BELIEFS ABOUT PROCESSING FLUENCY CAN IMPACT JUDGMENTS OF LEARNING WITHOUT DIFFERENTIAL PROCESSING FLUENCY

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by

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I. Introduction

Metacognition is the study of peoples’ thoughts about ongoing cognitive processes (Flavell, 1979; Dunlosky & Metcalfe, 2009). Metacognition broadly covers any cognitive activity that a person can engage in, but in the present work the primary concern is the thoughts that people have about their ongoing cognitive activity when considering how difficult it may be to remember something in the future. Consider a situation in which a person judges whether the word “dog” will be easier to remember than the non-word “arage”. For these items, a person may think the word is easier to remember due to it being from the language they have learned across their lifespan, whereas the non-word has no prior associations that will make it particularly easy to remember. The metacognitive knowledge from this example (i.e., having a belief about the memorability of words and non-words) may influence two reciprocal metacognitive processes: monitoring and control.

1.1. Monitoring and Control
Monitoring refers to the assessment of the ongoing cognitive activity, and in the present case a person may monitor by evaluating of the likelihood of remembering a particular piece of information, commonly known in the metacognitive literature as a judgment of learning (JOL). Control processes involve regulating ongoing cognitive activity, which is demonstrated by a person spending more time studying a piece of information, stopping the study of that information, or engaging in other cognitive activity. Monitoring of ongoing cognitive activity informs control processes, which in turn updates the monitoring of that activity (i.e., how well something is retained in memory). In the above example, realizing that the non-word may be more difficult to remember a learner may
engage in longer amounts of study time, and engaging in a longer period of study may better encode the non-word in memory leading to an increase in their JOL for that non-word (Dunlosky & Thiede, 1999).

For control to be effective, monitoring of the ongoing cognitive activity must be accurate. The previous example assumes that the learner is making accurate judgments (i.e., that the non-words are actually more difficult to remember than the words they are studying), and this will lead them to engage in studying the non-words for a longer period of time. Now consider the case where a learner inaccurately judges that non-words would be just as easy to remember as words. The learner’s inaccurate judgments may lead their control decisions to be ineffective (i.e., studying non-words and words for the same amount of time), and hence fewer non-words may be subsequently remembered. Thus, the reciprocal system begins to break down when inaccurate monitoring occurs. Many examples of inaccurate monitoring are reported in the literature (for a review see Bjork, Dunlosky, & Kornell, 2013), which highlights the importance of investigating how people monitor their memory and what leads to metacognitive illusions.

Thus, in the present work, I will focus on investigating people’s JOLs, which is the most widely investigated metacognitive judgment. The original work on JOLs by Arbuckle and Cuddy (1969) had participants study paired associates and predict the likelihood of remembering them in the future. Participants were able to accurately predict which paired associates they would remember on a final test. This established that people are able to evaluate how well information is encoded in memory (see also, King, Zechmeister, & Shaughnessy, 1980). This outcome has important implications for investigating student learning, because if people are able to accurately monitor their
learning, then they should be able to make effective restudy decisions for information that they think they will not remember in the future. This was originally established by Nelson, Dunlosky, Graf, & Narens (1994) by having participants make JOLs following study and then allowing them to restudy the information they had given the lowest JOLs (for evidence that JOLs are causally related to restudy decisions, see Finn & Metcalfe, 2008). Although the relationship between judgment accuracy and student learning has been widely investigated, the underlying factors that contribute to making JOLs during study is still unknown.

1.2. Contributing Factors to Judgments of Learning

The most widely cited paper in the JOL literature suggests that people use different kinds of cues during learning in order to make their JOLs (Koriat, 1997). More recently, JOLs are considered to be influenced by at least two factors that could contribute to their (in)accuracy: beliefs and processing fluency (Koriat, Bjork, Sheffer, & Bar, 2004). Beliefs are explicit knowledge that the learner has about the cues available to the learner during study and at the time of making the JOL. In the previous example with words and non-words, the learner may have an explicit belief that “non-words are more difficult to remember than words” and this belief will lead them to give higher JOLs to the words than the non-words. Importantly, this belief is accurate in terms of future memory performance and may help the learner make better control decisions. However, the basis for their JOL may instead be an inaccurate belief such as “words and non-words are equally memorable” or “non-words are more distinct, therefore I will remember them better”. Using either of these inaccurate beliefs to make their JOL could lead to inaccurate control decisions. Thus, inaccuracies in monitoring can be due to inaccurate
beliefs. Learners can also use processing fluency, which is the ease of processing information, as a basis for their judgments. Processing fluency is thought to have an unconscious influence on the learner’s judgments, due to learners making an attribution that the ease of processing something will lead to better memory performance in the future. Thus for words and non-words (assuming that the non-words are more difficult to process) the learner would give higher judgments for words, because they are comparatively easier to process than the non-words.

Processing fluency has become a dominant construct for explaining human judgment. When a stimulus is easily processed, it presumably evokes a subjective feeling of familiarity that leads to higher judgments in many contexts. For instance, when a stimulus is more easily processed, then it receives a higher judgment of liking, truth, typicality, confidence, and fame (for reviews, see Alter & Oppenheimer, 2009; Jacoby, Kelley, & Dywan, 1989; Unkelbach & Greifeneder, 2013a). Some evidence, however, suggests that fluency may not always impact judgments and that some effects that are attributed to fluency actually arise from other factors (Mueller, Dunlosky, Tauber & Rhodes, 2014; Poldrack & Logan, 1997; Susser, Jin, & Mulligan, in press). My thesis is not that fluency plays no role in human judgment, but instead that its role can be tenuous and other factors – such as people’s beliefs about fluency – can produce effects that may be mistakenly attributed to the subjective experience of fluency.

