Is source information automatically available in working memory?

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Abstract (150 words)

We often remember information without its source (e.g. word or picture format). This phenomenon has been studied extensively in long-term memory, but rarely in the context of short-term/working memory(WM). It is an open question as to whether source amnesia is the result of forgetting over a prolonged period of time. This study provided a series of striking and novel demonstrations showing participants' inability to report the source of a color representation immediately after that color was used in a task, and stored in memory. These counterintuitive findings occurred when participants repeatedly judged the congruency between two color representations from one single object (i.e., color and identity of a color word) or two distinct objects (i.e., color of a square and identity of a color word) and then were unexpectedly asked to report the source of one color representation. These discoveries suggested that source information was not spontaneously stored into WM.

In everyday life it is commonplace to remember a fact without its source. For instance, we all have some experience of recognizing a person but being unable to recollect where or when we met that person, or remembering a movie quote without remembering the movie. Most people, though, share the intuition that they will be able to remember the source of information that they have just encountered. Here we explore errors that challenge this intuition, demonstrating frequent source errors for information that was attended and used to perform a task moments before.

The phenomenon of failing to remember the source of retrievable information has been variously labeled as *source amnesia*, *source forgetting*, *source monitoring errors*, *source misattributions*, *source errors* and so on (Mitchell & Johnson, 2009) and has been extensively studied (e.g., Glisky, Polster, & Routhieaux, 1995; Johnson, Hashtroudi, & Lindsay, 1993; Hollins, Lange, Berry, & Dennis, 2016; Maillet, & Rajah, 2016; Mitchell & Johnson, 2009; Mitchell, Johnson, Raye, & Greene, 2004; 2006; Wilding & Rugg, 1996). *Source memory* is broadly defined as remembered information that specifies how an event was experienced, such as perceptual (e.g., col_or, format of a stimulus), spatial-temporal, and affective details (Glisky et al., 1995; Johnson, et al., 1993). Such memory is usually contrasted with *item memory* which relies on less differentiated information such as familiarity or recency (Glisky et al., 1995; Johnson, et al., 1993). For example, an item memory task usually asks

participants to determine whether a probed stimulus was seen before while a source memory task typically requires participants to retrieve associated information, such as which list a word was encountered on (e.g., Wilding & Rugg, 1996), whether a learned stimulus was presented in auditory or visual modality during study (e.g., Bornstein & LeCompte, 1995), or whether a stored semantic representation was acquired from a word or a picture (e.g., Mitchell et al., 2004; 2006).

Source amnesia has been extensively investigated using long-term memory paradigms, but has rarely been studied in short-term or working memory (WM). This might be because we intuitively believe that source information is always available immediately after stimulus processing and source amnesia would therefore be impossible in WM. Some prior studies (Mitchell et al., 2004, 2006) seem to support this intuition by showing that participants had good memory for source information (e.g., format or location) of stimuli they had just seen several seconds before.

However, in those studies participants had clear expectations that they would need to remember the source information. Thus, these studies did not address a critical question, which is whether or not participants automatically remember the source of content that had just been experienced, where there is no expectation that this source information should be remembered. We suspect this crucial question has not yet been studied might be because both our

intuition and many previous studies about object-based encoding (e.g., Gao et al., 2011; Shen et al., 2013; Xu, 2000; Zhou et al., 2016) and event files (Hommel, 2004, for a review) predict that the answer would obviously be “yes”; that is, source information of just-experienced stimuli should always be available.

The current study attempted to empirically address this issue by using an immediate surprise memory test developed in studies of inattention blindness (e.g., Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005; Simons & Chabris, 1999), change blindness (e.g., Rensink, O’Regan, & Clark, 1997; Simons & Levin, 1998), and attribute amnesia (Chen & Wyble, 2015a; 2015b, 2016; Chen, Swan, & Wyble, 2016). The results of this study showed that participants could not retrieve the source format (i.e. color word, or physical color) of information that had just (i.e. several seconds before) been attended and used to perform a color-congruence judgment. Thus the conclusion is that source format information is not automatically stored in WM.

