with other individuals and without such attachments, physical and/or mental consequences will ensue. The reaction time patterns found can be explained in this framework of desiring to maintain social attachments by being able to relate to others. Under-estimators are the individuals who perform better than average; therefore, if they feel they are performing less than average, they may be faster to respond to attempt to prove they are like the in-group. However, if they are performing well, they may respond slower to rating themselves in the top percentile for fear of being ostracized. Over-estimators may have the same mentality. They are the individuals who perform less than average and if they feel they are performing better than average, will respond faster to be accepted by the group and seen as smart. Otherwise, if they feel they are not performing well, they may be slower to respond for fear of being disliked because of their low performance.

The third account that the reaction time results can also be explained is by using Kruger and Dunning’s (1999) model of double ignorance of low performers (i.e. 1. They do not know the answer, 2. They do not know they are ignorant of the answer) together with the inability of high performers to estimate their place among their peers due to not realizing the weaknesses of their peer group. By this account, over-estimators would be fast to report that they are doing well because they believe they are actually doing well, while they are slow to report that they are performing poorly because they do not believe they usually perform poorly or do not want to admit to themselves that they are performing poorly.

Dunning-Kruger Physiology

We began exploring the neurophysiology of the DKE by examining brain activity for general differences in processing between the memory and metacognition tasks; that is, assessing the extent to which these two judgment types could be established as reflecting different kinds of processing. We assessed ERPs between all memory trials versus all self-estimates, and they were found to be different beginning from approximately 300 ms into the epoch and continuing throughout the epoch to 1200 ms at almost every electrode site, but being maximal first at posterior parietal sites and then later at mid-frontal regions (Figure 12). This indicated that subjects were processing the metacognitive judgments of the DKE in substantively different ways than a baseline condition of memory-based stimulus processing, and revealed that our paradigm could reliably detect these differences with the available trial counts of DK judgments and the precision of the ERPs.

The pattern of the ERPs (Figure 12) indicated that the large centro-parietal and mid-frontal effects, respectively, were reflecting patterns consistent with established properties of the P300 ERP effect, or P3a and P3b effects, that are known to have the same distributions of topography and latency, and which have been well-established as being associated with novelty processing (Dien, Spencer, & Donchin, 2003; Otten & Donchin, 2000; Simons, Graham, Miles, & Chen, 2001). This is consistent with the paradigm in that the DKE judgments were uncommon trials that appeared among the common memory trials in the test, and would have been salient stimuli for eliciting an orienting effect of attention as a novelty item (Kishiyama, Yonelinas, & Lazzara, 2006; Knight, 1996; Knight & Scabini, 1998).

Having established that the paradigm had sufficient signal-to-noise sensitivity for successfully identifying the physiology associated with DKE judgments, we next explored whether these different metacognitive judgments were associated with differential ERP patterns. When brain activity of all Dunning-Kruger responses were investigated together, over-estimators were found to have a higher mean ERP amplitude than under-estimators at frontal electrode sites during 400-600 ms (Figure 15). ERP effects varied as a function of whether people were performing well or performing poorly, suggesting that these ‘perceptions of grandeur’ may be caused by an over-reliance on a sense of familiarity, as opposed to recollecting the clear details of their past encounters from which to guide the proper placement of the perceptual judgments. Under-estimators, on the other hand, exhibited a larger LPC than over-estimators did from 600-900ms during memory judgments (hits to correct rejections; Figure 13), indicating that these humble under-estimators may be estimating their performance by reliance upon the clearer details of recollected information, as opposed to the fuzzy sense of familiarity that can come with less accuracy (Yonelinas et al., 2004; 2010).

Implications

This experiment had several novel contributions to the understanding of the DKE. First, this is the only Dunning-Kruger experiment, to our knowledge, in which self-estimates relative to a peer group were recorded repeatedly throughout the task. That is, normally, self-estimates in prior studies are only acquired once: at the end of the task (Adams & Adams, 1960; Burson, Larrick, & Klayman, 2006; Ehrlinger & Dunning, 2003; Kruger & Dunning, 1999; Oskamp, 1965; Pennycook, Ross, Koehler, & Fugelsang, 2017; Ryvkin, Krajč, & Ortmann, 2012a; Sanchez & Dunning, 2018) although there was a variation of the task using repeated estimates before the task itself (Simons, 2013). This novel adjustment to the classic Dunning-Kruger paradigm was critical to collecting both reaction time measures and brain activity during the metacognitive self-estimates.