I will explore this claim in the context of JOLs. A common interpretation of the prevailing evidence is that JOLs are largely driven by processing fluency at study. Nevertheless, the evidence is ambiguous, and rarely do investigators measure processing fluency to evaluate its contribution (but for recent exceptions, see Ball, Klein, & Brewer,
2014; Besken & Mulligan, 2014; Magreehan, Serra, Schwartz, & Narciss, 2015; Susser & Mulligan, 2014; Undorf & Erdfelder, 2015). And, when fluency is measured (e.g., by response latency), any empirical relation between latency and judgments can be explained by other factors (for details, see Dunlosky & Tauber, 2014; Matvey, Dunlosky, & Guttentag, 2001; Undorf & Erdfelder, 2011; 2013). Consider the font-size effect on JOLs (Rhodes & Castel, 2008), where JOLs are higher for words studied in a larger (48 pt) versus smaller (18 pt) font size. This effect was widely attributed to fluency (for a review, see Mueller et al., 2014), and it seems plausible that larger words are easier to process. Nevertheless, recent evidence suggests that most people believe that memory is better for larger words because they also believe that the larger words are easier to process. Thus, having this belief about processing fluency appears to produce the font-size effect (Mueller et al., 2014) and not differential processing fluency per se.

1.3. Analytic Processing Theory

According to analytic processing (AP) theory, instructing people to predict memory performance triggers analytic problem solving in which people search for cues to reduce uncertainty that will help them predict performance (Dunlosky, Mueller, & Tauber, 2014; Mueller, Dunlosky, & Tauber, in press). This theory was inspired by others who have argued that human judgments are partly based on analytic processes that involve explicitly using beliefs (e.g., Kelley & Jacoby, 1996; Nisbett & Wilson, 1977). Moreover, other researchers have speculated that people’s a priori theories about factors influence JOLs (e.g., Dunlosky & Matvey, 2001; Koriat, 1997); for instance, before participating in a JOL experiment, people may believe that a factor (e.g., the semantic relatedness of words within a paired associate) will influence memory, and hence this
factor will influence JOLs. The critical new twists to AP theory is that it emphasizes (a) that people first explicitly and consciously search for cues that will allow them to reduce their uncertainty in predicting future memory performance and (b) that people will develop beliefs on-line – as they are participating in an experiment – about how different factors influence memory. Either these newly formed beliefs or a priori beliefs will drive JOLs. If people do not construct beliefs (or retrieve a priori ones) relevant to the prediction context, then the subjective experience of fluency that subtly differs across items may influence JOLs. In contrast to other dual-process models of JOLs (e.g., cue-utilization framework, Koriat, 1997), AP theory emphasizes the dominant role of beliefs in constructing JOLs and provides a description of plausible processes for how beliefs may be developed and influence JOLs.

In the case of the font-size effect, I suspect that most people have never thought about the relationship between font size and memory before beginning the experiment. During the experiment, however, most people notice the changing font sizes and develop a plausible – but incorrect – theory that larger font size words are easier to process. Critically, people apparently believe that easier processing is related to better memory and performance (e.g., Bjork, Dunlosky, & Kornell, 2013; Simon & Bjork, 2001), so they then incorrectly infer that font-size will affect memory and make higher JOLs for words printed in larger than smaller font sizes. A key claim here is that JOL effects can result from the decisions that experimenters make when designing judgment tasks. In the case of JOL research, the experimenter may manipulate a variable that he or she believes affects processing fluency (e.g., stimulus readability), and then offers the reasonable prediction from the fluency hypothesis that the variable will influence JOLs. When the
variable does influence JOLs as predicted, then the conclusion is that fluency is responsible. However, the alternative possibility is that the participants hold the same beliefs as the experimenter – that is, the belief that the manipulated variable affects fluency (even if it does not). In this case, because people believe that factors that enhance fluency will also affect memory, their belief actually drives the variable-JOL relationship and not the subjective experience of processing itself. Currently, however, these implications of AP theory are speculative, and the theory requires direct empirical test.

1.4. Testing Analytic Processing Theory

One unique test of AP theory involves (a) manipulating a factor that people do not believe impacts processing fluency and then (b) leading them to believe that it does impact fluency. What is critical about this test is that it would provide the first experimental demonstration that people’s beliefs about how a factor affects fluency will cause differences in JOLs. Of course, another possibility is that people’s beliefs about processing have no causal impact, with processing cues such as fluency having only a direct and unconsciously mediated effect on JOLs. If so, then leading participants to believe that a factor affects fluency will not impact JOLs and will provide evidence against a focal prediction from AP theory. I evaluated these predictions (and others) across seven experiments. In general, words were presented in either blue or green font color, and during the instructions, some participants were led to believe that one color (e.g., blue) was easier to process. Notably, the instructions never referred to how fluency might be related to memory, and hence, any influence on JOLs is due to the belief that this factor impacts processing fluency. According to AP theory, this belief will lead
participants to make higher JOLs for words associated with the more (vs. less) fluently processed color.
II. Experiment 1

2.1. Introduction
To provide converging evidence, I examined both differentiated global judgments and immediate JOLs. The former involve making a global prediction for each item type (e.g., predict number of green words that will be recalled) and tap people’s beliefs about how that factor (i.e., color) influences memory (Dunlosky & Hertzog, 2000). JOLs can be influenced both by beliefs and also by processing that occurs during study. Thus, concerning the focal prediction from AP theory, I expected both differentiated global judgments and JOLs to be higher for the color associated with easier processing.

2.2. Methods
Design, Participants, and Materials
A 2 (font color: blue or green) × 2 (color associated with easier processing: neither or blue) mixed factorial design was used, with font color as the within-participant factor and the color associated with easier processing as the between-participants factor.

In the present experiments, I set a sample size of around 30 in each group (no analyses were conducted until data collection was completed), because the font-size effect is a robust effect that has been consistently significant with a sample size of around 25 participants (Mueller et al., 2014; Rhodes & Castel, 2008). In the present experiment, 64 students were recruited from the participant pool at Kent State University and were randomly assigned to either a group where neither color was associated with easier processing (n = 32) or blue was associated with easier processing (n = 32).

Thirty-six words from Rhodes and Castel (2008) were used with half of the items (i.e., 18) presented in blue and the other half presented in green. Font color was
counterbalanced between participants, such that words were presented equally often in blue or green. The order of the presentation of words was randomized for each participant with the restriction that no more than three words of the same color could appear consecutively.