Experiment 1

The first experiment investigated whether participants would automatically remember the source format of a color representation that they had just used to complete a task in the immediately preceding interval. To answer this question, we repeatedly asked participants to judge the congruency between the color and identity of a single color word (e.g., “RED” displayed in green ink color; we hereafter use “ink” to refer to the green color of phosphors

on a CRT display), and then on a surprise trial we asked them to recognize the *ink color* of the word that they had just seen on that trial, prior to reporting the congruency.

Note that the congruency judgment task requires participants to extract semantic representations from both the ink color and identity of the word, but has no requirement to link these semantic representations to their original source format (i.e., ink color or word). Thus, such a task examines the spontaneous storage of source information.

Method

Sample size. In the current study, we used a predetermined sample size of 20 participants for each experiment or each group in the between-subject design experiment. This sample size was based on previous studies that indicated the magnitude of the effect that could be expected (Chen & Wyble, 2015a; 2015b, 2016). In this entire study no participants were allowed to participate in more than one experiment.

Participants. Forty Pennsylvania State University undergraduates (divided randomly into two groups) completed Experiment 1 in exchange for course credits or \$5. All of them reported normal or corrected-to-normal visual acuity. An additional participant completed the experiment, but was removed for having accuracy in the pre-surprise trials lower than 60% (chance is 50%).

Apparatus. The stimuli were presented on a 17-in CRT computer monitor with a resolution of 1024×768 at 75 Hz refresh rate by using MATLAB with the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). The view distance was fixed at approximate 50 cm by using a chinrest. Participants made responses through a computer keyboard.

Stimuli. There were four different color words (RED, BLUE, YELLOW, and PURPLE), and each of them was displayed in one of four ink colors (RGB values: red = 200, 0, 0; blue = 0, 0, 200; yellow = 200, 200, 0; purple = 190, 45, 200), which yielded four *congruent words* (e.g., the word “RED” displayed in red ink color) and twelve *incongruent words* (e.g., the word “RED” displayed in green ink color). All words were displayed in a font size of 30 in Arial uppercase font. The four black placeholder circles (0.62°) were placed at the four corners of an invisible square ($6.25^\circ \times 6.25^\circ$), with a black fixation cross (0.62°) appearing in its center (see Figure 1). All these stimuli were displayed on a gray background (RGB: 150/150/150).

Procedure and Design. As shown in Figure 1, the trial started with the fixation display for a randomly determined duration in the range 1000 and 2000 ms, which was replaced by the stimuli display including only one single congruent or incongruent word at the center of the screen for 161 ms. The stimulus word was then covered by a colored mask for 522 ms. After the offset of the mask, two black words, “Congruent” and “Incongruent”, and two

corresponding numbers (1 and 2) appeared and remained on the screen until participants made a response. Participants were asked to report whether or not the word's ink color was congruent with its identity on these trials by pressing one of two number keys (1 or 2).

Then, on the 43th trial (i.e. the surprise trial), participants were unexpectedly presented with a forced-choice array including four different colored lines (i.e., red, blue, yellow, and purple, see Figure 1) and asked to indicate which one matched the *ink color* of the word they had just seen on that trial by pressing one of four corresponding number keys (5–8). The four colored lines were presented in a random order. After this surprise memory task, participants were also asked to do the congruency judgment task as in previous trials.

The surprise trial was then followed by four control trials that had the same format as the surprise trial. All responses in this and following experiments were self-paced, with no time pressure being applied.

Participants were divided into two groups according to the types of the word used on the surprise trial: half of them were defined as the *incongruent group* who were shown an *incongruent* word on the surprise trial, while the other half were the *congruent group* who were shown a *congruent* word on the surprise trial. Subsequent control trials in both groups were randomly assigned a congruent or incongruent word.

Figure 1. Sample trial sequences in Experiment 1. The surprise question reads “This is a surprise memory test! Here we test the “ink color” of the word. Press a corresponding number to indicate the ink color of the word”.

Results

The results of incongruent and congruent groups are depicted in Tables 1 and 2 respectively.

