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COMMENTARY

Source ROCs Are (Typically) Curvilinear: Comment on Yonelinas (1999)

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On the basis of his assumption that recollection is a threshold process, A. P. Yonelinas (1999) predicted linear source-identification receiver operating characteristics (ROCs) and recently reported data that were consistent with this prediction. In this article, the authors present data showing curvilinear source-identification ROCs across various encoding and test conditions. On the basis of the source-monitoring framework (e.g., M. K. Johnson, S. Hashtroudi, & D. S. Lindsay, 1993), the authors argue that curvilinearity of source-identification ROCs is a result of differences in the qualitative characteristics of memories rather than simply the influence of undifferentiated familiarity as the dual-process model might suggest.

Yonelinas and colleagues (Yonelinas, 1994, 1999; Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996) have proposed a type of dual-process (recollection and familiarity) model of recognition memory based on an extension of the process-dissociation procedure (Jacoby, 1991), which itself grew out of earlier dual-process models of recognition (e.g., Atkinson & Juola, 1974; Mandler, 1980). As described by Yonelinas (1994, 1999), recollection is a process by which specific detail is recovered, which he assumes is a threshold process, whereas familiarity decisions are assumed to be based on a continuum of familiarity information and characterized by signal detection (e.g., Green & Swets, 1966). Figure 1 shows examples of the expected shape of the receiver operating characteristic (ROC) curves and corresponding *z* ROCs (see Green & Swets, 1966, pp. 96–97) for data produced by a threshold decision process (Panels A and B) and a decision process based on continuous information (Panels C and D).

Yonelinas (1999) suggested that source identification can be modeled by this high-threshold recollection process and tested this prediction. Participants in four experiments made Source 1 or Source 2 confidence judgments (discriminating between words previously presented on the left from those presented on the right side of a computer screen; discriminating between words spoken by a male voice from those spoken by a female voice; discriminating between words spoken twice by a male voice from those spoken once by a female voice). In three out of four experiments, Yonelinas found linear ROCs for source discrimination as predicted by his model. In the fourth experiment, participants discriminated between words from two lists that had been presented 5 days apart. Only in the fourth experiment were source ROCs curvilinear. Yonelinas argued that the source ROCs in this experiment were curvilinear because familiarity (in the form of recency) provided a strong cue to source.

The source-monitoring framework (SMF) differs from Yonelinas's (1994) model in that we believe that recollection is best described as continuous (i.e., graded) rather than as discrete (Johnson, Hashtroudi, & Lindsay, 1993; Johnson & Raye, 1981; Mitchell & Johnson, 2000). According to the SMF, features (e.g., visual and auditory characteristics of the speakers, the experimental context, semantic content of the statements) are bound together (associated) as a result of encoding processes; subsequently, on any particular occasion a cue is likely to activate some subset of those encoded features (assumptions also shared by other theories of episodic memory, e.g., Tulving, 1983). A different subset of features may be activated by different cues, and remembering (recollection or retrieval) is frequently partial (e.g., Dodson, Holland, & Shimamura, 1998; Gruppuso, Lindsay, & Kelley, 1997) and varies in clarity and veridicality. Just as a single dimension such as familiarity can vary in a nondiscrete manner, the SMF assumes that so too can the subjective experience (e.g., vividness or amount of detail) that arises from the combined influence of multiple types of information (e.g., visual, auditory, location, temporal, emotion; see also Banks, 2000). That is, from this perspective, source judgments (including old–new recognition) involve decision processes that use the available activated information, which ranges from a vague sense of familiarity or vague detail (such as visual or emotional information) to a vivid sense of such features. Consequently, source attributions should typically look continuous rather than discrete. That is, we would expect curvilinear source ROCs even when source attributions could not be based on familiarity.[1]

In contrast to Yonelinas's (1999) results, and consistent with the SMF, we find curvilinear source-memory ROCs even when familiarity cannot be used to discriminate source. Here we report two examples, one from new analyses of data from a previously published study (Mather, Johnson, & De Leonardis, 1999) and the

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[1] It should be noted that signal-detection models traditionally assume Gaussian distributions of information, where the variances of the signal