Procedure

Instructions were timed, such that participants were given certain amount of time to read each set of instructions before they could click a button on the computer screen to continue. Participants in both groups were instructed that they were about to study words presented in either blue or green. They were also told that after studying each word they would be asked to make JOLs on a scale from 0 to 100 indicating the likelihood that they would remember the word they had just studied on a final free recall test.

After reading this set of instructions, participants in the group where blue was associated with easier processing were given additional instructions. They were shown a picture of an eye with certain parts labeled (e.g., retina, optic nerve, rods, cones, etc.) and were given the following instructions for at least 15 seconds:

Before you begin we would like to mention why we are presenting information in different colors. Your eyes work together with your brain in order for you to perceive color. Light receptors in the eye transmit messages to the brain, which produce sensations associated with certain colors. There are two kinds of receptors in your eye called rods and cones.

Please examine the picture below depicting how light enters the eye and is transmitted to the brain. Please take note of where the rods and cones are located in the image.

Participants in this group then advanced to another instruction screen that displayed the following for at least 30 seconds:

There are over 120 million rods in each eye, and these are used primarily for transmitting black and white information to the brain.
Cones, on the other hand, are responsible for perceiving color. There are about 6 million of these in each eye located at the back of the retina. There are three different kinds of cones which are responsible for seeing and interpreting the colors red, blue, and green. Combinations of these colors can be used to make any color.

Of particular importance, you have far more "blue" cones than "green" cones, making you far more receptive to blue light. Therefore in this experiment, when you see a word presented in blue it will be easier for your brain to process the word compared to when it is presented in green. Additionally, words presented in blue will be easier for you to focus on and will stand out more on the screen.

After both groups read their respective instructions, they made differentiated global judgments (i.e., “Please estimate how many blue words (0-18) you think you will remember on the final test”) for words presented in each font color (note that the order of the differentiated judgments was counterbalanced). Participants then studied each word presented on a white background for 5 s, and made a self-paced JOL for each one. After studying and judging all of the words, they again made differentiated global judgments for each font color. Then, participants were given a three minute free recall test. Following the recall test, they made retrospective differentiated global judgments for how many words of each color they remembered on the test. Finally, participants were debriefed appropriately by correcting the belief about the number of cones in each eye that are responsible for perceiving different colors and how this may lead to differential processing fluency.

2.3. Results and Discussion

Mean JOLs are presented in Figure 1. A 2 (font color) × 2 (color associated with easier processing) mixed ANOVA was conducted, and the interaction was significant, $F(1,62) = 5.43$, $MSE = 208.7$, $p = .023$, $\eta^2_p = .08$. Consistent with the prediction of AP theory, no difference in JOLs was found when neither color was associated with easier
processing, and higher JOLs were given to blue words when blue was associated with
easier processing, \( t(31) = 2.43, p = .021 \), Cohen’s (1992) \( d = .43 \). No other effects on
JOLs were significant, \( Fs < 1.82 \). Thus, providing participants with a plausible
explanation about how one color is easier to process than another led to higher JOLs for
words presented in that color.

Next, I examined differentiated global judgments (Table 1) using a 2 (font color: blue or green) \( \times \) 3 (timing: pre-study, post-study, or post-test) repeated measures ANOVA. In the group where neither color was associated with easier processing,
participants’ judgments decreased from pre-study to post-test, \( F(2,60) = 5.43, MSE =
15203.27, p < .001, \eta_p^2 = .6 \). No other effects were significant, \( Fs < 1 \). More important, in
the group where blue was associated with easier processing, global judgments were
higher for blue than green words, \( F(2,31) = 27.72, MSE = 3812.37, p < .001, \eta_p^2 = .47,\)
and decreased from pre-study to post-test, \( F(2,62) = 60.24, MSE = 18553.72, p < .001,\)
\( \eta_p^2 = .66 \). These effects were qualified by a significant interaction, \( F(2,62) = 5.21, MSE =
364.74, p = .008, \eta_p^2 = .14 \), with the effect of font color decreasing from pre-study to
post-test: pre-study, \( t(31) = 6.57, p < .001, d = 1.16 \), post-study, \( t(31) = 4.13, p < .001, d
= .73 \), post-test, \( t(31) = 1.44, p = .161 \). Thus, participants who had blue associated with
easier processing seem to update their knowledge about the impact of differential
processing fluency on memory from pre-study to post-test.

Finally, Recall performance (Table 2) was higher in the group where neither color
was associated with easier processing than in the group where blue was associated with
easier processing, \( F(1,62) = 4.58, MSE = 703.1, p = .036, \eta_p^2 = .07 \). No other effects on
recall performance were significant, \( Fs < 1 \). To foreshadow, this small effect was not
consistently obtained across the present experiments (see Table 2), so I do not discuss it further.
Figure 1. Mean judgment of learning for each font color and each group in Experiment 1. Error bars represent within-participant standard error (Franz & Loftus, 2012).
<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-study Globals</th>
<th>Post-study Globals</th>
<th>Post-Recall Globals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blue</td>
<td>Green</td>
<td>Blue</td>
</tr>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>56.8 (1.0)</td>
<td>55.0 (1.0)</td>
<td>45.7 (2.3)</td>
</tr>
<tr>
<td>Blue</td>
<td>64.1 (2.1)</td>
<td>50.4 (2.1)</td>
<td>51.4 (2.1)</td>
</tr>
<tr>
<td>Experiment 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>53.2 (2.6)</td>
<td>66.1 (2.6)</td>
<td>44.8 (2.3)</td>
</tr>
<tr>
<td>Blue</td>
<td>63.3 (2.3)</td>
<td>48.0 (2.3)</td>
<td>50.4 (1.9)</td>
</tr>
</tbody>
</table>

*Note.* Values are mean percentage of pre-study, post-study, and post-test differentiated global judgments for each font color and group. Group refers to the color associated with easier processing. Within-participant standard errors of the mean are in parentheses.
Table 2. Mean percentage of correct recall across all Experiments.