For the incongruent group, participants performed well on the congruency report task on pre-surprise trials (2% error). However, 40% (8/20) of

participants were incorrect in reporting the ink color of the word on the surprise trial. More importantly, of these incorrect-report participants, 75% (6/8) falsely selected the colored lines that matched the word's identity rather than the word's ink color (i.e., source misattribution), which was much higher than the chance of guessing ($1/3=33\%$)¹. This indicates that participants have memories of both semantic representations, but were often confused about whether a specific semantic representation was extracted from the ink color or identity of a color word. Furthermore, participants' error rates of ink color report on control trials (5%, 0, 0, and 5% error) were smaller than errors in the surprise trial (40% error), with the decrement reaching significance even on the first control trial (40% vs. 5%, $\chi^2(1, N = 40) = 7.025, p = .008, \phi = .42$). Their error rate of the congruency report on the surprise trial was 30%, which was much worse than pre-surprise (3%) and control trials (0, 0, 10%, and 0 errors).

Table 1. The error results of Experiment 1: Incongruent group (N=20)

	Pre- surprise	Surprise	Control 1	Control 2	Control 3	Control 4
Congruency	3%	30%	0	0	10%	0
Color	N/A	40%	5%	0	0	5%

Note. N/A= Not applicable

¹ We would combine these 8 error data with those from following experiments to conduct a statistical analysis.

As shown in Table 2, contrary to the incongruent group, only 10% (2/20) of the congruent group participants incorrectly reported the ink color of the word on the surprise trial, which was even numerically lower (though not significantly so) than the first control trial (10% vs. 20%, $\chi^2(1, N = 40) = .784$, $p = .376$, $\phi = .14$). More importantly, this error rate was significantly lower than that of incongruent group (10% vs. 40%, $\chi^2(1, N = 40) = 4.800$, $p = .028$, $\phi = .35$). This finding was consistent with the idea that participants had memory of both colors, despite a lack of memory for their corresponding source formats. Participants' congruency judgment performance on the surprise trial (5% error) was equally good in pre-surprise (3% error) and control trials (15%, 5%, 0, and 0 errors).

These findings showed that participants often could not report the source of information that had just been specifically attended and used in the immediately preceding task, indicating that source memory representations are not automatic. To the best of our knowledge, this is the first demonstration of source memory failure in short-term memory with young normal participants. Another important finding is that even though participants did not remember the source format of the two colors, the colors were retrievable in response to an unexpected question. These findings were consistent with previous long-term

source amnesia studies showing failure of source memory for successfully retrieved items.

Table 2. The error results of Experiment 1: Congruent group (N=20)

	Pre-surprise	Surprise	Control	Control	Control	Control
			1	2	3	4
Congruency	3%	5%	15%	5%	0	0
Color	N/A	10%	20%	0	0	0

Note. N/A= Not applicable.

Experiment 2

An alternative explanation of the findings of Experiment 1 could be that participants stored the word's identity but not the ink color, and were biased towards selecting the color bar corresponding to the word's identity when asked to report its ink color on the surprise trial. This follows from work on the Stroop paradigm, which finds that participants preferentially process a word color's identity compared to its ink color, (e.g., Sabri, Melara, & Algom, 2001; Stroop, 1935). The current experiment was designed to rule out this possibility.

Method

This experiment was identical to the incongruent surprise group of Experiment 1 except as follows. Twenty undergraduate students participated for course credits or \$ 5. Another participant completed the experiment but was

excluded from analysis because of low accuracy (< 60%) in pre-surprise trials. All participants received only incongruent surprise trials in this experiment. In the surprise memory test, participants were unexpectedly presented an array of four color words with the same identity but different ink colors, instead of four different colored lines as in Experiment 1. The identity of these four words was always identical to the word they had just seen on that trial. Participant's task was to select the target word that was exactly the same as the one they had just seen on that trial. Note that participants could only rely on the ink color information to select the target word from distractor words because all choices of words have the same identity.