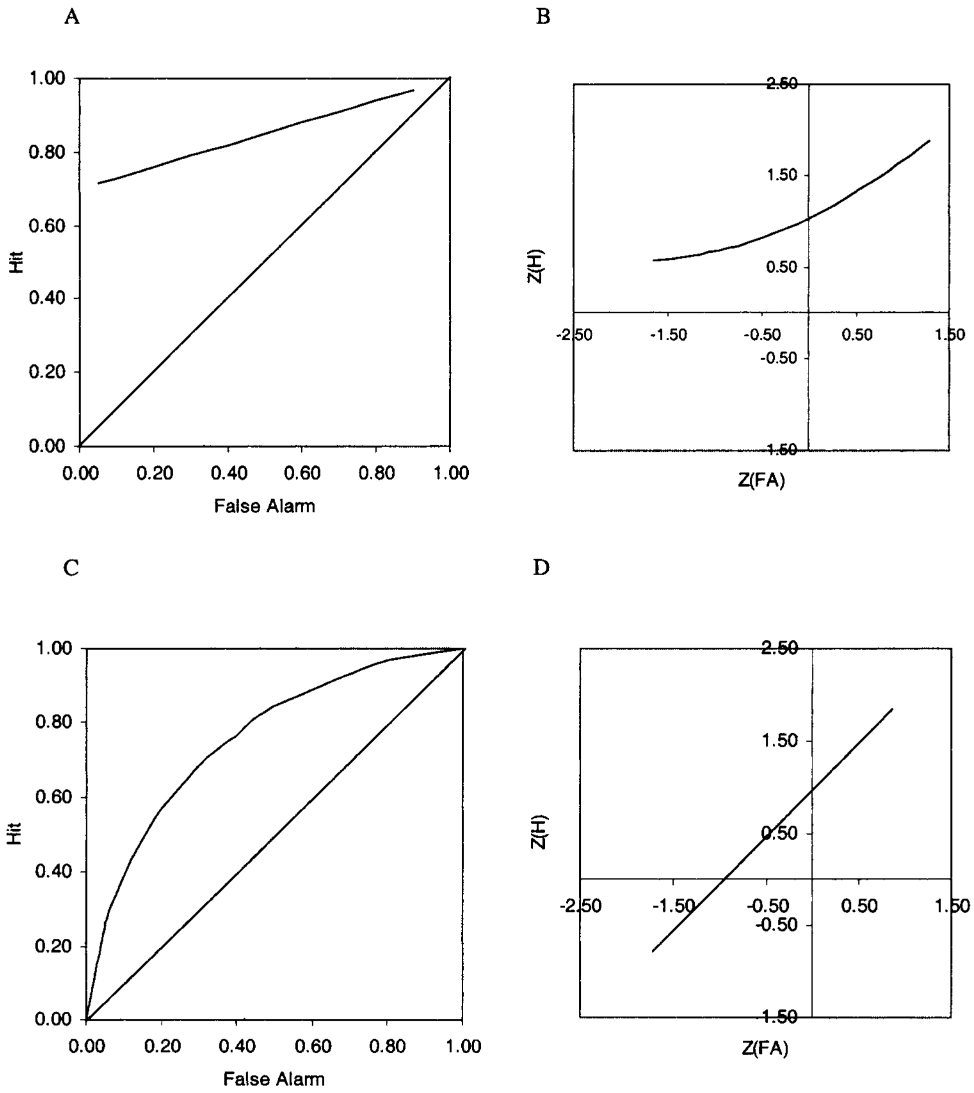

Figure 1. Expected shape of the receiver operating characteristic (ROC) and corresponding z ROC produced by a threshold decision process (Panels A and B) and a decision process based on continuous information (Panels C and D). Z(H) and Z(FA) represent z transformations of hit rates and false-alarm rates, respectively.

other from new data collected for this article. To examine the shape of the source ROCs we conducted the same comparisons and statistical test (Neter, Kutner, Nachtscheim, & Wasserman, 1996, pp. 547–559) used by Yonelinas (1999) to determine curvilinearity; that is, we examined whether introducing a quadratic term to the linear equation significantly improved the fit to the ROC function.