<table>
<thead>
<tr>
<th>Group</th>
<th>Recall Performance</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>24.7 (2.8)</td>
<td>25.3 (2.8)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>21.8 (2.8)</td>
<td>18.9 (2.8)</td>
<td></td>
</tr>
<tr>
<td>Experiment 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>20.2 (2.7)</td>
<td>22.2 (2.7)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>24.1 (2.5)</td>
<td>27.8 (2.5)</td>
<td></td>
</tr>
<tr>
<td>Experiment 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>23.9 (2.1)</td>
<td>23.3 (2.1)</td>
<td></td>
</tr>
<tr>
<td>Experiment 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>29.5 (2.7)</td>
<td>24.7 (2.7)</td>
<td></td>
</tr>
<tr>
<td>Experiment 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue Easier</td>
<td>20.2 (2.4)</td>
<td>19.4 (2.4)</td>
<td></td>
</tr>
<tr>
<td>Green Harder</td>
<td>19.3 (2.6)</td>
<td>18.5 (2.6)</td>
<td></td>
</tr>
<tr>
<td>Experiment 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JOL Blue</td>
<td>18.3 (3.2)</td>
<td>15.6 (3.2)</td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>12.1 (1.9)</td>
<td>13.2 (1.9)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>11.8 (1.8)</td>
<td>12.5 (1.8)</td>
<td></td>
</tr>
<tr>
<td>Experiment 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>23.1 (2.2)</td>
<td>20.0 (2.2)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>18.1 (2.1)</td>
<td>20.8 (2.1)</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Values are mean percentage of recall for each font color and group. Group refers to the color associated with easier processing. Within-participant standard errors of the mean are in parentheses.
III. Experiment 2

3.1. Introduction

Outcomes from Experiment 1 supported a critical prediction of AP theory. Namely, when a plausible explanation is provided about why a focal factor affects processing fluency, then that factor influenced JOLs. Given the importance of replication (Pashler & Harris, 2012), Experiment 2 included a group in which blue was associated with easier processing in the instructions (as in Experiment 1). I also extended the results to a new group where green was associated with easier processing. Observing an interaction would provide stronger evidence that people’s beliefs about processing fluency are responsible for the effects of color on JOLs.

3.2. Methods

Design, Participants, and Materials

A 2 (font color) × 2 (color associated with easier processing: green or blue) mixed factorial design was used, with font color as the within-participant factor and the color associated with easier processing as the between-participants factor. Sixty participants were recruited from Kent State University to fulfill a partial course requirement and were randomly assigned to either a group where green (n = 30) or blue (n = 30) was associated with being easier to process. The same word lists and counterbalancing procedures were used as in Experiment 1.

Procedure

The procedure was identical to Experiment 1, except in the group where green was associated with easier processing the final paragraph of the instructional manipulation had the words blue and green swapped.
3.3 Results and Discussion

As shown in Figure 2, the predicted crossover interaction was obtained, $F(1,58) = 18.33$, $MSE = 616.78$, $p < .001$, $\eta^2_p = .24$, such that JOLs were higher for green words when green was associated with being easier to process, $t(29) = 2.74$, $p = .011$, $d = .50$, and higher for blue words when blue was associated with being easier to process, $t(29) = 3.71$, $p = .001$, $d = .68$. No other effects were significant, $Fs < 1$.

For differentiated global judgments (Table 1), I collapsed across groups and conducted a $2 \times 3$ within-participant ANOVA. The pattern of results is similar to the group that received an instructional manipulation in Experiment 1, such that differentiated global judgments were higher for the condition associated with easier processing, $F(1,59) = 53.3$, $MSE = 6203.84$, $p < .001$, $\eta^2_p = .48$, and decreased from pre-study to post-test, $F(1,118) = 116.56$, $MSE = 33022.8$, $p < .001$, $\eta^2_p = .66$. These main effects were qualified by a significant interaction, $F(2,118) = 19.11$, $MSE = 887.11$, $p < .001$, $\eta^2_p = .25$, with the effect of the color being associated with easier processing decreasing from pre-study to post-test: pre-study, $t(59) = 8.22$, $p < .001$, $d = 1.06$, post-study, $t(59) = 4.89$, $p < .001$, $d = .63$, and post-test, $t(59) = 2.58$, $p = .001$, $d = .33$.

No differences in recall performance occurred (Table 2), $Fs < 2.45$. Thus, participants displayed a metacognitive illusion in which higher recall performance was predicted for the color associated with easier processing, yet word color had no impact on recall.
Figure 2. Mean judgment of learning for each font color and each group in Experiment 2. Error bars represent within-participant standard error.
IV. Experiment 3

4.1. Introduction

An alternative explanation is that the instructional effect on JOLs was due to a reactive effect of making differentiated global judgments. For instance, given that differentiated global judgments highlight the focal manipulation (by having participants explicitly make predictions about memory for items presented in each color), making them may lead participants to contrast the two colors and develop a belief about whether color would influence memory. That is, participants may develop their beliefs about this factor when they make global differentiated judgments, and this belief in turn would be available as a basis for item-by-item JOLs. Although this causal chain would be consistent with AP theory, if participants do not make differentiated global judgments, the instructional manipulation may not affect JOLs. This outcome would constrain the scope of AP theory to differentiated global judgments where beliefs may be the dominant bases for people’s judgments (Dunlosky & Hertzog, 2000). Thus, Experiment 3 was conducted to evaluate this possibility. I used instructions where blue was associated with easier processing (as in Experiment 1), and participants only made immediate JOLs.

4.2. Methods

Design, Participants, and Materials

Font color (either blue or green) was manipulated within each participant. Thirty-two participants were recruited from Kent State University to fulfill a partial course requirement and were given instructions where blue was associated with easier
processing. The same word lists and counterbalancing procedures were used as in the prior experiments.

Procedure

The procedure was identical to the group where blue was associated with easier processing in Experiment 1, except participants did not make differentiated global judgments.