Our finding that under-estimators had a larger LPC than over-estimators is a novel finding and gives some insight into the inaccurate estimates that occur in over-estimators. Because the over-estimators (under-performers) had a smaller LPC, this finding suggests that they used less recollection during episodic memory retrieval. It is then logical to suggest that their memories for episodic events were diminished as well, leading to more inaccuracies when trying to recall episodic events related to their performance.

We also found evidence of differences in brain activity between under-estimators and over-estimators when collapsing brain activity for all Dunning-Kruger metacognitive responses. Over-estimators had a larger ERP mean amplitude than under-estimators at mid-frontal electrode sites from 400-600ms, which is the characteristic position and latency of the FN400 that has been synonymous with familiarity in many prior studies (Addante et al., 2012; Curran, 2000; Friedman, 2013; Gherman & Philiastides, 2015; Rugg et al., 1998; Rugg &

Curran, 2007). In the framework of a memory-related interpretation of these results, one could argue that because we found an FN400 in this condition, over-estimators may have relied more upon familiarity than under-estimators in making these judgments, in lieu of the recollections that under-estimators were evidently relying upon instead. That is, each group was arriving at fundamentally different metacognitive conclusions because they were relying upon, or being influenced by, fundamentally different neurocognitive processes of memory.

Limitations and Considerations for Future Research

Interpreting ERP findings of FN400 and LPC effects should always be doen with caution, relative to experimental conditions and inherent constraints (Paller, Lucas, & Voss., 2012; Voss, Lucas, & Paller, 2012); this remains true when interpreting ERPs associated with Dunning-Kruger judgments. An important consideration is to avoid an over-reliance on reverse inference, since effects like the FN400 have also been characterized as including contributions of other cognitive processes such as implicit fluency and conceptual priming (Voss & Paller, 2010, 2012; Leynes & Zish, 2012; Leynes & Addante, 2016). For these and other reasons, we believe that the current work, while provocative, is best viewed as motivating future research that can further investigate these effects, extend them, and test them against competing hypotheses.

There were some limitations in the design of the current study that could be addressed in future research. The scale that was used to report percentile self-estimates was limited to five button presses. The reason why the Dunning-

Kruger estimates used a five-point scale was because we sought to keep response options easy for participants using the same 5-point scale in the memory judgments. However, that meant that the lowest participants could indicate their percentile ranking was 59th percent and below which is more than half of the scale. Previous research on the better-than-average effect (Alicke & Govorun, 2005; Brown, 2012) has shown that participants are motivated to rate themselves more highly than other individuals, especially on important matters. Therefore, this effect gives support to the validity of our scale but we recognize that a considerable amount of sensitivity is lost due to this adapted scale.

In addition, anchoring effects may have played a role in determining which buttons participants pressed. Anchoring effects occur when answers remain close to offered information and correct answers are not searched for when far away from initially offered choices (Epley & Gilovich, 2006; Tversky & Kahneman, 1974). Though it would be impractical to expect naturalistic subjects to necessarily have an equal distribution of honest responses across our scale, participants pressed ‘1’ and ‘5’ much less often than ‘2’, ‘3’, or ‘4. This may have been due to anchoring effects because participants were told to fixate on the middle of the screen to avoid eye movements and the response of ‘3’ was shown in the middle of the screen. Therefore, participants may have anchored onto ‘3’ which could explain why it was the most chosen response.

One way to address both of these issues in future research is to have participants speak their estimated percentile ranking using a digital microphone, (i.e.: the SV-1 Voice Key https://www.cedrus.com/sv1/), that is engineered to record precise reaction times by logging when a sound above a certain threshold is reached. Our lab has recently developed procedures for doing this in ERP studies of cued-recall in episodic memory (Sirianni & Addante, 2019; manuscript in preparation). In future work utilizing such designs, participants could be given a prompt on the screen to speak their estimated percentile ranking on a scale of 0 to 99, which would provide a more sensitive scale and possibly even better resolution of DKE estimates than our current Likert scale options much the way that improved resolution measures have revealed insightful advances in understanding working memory (Koen, et. al., 2017; Kolarik, et al., 2017; Yonelinas, 2013; Zhang & Luck, 2008, 2015).