Study 1

In Mather et al. (1999), 96 participants watched a videotape of two women making statements. As they watched the video, a random half of the participants focused on their own feelings about the statements (self-focus condition) and the other half focused on the speakers' feelings (other-focus condition). Statements by the two speakers were randomly intermixed (with the constraint that no speaker said more than two statements in a row) at acquisition. There were 48 statements; each was followed by a 15-s pause and

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(target) and noise (distractor) distributions are equal (e.g., Green & Swets, 1966). This yields ROC curves that are curvilinear, monotonically increasing, and symmetrical. From the perspective of the SMF, there is no theoretical reason to suppose that the variances associated with two sources are necessarily equal, although in many experimental situations (e.g., discriminating Speaker A from Speaker B, or words presented on the left from those presented on the right) this is a reasonable assumption. However, even with a factor of 3–4 difference in variance between signal and noise distributions, ROCs, especially those based on rating data, are often curvilinear, monotonically increasing, and nearly symmetrical (Green & Swets, 1966, pp. 103–106). Therefore, even with unequal variance, linear versus curvilinear ROCs can serve as evidence consistent with high threshold versus continuous accounts of remembering, respectively.

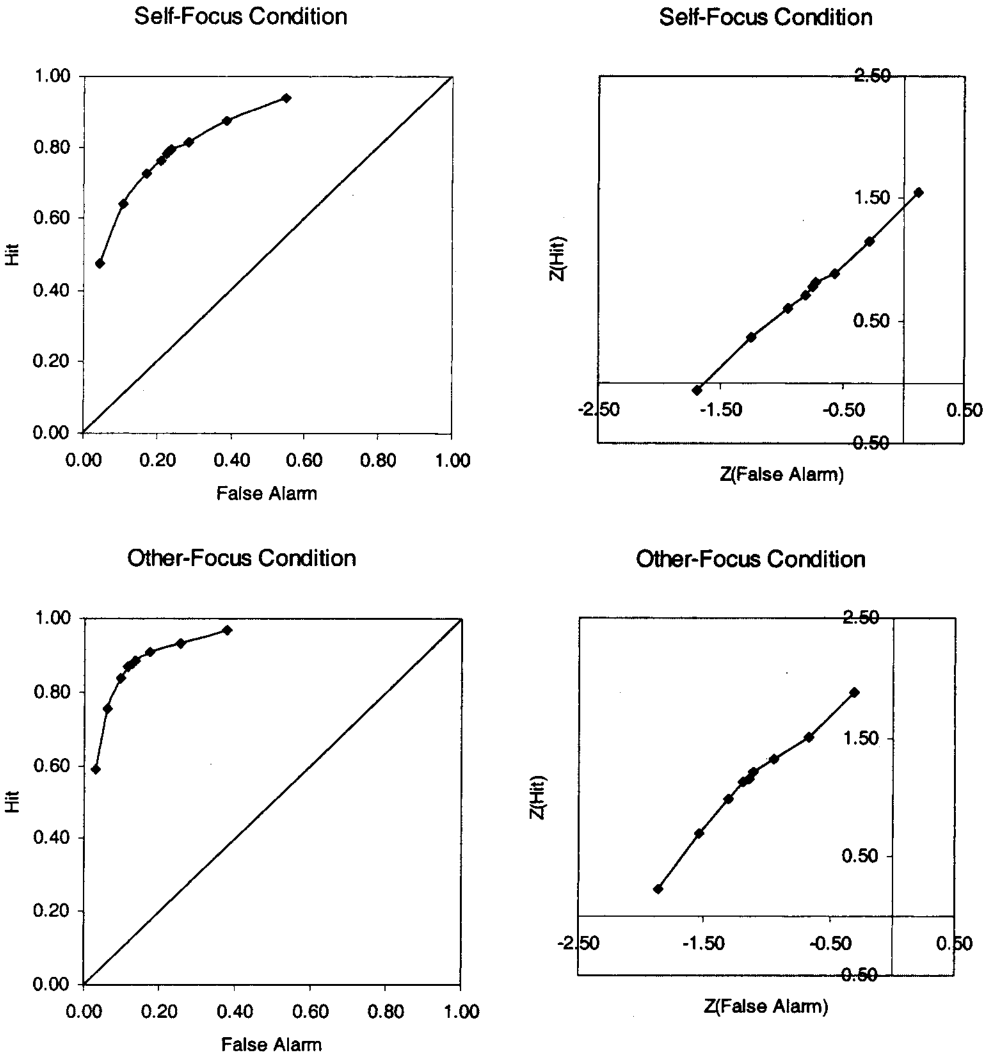


Figure 2. Source-identification receiver operating characteristics derived from Mather, Johnson, and De Leonardis (1999), plotted in probability space (left panels) and z space (right panels). $N = 96$ (48 each in the self-focus and other-focus conditions). Z(Hit) and Z(False Alarm) represent z transformations of hit rates and false-alarm rates, respectively.