4.3. Results and Discussion

As shown in Table 3, JOLs were higher for words presented in blue than green, $t(31) = 3.27, p = .003, d = .58$, which establishes that the instructional effect on JOLs is not a reactive effect of making global differentiated judgments. No differences in recall occurred (Table 2), $t(31) = .33, p = .731$. 
Table 3. Mean JOL percentage for blue and green words in Experiments 3, 4, 5, 6, and 7.

<table>
<thead>
<tr>
<th>Group</th>
<th>JOLs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blue</td>
</tr>
<tr>
<td>Experiment 3</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>58.5 (2.2)</td>
</tr>
<tr>
<td>Experiment 4</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>65.3 (2.1)</td>
</tr>
<tr>
<td>Experiment 5</td>
<td></td>
</tr>
<tr>
<td>Blue Easier</td>
<td>54.6 (1.5)</td>
</tr>
<tr>
<td>Green Harder</td>
<td>59.1 (1.6)</td>
</tr>
<tr>
<td>Experiment 6</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>68.1 (2.1)</td>
</tr>
<tr>
<td>Experiment 7</td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>54.0 (1.9)</td>
</tr>
<tr>
<td>Blue</td>
<td>50.4 (1.8)</td>
</tr>
</tbody>
</table>

*Note.* Values are mean percentage of JOLs for each font color and group. Group refers to the color associated with easier processing. Within-participant standard errors of the mean are in parentheses.
V. Experiment 4

5.1. Introduction

Although the removal of differentiated global judgments rules out one explanation for the present effect, some other explanations for the impact of word color on JOLs need to be evaluated. In particular, instructions in prior experiments mentioned fluency and attention. Given that poor attention can lead to poor memory, the instructional effect on JOLs may be driven more by participants’ beliefs about attention than about fluency. This outcome would still be consistent with AP theory, but it would indicate the beliefs about processing fluency per se are relatively inert. Given the current interest is about fluency, Experiment 4 attempted to rule out the explanation that participants are using a belief about attention from the manipulation (i.e., “words presented in blue will be easier for you to focus on and will stand out more on the screen”) rather than a belief about processing fluency as a basis for their judgments. To do so, the instructional manipulation was changed to reflect only the impact of perceptual processing fluency for words presented in different colors.
5.2. Methods

Design, Participants, and Materials

Font color (either blue or green) was manipulated within each participant. Thirty-three participants were recruited from Kent State University to fulfill a partial course requirement and they were given the instructions where blue is associated with easier processing. The same word lists and counterbalancing procedures were used as in the prior experiments.

Procedure

The procedure was identical to that of the group where blue was associated with easier processing in the prior experiments, and as in Experiment 3, participants did not make differentiated global judgments. Notably, the last two sentences of the manipulation were changed as follows: “Therefore in this experiment, when you see a word presented in blue it will be easier for your brain to process the word compared to when it is presented in green. Additionally, words presented in blue will be easier for you to see and easier for you to read.”

5.3. Results and Discussion

As shown in Table 3, JOLs were higher for the words that were presented in blue than in green font, $t(32) = 2.48, p = .019, d = .43$, showing that instructions that focus on perceptual processing fluency alone (e.g., ease of seeing and reading words) produces the predicted effect. A trend for differences in recall performance based on font color occurred (Table 2), $t(32) = 1.7, p = .10$. 
VI. Experiment 5

6.1. Introduction

Experiment 5 attempted to replicate the instructional effect on JOLs from Experiment 4 and included a new group to rule out a potentially uninteresting explanation for it. Specifically, participants may be focusing on the term “easy” in the instructions and reflexively giving higher JOLs for the words presented in the allegedly easier color. To rule out this explanation, the manipulation was changed to emphasize the disfluent processing of one of the colors. In the present experiment, one group had the color blue associated with easier processing with the same instructions used in Experiment 4, whereas another group had the color green associated with more difficult processing using a new set of instructions. In the latter group, green was described as being more difficult to read and difficult to see. If the manipulation is truly tapping into participants’ general belief about processing fluency, then it should not matter whether processing fluency of a color is framed as easier or difficult.

According to AP theory, beliefs about fluency are responsible for the impact of the instructions on people’s JOLs. As shown in Experiments 1 and 2, however, the beliefs that one color is easier to process (than the other) diminish at least for some participants across the task. Namely, as indicated by the differentiated global judgments (Table 2), the target effect diminishes after the study session, as if the belief that one color is actually easier to process is disconfirmed by experience during study. Thus, as participants gain task experience, some may begin to disbelieve the instructions. To evaluate this possibility, following the study phase of the experiment, participants were asked to report which color they believed was easier to process. I suspected individual
differences in beliefs would emerge, and as important, these beliefs about processing fluency should account for the impact of color on JOLs. In particular, those who still hold the belief that one color is easier to process will show a significant instruction effect on JOLs. By contrast, those who report not believing that color affects processing fluency will show a diminished (or no) effect.

6.2. Methods

Design, Participants, and Materials

A 2 (font color) × 2 (processing ease: easier or difficult) mixed factorial design was used, with font color as the within-participant factor and processing ease as the between-participants factor. Sixty participants were recruited from Kent State University to fulfill a partial course requirement. They were randomly assigned to either a group where blue was associated with easier processing or a group where green was associated with more difficult processing. The same word lists and counterbalancing procedures were used as in the prior experiments.

Procedure

The procedure was identical to Experiment 4, except for the following changes. One group had the last paragraph of their instructions changed to emphasize that green was more difficult to process. These participants received the following instructions:

Of particular importance, you have far less "green" cones than "blue" cones, making you far less receptive to green light. Therefore in this experiment, when you see a word presented in green it will be harder for your brain to process the word compared to when it is presented in blue. Additionally, words presented in green will be harder for you to see and harder for you to read.

Following the study phase, all participants were asked “Which color do you think is
"easier for you to process?" Participants indicated whether they believed blue, green, or neither color was easier to process.