Summary and Conclusions

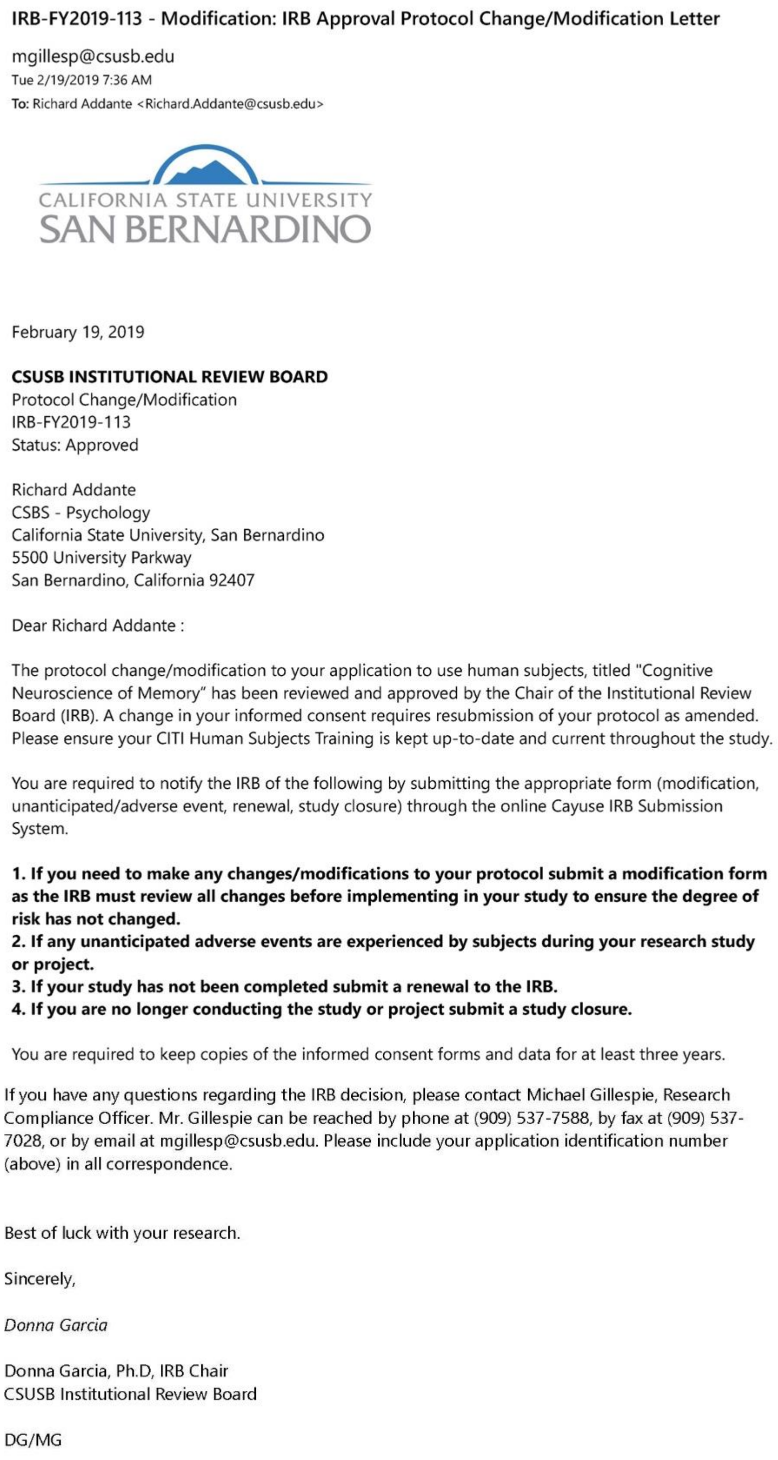
By establishing that we can extend the DKE to studies of episodic memory, in which we can measure both response speeds and physiology occurring over multiple samples, we were able to identify physiological correlates that distinguished Dunning-Kruger responding. These findings of differing physiology between under- and over-estimators have large implications for the field of social cognition. By investigating the underlying neural correlates of this effect, we can begin to categorize exactly why or how such illusory errors of metacognition are occurring. Our finding that over-estimators (under-performers) have a smaller LPC related to recollection-based processing introduces the possibility of developing countermeasures to improve their memory (such as entrainment devices known to improve memory in our paradigm (Roberts et al., 2018)) or non-invasive brain stimulation such as transcranial direct current stimulation (tDCS) and investigate if their self-estimates improve in accuracy with better memory (Boudewyn, Roberts, Mizrak, Ranganath, & Carter, 2018; Cappiello, Xie, David, Bikson, & Zhang, 2016; Mizrak et al., 2018). More experimentation is needed to assess exactly what cognitive processes are being employed, but the present work may constitute an important first step in identifying them.