Results

As depicted in Table 3, only 4 of 20 participants (20% error) were incorrect in the surprise memory test, and this error rate did not significantly differ from that of the first control trial (20% vs. 10%, $\chi^2(1, N = 40) = .784, p = .376, \phi = .14$). The following three control trials also yielded consistent low error rates (0, 5%, and 5%). Participants performed the congruency judgment task very well in pre-surprise (5% error), surprise (15% error), and control trials (10%, 0, 0, and 5% errors). The results demonstrated that participants also stored the ink color representation in memory, indicating that the findings of Experiment 1 indeed reflect the fact that participants had memory of both color representations despite a lack of memory for their original source formats.

Table 3. The error results of Experiment 2 (N=20)

	Pre-surprise	Surprise	Control	Control	Control	Control
			1	2	3	4
Congruency	5%	15%	10%	0	0	5%
Color	N/A	20%	10%	0	5%	5%

Note. N/A= Not applicable

Experiment 3

Experiments 1–2 showed that participants do not automatically remember source information of an input representation (i.e., semantic representation of a color), even though they had just used that representation for a task immediately before. Experiment 3 extended this finding further by examining whether the need to hold information in WM prior to use results in obligatory source storage.

Method

This experiment was identical to Experiment 1 with the following exceptions. Forty undergraduate students completed this experiment (divided randomly into two groups). As depicted in Figure 2, participants saw two sequential stimuli: one colored square and one black word, and judged whether the color of the square was congruent with the identity of the word in pre-surprise trials. Each stimulus appeared on the screen for 161 ms and was then masked for 522 ms. Thus, participants had to hold the first stimulus in WM for

more than half a second in order to make the congruency judgment. Half of the participants always saw the colored square first (square-first-group), while the other half always saw the word first (word-first-group).

On the surprise (33th trial) and control trials, participants from both groups were required to select the exact colored square (among three distractor colored squares) they just saw on that trial before the congruency task.

Figure 2. Sample trial sequences in Experiment 3. The surprise question reads “This is a surprise memory test! What was the colored square you just saw on this trial? Press a corresponding number to indicate it”.

Results

For the word-first-group, 12 of 20 (60% error) participants incorrectly selected the colored square on the surprise trial, which was substantially worse than performance on the first control trial (60% vs. 5%, $\chi^2(1, N = 40) = 13.789$, $p < .001$, $\phi = .59$). Furthermore, consistent with Experiment 1 (incongruent group), of these 12 incorrect-report participants, 8 (8/12=67%) suffer from source misattribution (i.e., chose the square with the color referring to the identity of the word on that same trial), which was much higher than the chance (1/3 = 33%). We collapsed these 12 error data with 8 error data from Experiment 1 (incongruent group) for a statistical analysis and found that, the probability of source misattribution is significantly higher than guessing (70% vs. 33%, $\chi^2(1, N = 40) = 4.912$, $p = .027$, $\phi = .35$). These results again suggested participants had the memories of both color representations but had not bound them to their source formats (i.e., word and square), thereby leading to source misattribution in the surprise test. To further confirm that participants had memory for color representations, we ran a control experiment in which we replicated this experiment but removed the square with the color referring to the word’s identity from the array of choices on the surprise question. In other words, during the surprise test we only showed participants three choices of

color: the correct square color and two new colors that had not appeared on that trial. The results showed that 18 of 20 (90% correct) participants correctly selected the target square on the surprise trial, indicating that participants indeed had a memory of the square's color representation.

In addition, their performance on the congruency task was high across trial types, despite slightly lower performance on the surprise trial (pre-surprise: 6% error; surprise: 25% error; controls 1-4: 10%, 10%, 5%, and 0 error).

Table 4. The error results of Experiment 3: Word-first-group (N=20)

	Pre-surprise	Surprise	Control 1	Control 2	Control 3	Control 4
Congruency	6%	25%	10%	10%	5%	0
Color	N/A	60%	5%	10%	0	10%

Note. N/A= Not applicable

By contrast, only 3 of 20 participants from the square-first-group were incorrect at selecting the target square on the surprise trial, which did not significantly differ from the first control trial (15% vs. 5%, $\chi^2(1, N = 40) = 1.111, p = .292, \phi = .17$). More importantly, this error rate was significantly lower than that of the surprise trial in the word-first-group (15% vs. 60%, $\chi^2(1, N = 40) = 8.640, p = .003, \phi = .46$). In addition, performance on the congruency

task was high across trial types (pre-surprise: 2% error; surprise: 15% error; controls 1-4: 0%, 5%, 5%, and 5% error).