6.3. Results and Discussion

Both sets of instructions impacted JOLs in the expected direction (see Table 3), with JOLs being higher for blue words than green words, \( F(1,58) = 22.76, \text{MSE} = 816.48, p < .001, \eta_p^2 = .28 \). No other effects were significant, \( Fs < 1 \). Additionally, no differences in recall performance occurred (Table 2), \( Fs < 1 \).

Next, I evaluated participant responses regarding their beliefs about the processing fluency of blue and green color words. After the study phase, 30 participants reported that blue was easier to process, 5 responded that green was easier to process, and 25 responded that neither color was easier to process. Given these individual differences, I evaluated whether the instructional effect on JOLs would be moderated by participants’ beliefs. Few participants reported that green words as easier to process, so I included only those who responded that blue was easier to process and those that said neither color was easier to process. A significant interaction was found, \( F(1,53) = 15.01, \text{MSE} = 384.19, p < .001, \eta_p^2 = .22 \). Namely, participants who reported blue as being easier to process following study displayed the instructional effect on JOLs (Blue JOL \( M = 57.18 \), Green JOL \( M = 47.76 \)), \( t(29) = 7.3, p < .001, d = 1.33 \), and this effect was attenuated when participants reported not believing either color was being easier to process (Blue JOL \( M = 58.34 \), Green JOL \( M = 56.42 \)), \( t(24) = 1.32, p = .20, d = .26 \).
VII. Experiment 6

7.1. Introduction

In the prior experiments, I have assumed that differential processing fluency was not contributing to the instructional effect on JOLs, with the crossover interaction in Experiment 2 providing the most convincing evidence. This assumption may be faulty, because telling participants that one color is easier to process may affect how they processed words presented in different colors. For instance, participants who were instructed that blue was easier to process may set a lower threshold for responding to words presented in a color that they believe is easier to process (e.g., changing the criterion to respond in the diffusion model, Wagenmakers, Ratcliff, Gomez, & McKoon, 2008). Another possibility is that participants will do more post-decision monitoring (e.g., double checking) when they believe words presented in a color are difficult to process.

These possibilities indicate that the instructional manipulation could plausibly impact people’s actual processing time. To evaluate whether this occurs, I used a lexical decision task to establish whether processing speed differences were occurring for the two colors, and whether the manipulation had any impact on processing speed. Although it seems unlikely that the manipulation would lead to differences in lexical access, participants may still consider the manipulation when making the decision, which could lead to differences in processing time. Notably, in the present context, because the argument that having a belief about processing fluency impacting JOLs hinges on blue and green being processed at a similar speed, I also included the standard control group (as in Experiment 1) to evaluate whether lexical-decision times are biased by font color.
In addition to the groups who performed the lexical decision task, another group that made JOLs and had blue font associated with easier processing was included. This group provided evidence that the instructional effect on JOLs occurred in current sample of participants, and whether it persists for non-words.

7.2. Methods

**Design, Participants, and Materials**

A 2 (font color) × 2 (word type: word or non-word) × 2 (group: blue associated with easier processing or neither color associated with easier processing) mixed factorial design was used, with font color and word type as the within-participant factor and group as the between-participants factor. I included a third group in which participants had blue associated with easier processing and made only JOLs. Thus, 90 participants were recruited from Kent State University to fulfill a partial course requirement and were randomly assigned to one of the three groups. Two participants were removed for performing below 80% on the lexical decision task, leaving 88 participants. In the lexical decision groups, participants either received no instructional manipulation (n = 29) or the instructional manipulation where blue is associated with easier processing (n = 29). The remaining group (n = 30) studied words and non-words and made a JOL following each one. The same word lists and counterbalancing procedures were used as in the prior experiments. Each word had a non-word counterpart (e.g., arage; sampled from the English Lexicon Project, Balota et al., 2007) matched for length and orthography. Half of the words and non-words were presented in blue or green.
Procedure

Seventy-two items (36 words and 36 non-words) were presented for the lexical decision task. Participants were instructed to study all items for an upcoming test. All items were presented on the screen for 5 s each. Participants were instructed that they would be completing a lexical decision task where they must decide whether the item presented was a word or a non-word as quickly as possible. Participants read the initial instructions and then completed a practice phase to familiarize them with the task. After the practice phase, participants received instructions appropriate to their group.

For the lexical decision task, before each trial, a screen appeared telling participants to get ready for the next item while a progress bar counted down for 2 s. Then a fixation point appeared in the center of the screen for .5 s, followed by the item. When the item was displayed on the screen, participants made their decision by pressing the “Z” key to indicate the item on the screen was a word or by pressing the “M” key to indicate the item on the screen was a non-word. The word remained on the screen until the study time had elapsed. In the JOL group, participants did not make a lexical decision when the item was presented for study. After each item was presented, participants made a JOL on a scale from 0 to 100 as in the prior experiments. After presenting all of the items, participants had 3 minutes to recall the 36 only the words that they had studied.

7.3. Results and Discussion

JOLs for only the words are presented in Table 3. Participants who made JOLs for all words and non-words following the manipulation gave higher JOLs for blue items ($M = 50.07, SE = 2.89$) than green items ($M = 44.22, SE = 2.73$), $F(1,29) = 13.05, MSE = 1026.35, p = .001, \eta_p^2 = .31$. JOLs were higher for words ($M = 64.97, SE = 3.64$) than
non-words ($M = 29.31, SE = 3.14$). The interaction was not significant, $F < 1$. Thus, the manipulation had an impact on JOLs for the current set of sampled individuals.

Of primary interest, mean lexical decision times are presented in Table 4. Before computing these values, data were removed for any trial where an incorrect lexical decision was made. After removing data from these trials, I removed trials where lexical decision time was above or below 2 standard deviations. The cutoff values for the standard deviation of lexical decision time were calculated separately for each participant and each item type (word and non-word). Altogether, approximately 6% of the trials were removed. Lexical decision times were faster for words than non-words, $F(1,56) = 80.09, MSE = 7.78, p < .001, \eta_p^2 = .59$. A significant three-way interaction was found, $F(1,56) = 4.47, MSE = .03, p = .04, \eta_p^2 = .08$. This interaction appeared to be driven by the non-words; namely, in the two groups, response times trended in the opposite direction for the two colors. I had no reason to expect this interaction, and more importantly, the interaction does not qualify the primary conclusion about the instructional effect on JOLs. No other effects were significant, $Fs < 2.57$, indicating that presenting words in different colors may not impact processing time as measured by lexical decision.