a beep that signaled the next statement. After watching the video, participants received an unexpected source-identification test that included 48 old statements and 24 new statements presented in a random order. Participants first judged whether a statement was old or new and then rated each old–new judgment on a scale from 1 (*lowest confidence*) to 5 (*highest confidence*). For statements that were judged as old, participants further judged which of the two speakers made the statement and then made a confidence rating for the source judgment, using the same scale as for the old–new judgment.

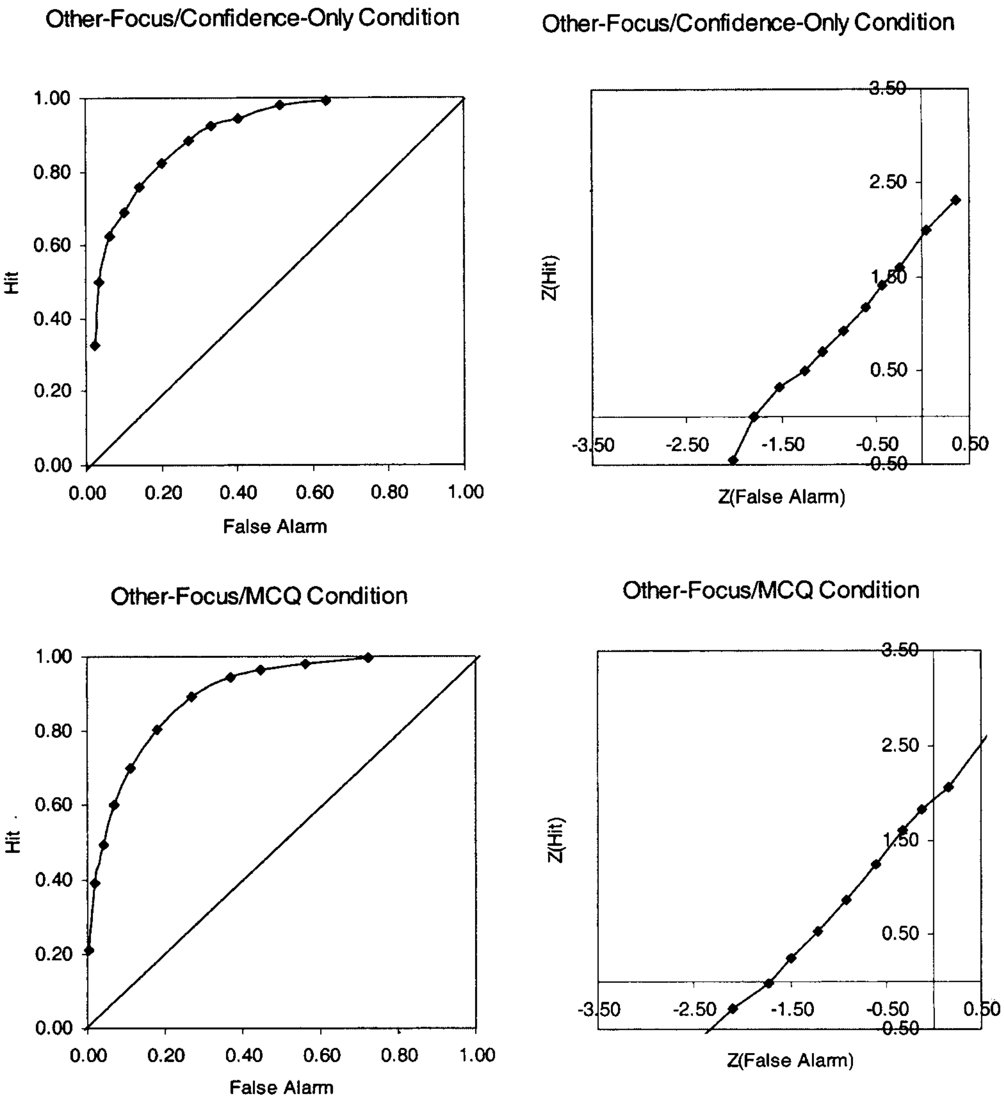
Although the Mather et al. (1999) study was not conducted specifically with ROC analyses in mind, the data were collected in a way that allowed us to plot and examine the source ROCs for the present purpose (see Macmillan & Creelman, 1991, pp. 60–63). We arbitrarily designated statements made by one of the speakers as targets and statements by the other speaker as lures. Combining speaker response and confidence rating yielded 10 possible responses to each item, from high-confidence "Speaker 1" to high-confidence "Speaker 2," where the highest confidence Speaker 2 response to a Speaker 1 item is considered the lowest possible confidence Speaker 1 response and vice versa. Cumulative proportions were calculated for each stimulus class (Speaker 1, Speaker 2) across the 10 levels of confidence. Because the cumulative probability of the last response category is necessarily 100%, this procedure yields a 9-point ROC curve.