These findings seem to suggest that holding a color representation in WM for a brief time is sufficient for storing its source, as indicated by the results of the square-first-group. However, an alternative explanation could be that participants did not remember the source information even for the stimulus held in WM, and they were just biased towards reporting the color of the first-presented stimulus as the target color. Such a bias might arise from the fact that participants had to hold the color representation of the first stimulus, which increases the activation of that representation and thus make it be more familiar.

Table 5. The error results of Experiment 3: Square-first-group (N=20)

	Pre-surprise	Surprise	Control 1	Control 2	Control 3	Control 4
Congruency	2%	15%	0	5%	5%	5%
Color	N/A	15%	5%	5%	0	5%

Note. N/A= Not applicable

Experiment 4

The final experiment attempted to tease apart the two aforementioned explanations for the findings of Experiment 3. That is, we asked whether the results of the square-first group reflect automatic source memory for an input

held in WM, or alternatively, a bias to report the stimulus with stronger activation or familiarity due to being the first item. We addressed this issue by directly asking participants to report whether a given probed color representation, which refers to the color of the first-presented item, comes from Source A (e.g., square color) or Source B (e.g., word identity). Also, the presentation order of the two stimuli was randomized in the pre-surprise trials. Obviously, bias to report the first-presented item would not help to answer this source memory task. Thus, if the bias hypothesis is correct, then participants would be unable to do such a source memory task.

Method

This experiment was identical to Experiment 3 except as follows. Another twenty undergraduate students completed this experiment. In 35 pre-surprise trials, participants either saw a colored square followed by a black word or vice versa, and did congruency judgment task. On the surprise trial, the square was always presented before the word and participants were surprisingly asked to judge whether a given probed color representation (which always referred to the square color) came from a square or a word by pressing one of two keys. For instance, the surprise question on the screen reads:” Surprise test! On the last trial, Did the color *RED* come from a square or a word? Press 3 if square, Press 4 if word”. The presentation order of the answer choices (i.e., Press 3 if square, Press 4 if word; or vice versa) on the surprise test were counterbalanced among

participants. We used a different font for the color to minimize a template based strategy. The following control trials had the same format as the surprise trial, except that the stimulus presentation sequence and the probed color representation (either from square or word) were counterbalanced among participants.

Results

The results are shown in Table 6. Participants performed poorly on the source judgment task on the surprise trial, with 9 of 20 (45% error) participants being incorrect. However, their performance increased in control trials (30%, 10%, 5%, and 0% error), with the improvement reaching significance by the second control trial (45% vs. 10%, $\chi^2(1, N = 40) = 6.144, p = .013, \phi = .39$). The congruency task performance was highly accurate on pre-surprise (4% error) and control trials (0, 0, 5%, and 0 error), but worse on the surprise trial (25% error).

The current experiment clearly showed a failure to remember source format information of a color representation that had even just been encoded into WM. This indicates that the findings of Experiment 3 might result from a bias to report the color representation of the first-presented item that was held in WM, rather than an automatic encoding of source information for the first color, which had to be maintained in WM for a brief duration.

Table 6. The error results of Experiment 4 (N=20)

	Pre-surprise	Surprise	Control	Control	Control	Control
			1	2	3	4
Congruency	4%	25%	0%	0%	5%	0%
Source	N/A	45%	30%	10%	5%	0%
Note. N/A= Not applicable						

General discussion

These studies showed that participants often failed to remember the original format of a stimulus they had just attended to perform a congruence judgement when they did not expect to be asked to report that source. These findings, to the best of our knowledge, provide the first demonstration of source amnesia for information represented in WM with young normal participants.

Is source information automatically stored?

Mitchell et al's (2004, 2006) studies used a short-term source memory task and found that young participants could accurately report the source (i.e., stimulus format or location) of a probed stimulus held in WM. However, those subjects were instructed in advance to remember the source format of stimuli while our participants did not expect to report the source format of the colors used in the congruency judgement. Our findings suggest that participants' expectation of the need to report source information plays a critical role in determining whether it will be remembered.