The current study thus represents a step forward in understanding one of the most pervasive observations about human behavior: persistent metacognitive illusions that cause us to both over-estimate and under-estimate our performances. Those who tend to perform best often under-estimate, whereas those who perform worst tend to over-estimate the most. This pernicious pattern has been observed by thinkers from Aristotle to Confucius and throughout the modern age. The basic premise of the DKE - that we have inherent illusions of metacognition and self-assessment- is thus a fundamental force that shapes our psychological universe in much the way that gravity is a fundamental force that shapes our physical universe. As gravity works to shape our physical world, our abilities to make metacognitive assessments of ourselves can likewise be seen as one of the parallel natural forces at work in shaping our own psychological universe. The effect is timeless, discriminates upon no one, and affects everyone at some point, large or small. Overcoming these psychological errors is possible, but like overcoming gravity, it takes energy, resources, and concerted effort, and then persists only for transient moments in time until returning back to baseline levels.

In conclusion, empirical investigations into the DKE have to date been limited to behavioral measures of simple tasks that collected only one metacognitive judgment per task, and that lacked any physiological measures of the neurocognitive processes underlying this phenomenon. The current study adds to the literature in several ways: First, it represents the first known physiological recordings of the DKE. Second, this was made possible by using an integrative new paradigm that permitted multiple recurring trials of Dunning-Kruger metacognitive judgments. Third, this paradigmatic innovation made it possible to capture the DKE in a complex episodic memory task which extends the body of work on the DKE from logic and math problems used in prior studies. Fourth, the current study also contributed the first known behavioral data measuring reaction times for these metacognitive decisions, providing revealing insight into why people differ in this phenomenon. We hope that this work can inspire new explorations to discover the neural correlates of our psychological processes, with the overarching goal of better understanding human behavior and cognition.

APPENDIX A

INSTITUTIONAL REVIEW BOARD



IRB-FY2019-113 - Modification: IRB Approval Protocol Change/Modification Letter

mgillesp@csusb.edu
Tue 2/19/2019 7:36 AM
To: Richard Addante <Richard.Addante@csusb.edu>

CALIFORNIA STATE UNIVERSITY
SAN BERNARDINO

February 19, 2019

CSUSB INSTITUTIONAL REVIEW BOARD
Protocol Change/Modification
IRB-FY2019-113
Status: Approved

Richard Addante
CSBS - Psychology
California State University, San Bernardino
5500 University Parkway
San Bernardino, California 92407

Dear Richard Addante :

The protocol change/modification to your application to use human subjects, titled "Cognitive Neuroscience of Memory" has been reviewed and approved by the Chair of the Institutional Review Board (IRB). A change in your informed consent requires resubmission of your protocol as amended. Please ensure your CITI Human Subjects Training is kept up-to-date and current throughout the study.

You are required to notify the IRB of the following by submitting the appropriate form (modification, unanticipated/adverse event, renewal, study closure) through the online Cayuse IRB Submission System.

1. If you need to make any changes/modifications to your protocol submit a modification form as the IRB must review all changes before implementing in your study to ensure the degree of risk has not changed.
2. If any unanticipated adverse events are experienced by subjects during your research study or project.
3. If your study has not been completed submit a renewal to the IRB.
4. If you are no longer conducting the study or project submit a study closure.

You are required to keep copies of the informed consent forms and data for at least three years.

If you have any questions regarding the IRB decision, please contact Michael Gillespie, Research Compliance Officer. Mr. Gillespie can be reached by phone at (909) 537-7588, by fax at (909) 537-7028, or by email at mgillesp@csusb.edu. Please include your application identification number (above) in all correspondence.

Best of luck with your research.

Sincerely,

Donna Garcia

Donna Garcia, Ph.D, IRB Chair
CSUSB Institutional Review Board

DG/MG

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