Recall performance (see Table 2) was higher in the JOL group, but not significantly so, $F(2,87) = 2.46, MSE = 4.2, p = .09, \eta_p^2 = .05$. No other effects were significant, $Fs < 1$.

Although no differences occurred in processing fluency as measured by lexical decision response time, I wanted to replicate and extend these outcomes to instructions that associated green with easier processing. To do so, I conducted a follow-up experiment with two groups. One group received instructions where blue was
associated with easier processing (n = 28) and the other group received instructions
where green was associated with easier processing (n = 29). The same analysis on lexical
decision times was conducted. Again, lexical decision times were faster for words than
non-words, $F(1,55) = 91.7, MSE = 5.57, p < .001, \eta^2_p = .63$. No other effects were
significant, $Fs < 1$. 
Table 4. Mean fluency measure in seconds for Experiments 6 and 7.

<table>
<thead>
<tr>
<th>Fluency Measure</th>
<th>Group</th>
<th>Blue Word</th>
<th>Green Word</th>
<th>Blue Non-word</th>
<th>Green Non-word</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment 6&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>.76 (.03)</td>
<td>.75 (.03)</td>
<td>1.09 (.06)</td>
<td>1.14 (.06)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>.73 (.04)</td>
<td>.74 (.04)</td>
<td>1.12 (.09)</td>
<td>1.09 (.09)</td>
<td></td>
</tr>
<tr>
<td>Experiment 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neither</td>
<td>5.20 (.65)</td>
<td>4.88 (.61)</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>5.24 (.64)</td>
<td>5.21 (.85)</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Processing fluency was measured using lexical decision times in Experiment 6 and self-paced study times in Experiment 7. Values are mean response times in seconds for fluency measures for each font color, word type, and group. Group refers to the color associated with easier processing. Standard errors of the mean for the fluency measures are in parentheses.
VIII. Experiment 7 - Circuitry Involved in Estradiol-Induced Fear Generalization

8.1. Introduction

Although lexical decision times were not consistently influenced by the instructional manipulation that one color is easier to process than another, perhaps a measure of processing fluency that is arguably more influenced by self-regulation will demonstrate differences. In particular, self-paced study time may reveal how individuals control their learning based on their beliefs about processing fluency. Study time is influenced by judged item difficulty in that people focus more on those items that are judged as less well learned (vs. well learned) (e.g., see Soderstrom & McCabe, 2011; Tullis & Benjamin, 2011; for a review, see Son & Kornell, 2008). Importantly, the impact of judged difficulty on study time occurs even when those judgments do not reflect actual differences in learning (Metcalfe & Finn, 2008). Thus, in the present case, study times may be faster for words presented in a color that participants believe are easier (vs. more difficult) to process.

To evaluate this possibility in Experiment 7, one group had blue associated with easier processing and self-paced their study. If associating a color with easier processing leads to differential processing effort by the participant, then it should be reflected in their self-paced study times with blue words being studied for less time than green words. I also included the standard control group (as in Experiments 1 and 6) to estimate whether self-paced study times are biased by font color.
8.2. Methods

Design, Participants, and Materials

A 2 (font color) × 2 (color associated with easier processing: blue or neither) mixed factorial design was used, with font color as the within-participant factor and the manipulation as the between-participants factor. Fifty-nine participants were recruited from Kent State University to fulfill a partial course requirement. Participants were randomly assigned to receive no instructional manipulation (n = 28) or the instructional manipulation where blue was associated with easier processing (n = 31). The same word lists and counterbalancing procedures were used as in the prior experiments.

Procedure

The procedure was identical to Experiment 4, except that participants pressed the spacebar on the keyboard to indicate when they had finished studying each item. Following each item, participants made a self-paced JOL indicating their likelihood of remembering that word on the final free recall test.

8.3. Results and Discussion

I found a significant interaction on JOLs (see Table 3), $F(1,57) = 4.27, MSE = 205.01, p = .04, \eta_p^2 = .07$. The participants who had blue associated with easier processing gave higher JOLs to blue words than green words, $t(30) = 2.12, p = .04, d = .38$, and the participants that did not receive instructional manipulation had no difference in JOLs for blue words and green words, $t(27) = .84, p = .41$. This extends the pattern of results from Experiment 1 to a context where learners self-regulated their study. No other effects were significant, $Fs < 2.21$. Although an interaction was trending for recall performance...
(see Table 2), $F(1, 57) = 3.5$, $MSE = .025$, $p = .07$, no other significant differences in recall occurred, $F$s $< 1$.

Of primary interest, self-paced study times in seconds are presented in Table 4. No significant effects were found on study time, $F$s $< 1$, suggesting that the instructions do not lead to differential allocation of study time.
IX. General Discussion

9.1. Main Findings

Results from seven experiments demonstrated that if people believe that human eyes (and brains) more fluently perceive a color, then words presented in that color will be more memorable. That is, providing participants with a plausible explanation in the task instructions about why color would influence perceptual processing fluency also influenced their JOLs. Critically, the instructions never linked processing fluency to memory, so participant’s a priori beliefs – that fluency is an indicator of memory (Mueller et al., 2014; Simon & Bjork, 2001) – along with the instructional manipulation (in which they were misled about color and fluency) combined to affect JOLs. Given that the present research is the first to demonstrate such an instructional effect, it was critical to replicate it, and hence I conducted both direct and conceptual replications. In Figure 3, I present these replications in terms of the difference in JOL magnitude for the color that was associated with more fluent processing versus the color that was associated with less fluent processing. Inspection of Figure 3 reveals that the instructional effect is robust, with effect sizes (Cohen’s $d$) ranging from .38 to .68.