Figure 2 shows the ROCs (and corresponding z ROCs) for the self-focus and other-focus conditions. As is apparent, the ROCs for both conditions exhibited a pronounced inverted-U shape. In the self-focus condition, the quadratic function ($R^2 = .99$) provided a significantly better fit to the source-identification ROC data than the linear function ($R^2 = .80$), $F(1, 6) = 130.67$, $p < .001$. Similarly in the other-focus condition, the quadratic function

($R^2 = .92$) provided a significantly better fit to the source ROC than the linear function ($R^2 = .60$), $F(1, 6) = 24.00$, $p < .01$. As Mather et al. (1999) reported, and consistent with previous studies (e.g., Johnson, Nolde, & De Leonardis, 1996), participants in the other-focus condition were better at discriminating sources as measured by d' ($M = 2.20$, $SD = .94$) than were participants in the self-focus condition ($M = 1.69$, $SD = .96$), $F(1, 94) = 7.02$, $p < .01$.

Study 2

Data from Mather et al. (1999) show curvilinear source-identification ROCs for two encoding conditions when the source judgments were conditioned on old–new recognition. For generality, we examined source ROCs in a new study under two test conditions, both including only old statements. Thirty-eight Princeton University undergraduates viewed a videotape, previously used by Johnson et al. (1996), of two women reading statements. There were 30 statements made by each woman, randomly intermixed and presented with a 6-s pause between the statements. The statements were about various facts and feelings, for example, "Classical music is soothing" and "Children should never be physically disciplined." All participants received an unexpected source-identification test, and we manipulated whether participants were explicitly instructed to focus on specific memory details during the test. A random half of the participants were asked to judge which of the two speakers made each statement and then rate their confidence on a scale from 1 (*lowest confidence*) to 6 (*highest confidence;* the confidence-only condition). The other


Other-Focus/Confidence-Only Condition

Other-Focus/Confidence-Only Condition

Other-Focus/MCQ Condition

Other-Focus/MCQ Condition

Figure 3. Source-identification receiver operating characteristics from new study (see text), plotted in probability space (left panels) and z space (right panels). $N = 38$ (19 each in the confidence-only and the memory characteristics questionnaire (MCQ) conditions). Z(Hit) and Z(False Alarm) represent z transformations of hit rates and false-alarm rates, respectively.

half of the participants made source judgments and confidence ratings, and also responded to a memory characteristics questionnaire (MCQ; Johnson, Foley, Suengas, & Raye, 1988). On the MCQ, participants were asked to rate four characteristics of their memory for each statement, ranging on a scale from 1 (*least information*) to 6 (*most information*): visual detail (e.g., facial expressions of the speaker), auditory detail (e.g., the tone of the voice of the speaker saying the sentence), information about their own feelings or emotional reactions, and information about the speaker's feelings or emotional reactions. Using the procedure described in Study 1, source ROCs for each condition were plotted on the basis of combining speaker response and confidence ratings, yielding 12 response possibilities and 11 ROC points.