Previous studies demonstrated that long-term source amnesia occurred regardless of whether participants expected to report the source information (see Table 7; e.g., Jacoby, 1991; Mitchell et al., 2004; Naveh-Benjamin, 2000; Schacter, Harbluk, & McLachlan, 1984), while short-term source amnesia was not present when participants expected to report source information (e.g., Mitchell et al., 2004, 2006). The short-term source amnesia in an incidental memory task observed here thus provides an important complement to the existing literature by showing that it occurs in the short-term when for an incidental probe.

Table 7. Long-term and short-term source amnesia in different task demands

	Long-term source amnesia	Short-term source amnesia
	Yes	No
Intentional/Expected	(e.g., Mitchell et al., 2004; Schacter et al., 1984)	(e.g., Mitchell et al., 2004, 2006)
Incidental/Unexpected	Yes (e.g., Jacoby, 1991; Naveh-Benjamin, 2000)	Yes (Current study)

The locus of source amnesia: encoding or retrieval?

It is difficult to determine the locus of long-term source amnesia that occurs in the context of incidental memory tasks, since a failure of report in

these tasks could be attributed to failures of encoding or retrieval. The current study showed that source amnesia could occur even in short-term memory paradigms, suggesting that some demonstrations of source amnesia, at least those occurring in the context of incidental memory tasks, reflected a lack of initial memory encoding of source information. This argument assumes that errors in short-term memory for the most recent trial will not result from retrieval errors. This assumption is consistent with previous findings showing that source memory deficits in old adults are primarily caused by declining frontal function, which is critical for encoding (Glisky, Rubin, & Davidson, 2001).

One might argue that the surprise nature of the test used in the current study caused forgetting of source information that had been encoded into WM. This possibility seems unlikely, because previous studies using very similar surprise tests demonstrated that participants could correctly report a color once it was encoded into WM, even in a surprise test (Chen & Wyble, 2016).

Comparison with Attribute Amnesia

The present results can be contrasted with attribute amnesia, a failure to report features (e.g., color or identity) of a target that they had just attended but did not expect to report (Chen & Wyble, 2015a). In contrast, we find here that participants could remember individual features of an attended stimulus, even though they had no expectation to report them. The distinction between these new results and attribute amnesia suggests that attribute amnesia occurs

primarily when one item needs to be selected from an array of multiple items. In these congruence judgement experiments, with only a single stimulus presented, it might have been easier to use familiarity to respond correctly. In other demonstrations of memory performance in the face of surprise questions, subjects were better able to remember when there were only two (Chen, Swan, & Wyble, 2016) or one stimulus presented at a time (Eitam, Yeshurun, & Hassan, 2013; Swan, Collins & Wyble 2016).

Conclusion

These results suggest a cognitive-economy view of memory function, in which source information is only stored when it is expected to be useful. In the absence of such expectation, information is stored at a conceptual level, without its accompanying source format. In such a case, the source format may be stored at a schema level for the entire task; e.g., I remember that in this study, colors are presented as words or ink colors. This would allow the essential information necessary for completing each trial, but without wasting resources storing the source format for each stimulus. These results also suggest that in long-term source amnesia effects using incidental tests in which subjects did not expect to be asked about source, the unretrievable source information may not have been encoded at all.

Our findings challenge the common intuition that if we have just experienced and made use of information, we will know its source. This is a

strong intuition for most people, despite phenomena such as not knowing that the source of a song in one's head was the background music in a store, or not knowing whether a word in mind came from reading or listening to a concurrent television program. Together with previous work on attribute amnesia (e.g., Chen & Wyble, 2015a), these results demonstrate that attention and awareness do not automatically result in memory durable enough even for short-term retrieval. They go beyond those previous results by demonstrating that even using information to make inferences is not sufficient for such encoding of the information's source.

Author Contributions

Hui Chen, Brad Wyble, and Richard Carlson developed the study concept. Hui Chen performed the programming, data collection, analysis and most of the writing. Brad Wyble and Richard Carlson contributed writing and editing. All authors approved the final version of the manuscript for submission.

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