Whereas the direct replications highlight that the instructional effect is robust, the conceptual replications allowed me to evaluate relatively uninteresting explanations for the effect, which is discussed in turn: (1) I removed global differentiated judgments from the procedure (Experiments 3-7) to ensure that they did not have a reactive effect on JOLs during the task, and the instructional effect was still obtained; (2) because the impact of the instructional manipulation in Experiments 1-3 could have been due to associating a color with better attention instead of easier processing, I changed the
language to remove any language associating color with attention. When the instructions included discussion of the colors impacting only perceptual processing fluency, the instructional effect on JOLs remained (Experiment 4) and was replicated in Experiments 5, 6, and 7; (3) In Experiment 5, I evaluated whether the instructional effect would occur when the impact of color was described as leading to easier or more difficult processing. In both cases, JOLs were similarly impacted, ruling out that the focus on the term “easier” in the instructions was responsible for the effect; and (4) blue versus green font colors alone did not influence processing fluency, as measured by lexical decision response times and self-paced study times, and these measures were not influenced when participants were instructed that one color was easier to process than another. Thus, it appears that the instructional effect on JOLs cannot be explained by differences in perceptual processing fluency. The evidence just described disconfirms a variety of less interesting explanations for the instructional effect on JOLs, and much of the evidence is also relevant to AP theory, as I discuss next.
Figure 3. Mean difference and 95% confidence interval for the effect on JOLs following the instructional manipulation across all experiments. 1 = Experiment 1, Blue group; 2 = Experiment 2, Blue group; 3 = Experiment 2, Green group; 4 = Experiment 3, Blue group; 5 = Experiment 4, Blue group; 6 = Experiment 5, Blue easier group; 7 = Experiment 5, Green harder group; 8 = Experiment 6, Blue group; and 9 = Experiment 7, Blue group. Figure was generated using the ESCI software from Cumming (2012).
9.2. *Implications and Conclusions*

First, the effects presented in Figure 3 are naturally explained by AP theory, which emphasizes the problem-solving aspect of making JOLs. People search for cues to reduce their uncertainty about which words they will remember or forget, and cues about fluency (even invalid ones) are apparently important when they attempt to predict their memory. In the present experiments, color alone did not consistently influence recall or JOLs when standard instructions were used, so participants only linked color with memory when they were instructed that color influenced processing fluency.

Second, evidence from the present experiments provides unique support for AP theory. The role of beliefs about fluency in making memory predictions is further supported by outcomes from global differentiated judgments in Experiments 1 and 2. Global differentiated judgments indicate that participants change their beliefs about the task in regard to memorability for the instructional manipulation. In particular, pre-study global judgments were higher for the color associated with easier processing, and this difference in global judgments diminished after study, which suggests (at least some) participants attempted to adjust their judgments as they gained experience with the task. Similarly, the global judgments also decreased from pre-study to post-study and from post-study to post-test. Moreover, evidence from self-reports in Experiment 5 following the study phase indicated that some participants still believed one color was easier to process, whereas others did not. Only participants who reported a color as being easier to process (i.e., the color associated in the instructions) demonstrated the instructional effect on JOLs. Taken together, these outcomes provide evidence for AP theory that participants are actively problem solving while engaging in a task.
The current explanation appeals to demand characteristics, but in a manner different from its normal use. That is, according to AP theory, when asked to predict their performance, people will evaluate the characteristics of the learning task with the goal of discovering cues that may help them make more accurate JOLs, which is a central goal of JOL tasks. In the case of making judgments, the impact of task demands are psychologically interesting, because when people are uncertain in this judgmental context, they consider which cues of the task may be diagnostic of future performance and use them to make more accurate JOLs. Note, however, that participants did not merely make higher JOLs for the color that the experimenter indicated was easier to process, but instead the JOLs are linked directly to people’s beliefs about processing fluency (Experiment 6). Despite the instructions to convince them (using a plausible explanation) that one color is easier to process, some participants did not believe it, and hence they did not use this cue as a basis for their JOLs.

Task demands may be influential whenever people are asked to make JOLs. People assume their task is to discover cues that are relevant to memory, and in doing so, they may attempt to develop reasons for why a particular cue could impact memory. Evidently, color alone is not a cue that people spontaneously perceive as relevant to memory (e.g., see outcomes when neither color was linked to processing fluency, Figure 1 and Table 3). By contrast, other cues may trigger interpretations that suggest they are related to memory – perhaps especially so in the context of a memory experiment. Although speculative, I illustrate this possibility with respect to the font size effect, because the AP theory underscores how informative it may be to investigate the role of task demands on JOLs in different contexts. In particular, the available evidence points
to the same explanation for the effect of font size on JOLs. People believe larger fonts are easier to process, so they also believe words presented in the larger font size will also be better remembered – even though the larger words are not easier to process or better remembered (Hu, Li, Zheng, Su, Liu, & Luo, 2015; Hu, Liu, Li, & Luo, 2016; Mueller, et al., 2014). It is essential to consider, however, a difference between the present effect of color and that of font size. In the latter case, researchers – like participants – initially believed that font size would impact JOLs. When researchers manipulate a factor that they believe impacts processing fluency and participants hold the same intuitive belief, then the outcomes of the experiment will conform to the researcher’s expectations: Fluency will be used to explain why that factor impacts the judgment, when in fact people’s beliefs about fluency are responsible.

Finally, my focus in the present experiments was to explore the impact of beliefs on JOLs as suggested by AP theory. However, as I have discussed in detail elsewhere (Mueller et al., 2015), AP theory does not state that processing fluency cannot have a direct impact on judgments (for a critical review, however, see Newell & Shanks, 2014), such as by impacting people’s subjective experiences in a manner that is not reflected in objective measures (Unkelbach & Greifeneder, 2013b). This possibility needs to be empirically investigated, but presently, the prevailing evidence indicates that people’s beliefs about fluency (and how it relates to memory) may be one important basis of people’s JOLs.
REFERENCES