The results indicated that regardless of test condition, source ROCs exhibited an inverted-U shape (Figure 3). Linearity analyses again indicated that in both conditions quadratic functions provided a better fit than linear functions: in the confidence-only condition, the quadratic equation ($R^2 = .94$) fit the data significantly better than the linear equation ($R^2 = .74$), $F(1, 8) = 26.13$, $p < .01$. In the MCQ condition, the quadratic equation ($R^2 = .93$) also fit the data significantly better than the linear equation ($R^2 = .73$), $F(1, 8) = 22.08$, $p < .01$. There was no significant difference between d' for participants in the confidence-only condition ($M = 1.97$, $SD = .90$) and participants in the MCQ condition ($M = 1.90$, $SD = .68$), $F < 1.00$ (but see Henkel, Franklin, & Johnson, 2000; Mather, Henkel, & Johnson, 1997).

To further examine whether the recollection of information that accompanied the participants' memories of the statements can better be described as graded or discrete, we plotted additional ROCs based on the MCQ ratings for each type of memory characteristic and then conducted linearity analyses. The results indicated that the MCQ ROCs for all four types of information were curvilinear, in that the quadratic equations (R^2s $\geq .88$) provided significantly better fits than the linear functions (R^2s $\leq .67$), Fs$(1, 8) \geq 14.00$, ps $< .01$.

Because the levels of source-identification performance in our studies tended to be higher than those in Yonelinas's (1999) study, we examined the possibility that the observed curvilinearity of the source ROCs in our studies was due to ceiling effects. We conducted analyses including only participants who had midrange d's (between 1.5 and 2.0) in Study 1 ($n = 20$) and Study 2 ($n = 14$) to avoid potential ceiling and floor effects. Data were collapsed across self-focus and other-focus conditions in Study 1 and collapsed across confidence-only and MCQ conditions in Study 2. In both studies, a quadratic equation ($R^2 = .98$ and .85 for Study 1 and Study 2, respectively) fit the data better than a linear equation ($R^2 = .75$ and .61, respectively), $F(1, 6) = 63.00$, $p < .001$, and $F(1, 8) = 13.32$, $p < .01$, respectively.

Discussion

Consistent with the predictions from the SMF outlined in the introduction, we observed curvilinear source-identification ROCs in the two studies described here. Regardless of whether participants were instructed to focus their attention on internal feelings or on the external source of information during encoding (Study 1), whether they were instructed to focus on specific details of their memory during retrieval (Study 2), and whether the source decision was conditioned on old–new recognition (Study 1 vs. Study 2), source ROCs were curvilinear rather than linear. Because the statements from both of the two sources were presented only once and were intermixed at acquisition, neither frequency nor recency provided a source cue. Thus, we attribute the observed curvilinearity in source ROCs to differences in the qualitative characteristics of memories (e.g., tone of voice, appearance of the speakers, emotion) rather than, necessarily, the influence of undifferentiated familiarity as Yonelinas's (1994) dual-process model might suggest. Also consistent with our view is the finding that the MCQ ROCs for all four types of qualitative information were curvilinear, suggesting that visual detail, auditory detail, information about participants' own feelings, and information about others' feelings each can better be described as continuous rather than discrete.

One potentially important difference between our two studies and Yonelinas's (1999) studies may be that our studies provided richer initial learning episodes. Yonelinas commented that when participants are able to retrieve numerous types of information about the study events or if the recollected information is less than a perfect predictor of source, even if recollection is a threshold retrieval process, it might begin to behave in a more continuous manner, leading to curvilinear source ROCs. Such a characterization of recollection as involving variation in the number of features recollected begins to approximate the SMF. What would be missing, which is explicit in the SMF, is that amount of information about individual features can vary as well (as indicated by our MCQ ROCs). In short, from the source-monitoring perspective, we expect curvilinear source ROCs may be the rule rather than the exception in source attribution in the real world. We propose that source ROCs are typically curvilinear, except perhaps when the source information available for most items is very impoverished or when there is not much variation among items in the amount of information recovered (i.e., a sparse range of experiences; Green & Swets, 1966, p. 70). Thus, a potential direction for future research is identifying conditions under which the phenomenal experience of recollecting might be best described as continuous or as discrete, whether in the context of old–new recognition judgments or source-identification judgments.

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