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Changes over 10 years in the retelling of the flashbulb memories of the attack of September 11, 2001

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A flashbulb memory is a highly detailed and vivid autobiographical memory for the circumstances in which one first learned of a surprising, consequential, and emotionally arousing event. How retelling of different features of a flashbulb memory changes over time is not totally understood. Moreover, little is known about how the emotional feeling experienced by individuals when they learned about the event modulates these changes. In this study, we explored changes over time in American individuals' retelling of their flashbulb memories of the terrorist attack of September 11, 2001. We conducted textual analysis of 824 testimonies collected from the same 206 individuals one week, 11, 25 and again 119 months after the attack. Results showed individuals were more likely to report temporal and emotional details in their retelling early after the event and spatial details in their long-term retelling. In addition, intensity of emotions felt upon hearing the news about the attack influenced how individuals reported their flashbulb memories over time. Overall, this study provides further support for theories suggesting different rates of forgetting for different canonical features of emotional arousal events.

Keywords: 9/11; flashbulb memories; retellings; longitudinal study; textometry

## **Introduction**

A flashbulb memory is a highly detailed and vivid autobiographical memory for the circumstances in which one first learned of a surprising, consequential and emotionally arousing event (Brown & Kulik, 1977). It mostly forms following a public negative event, but positive and private events can also lead to its formation. It is characterized by an immediate and involuntary memorization of canonical characteristics relating to the circumstances in which one has learned the news. Six have been the focus of research of flashbulb memories: the moment, the place, the ongoing activity, the identity of the first-informant, the immediate consequences, as well as some details about the event (Hirst & Phelps, 2016; Luminet & Curci, 2017). Long-term retention of flashbulb memories was investigated through measurements of consistency, vividness, long-term retention, and level of confidence. According to these studies, individuals generally describe their recollection as more vivid and permanent than that of classic autobiographical memories. They also experience an exacerbated confidence in the accuracy of their recollection whatever its effective accuracy (Hirst & Phelps, 2016).

### ***Assessing properties of flashbulb memories: Recalling vs. Retelling***

An objective measure of recollection *accuracy* is difficult to provide, inasmuch as assessment usually occurs a few days after the initiating event and because it relies on an unverifiable personal history and an inaccessible subjective experience. Moreover, quantification of the features reported by participants is insufficient since this methodology takes omissions errors but not commissions errors into account (Hirst et al., 2015). To address these concerns, most researchers examine *consistency*, that is, the stability of the content of the recollection over time, employing a test/retest methodology. Participants have to provide a first description of the canonical features of their flashbulb memories by answering semi-structured questions (e.g., How did you first learn?; Where were you?; What were you doing?) as soon as possible after the event and complete follow-up assessments several months later or more afterwards. The contents of the follow-up recollections are then compared with the content of the initial recollection to obtain a consistency score and plot a forgetting curve. Studies using structured questionnaires and consistency measure mainly reported a rapid forgetting of details about a flashbulb memory in the first year after the event followed by a slow-down of forgetting between the first and the third year, and levelling off of performance thereafter

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(Hirst et al., 2009, 2015; Talarico & Rubin, 2003). Overall this forgetting curve might even resemble the one reported for recollection of ordinary autobiographical memories, at least for fairly short time intervals (Talarico & Rubin, 2003).

Marsh (2007) distinguished between the *retelling* of a memory from its recall. In the latter, people are pressed to remember all that they can remember generally during a semi-structured interview or questionnaire, whereas in the former, they are simply asked to tell or write their story without pre-established framework. As Marsh noted, retelling reflects properties of memory and is sensitive to both audience demands and the rememberer's own conception about how to create an appropriate narrative about the event. Thus, while recalling is oriented towards the study of forgetting, retelling allow study of the flexibility with which people reconstruct their memories in social contexts.

Social identity, rather than personal relevance, is central for the formation and maintenance of flashbulb memories (Berntsen, 2017). The collective consequentiality of the event increases the interpersonal exchanges about it, also referred to as memory practices of the community (Hirst et al., 2009). Thereby, flashbulb memories for public events are frequently reactivated and shared in a social context. As a result, an examination not of responses to memory probes, but of retellings may provide greater insight into what features may play a significant role in the construction and reconstruction of flashbulb memories. Yet, changes over time in retelling of flashbulb memory is understudied.

### ***Spatial, temporal, and emotional details of the memory***

Memories for specific events (i.e., retrospective episodic memory) are organized in time and space, two separate dimensions of experience combined in our memory (Eichenbaum, 2017; Tulving, 1972). The way the brain combines these dimensions helps us to embed our memory for an event within a unified representation of “spatiotemporal context”. Interestingly, the accessibility of these contextual details has been proposed to drive the subjective recollective experience of an event (Johnson & Raye, 1981). Thus, when recalling the memory for an experience, one can rely on spatial and temporal features as landmarks to structure his/her narrative and facilitate retrieval following the natural course of events in time and across places. A vivid and detailed recollection of an event is often associated with high remembrance of these contextual features (Yonelinas, 2002).

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In studies of flashbulb memory, the score of consistency generally reported was the sum of the consistency scores obtained for each canonical feature, which did not allow drawing a distinct forgetting curve for each feature. To the best of our knowledge, the only study investigating the consistency of event features separately showed that individuals tended to remember better spatial location and temporal details of their flashbulb memory than any other details. Moreover, the memory for temporal and spatial details seems to evolve over time, individuals remembered better the spatial location where they learned about the attacks than any other feature over time (Rimmele et al., 2012). However, the retelling of temporal and spatial details of flashbulb memory is still under-investigated.

Memory for emotions can be quite unreliable (Levine et al., 2006) and tends to be inconsistent and forgotten quickly over time (Hirst et al., 2009, 2015; Levine & Pizarro, 2004). Most participants in Hirst et al. (2009) reported experiencing fear when hearing the news about the event, whereas what they initially reported was shock. Given that the emotional intensity of an event subsides over time (Hirst et al., 2009; Levine & Pizarro, 2004), we might expect that not only would individuals incorrectly recollect their initial emotions, but they would also decrease reporting emotions in their longer-term retellings.

### ***Influence of emotional feeling on memory***

Over the past twenty years, studies have shown that emotion improves the encoding and facilitates the recollection of the memory associated to an event. Initial cognitive and visceral emotions have been found to exacerbate subjective sense of remembering during recollection and enhance confidence in the accuracy of episodic autobiographical memories. Emotion has been shown to intensify subjective feeling of remembering, despite lower accuracy for contextual details memory (Rimmele et al., 2011). Similarly, the recollection of flashbulb memory of a highly emotional event is associated with high vividness and exacerbated confidence in the quality of the memories, without being accompanied by a particularly high consistency in the details reported, for example in comparison to a classical autobiographical memory (Talarico & Rubin, 2003).

The valence and the intensity of the emotion associated with the event has been explored. Highly emotional events are generally better recalled than neutral events. Narratives of negative events tend to be longer, more vivid, and more consistent over time than narratives of positive events, whereas narratives of positive events are more

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structurally complex (see Fivush et al., 2009 for review). Moreover, the more intense the negative event is, the longer, more vivid, and more detailed the narratives are (see Fivush et al., 2009 for review). Concerning flashbulb memory, positive and negative events elicit equally detailed memories. However negative events may elicit more confident and consistent flashbulb memories, while positive events may elicit more vivid memories (see Stone & Jay, 2017 for review). The findings on the relation between emotion intensity and flashbulb memory are contradictory, with some studies reporting an association between emotional intensity and flashbulb memory formation, consistency and vividness, while nearly as many studies reported no association (see Talarico & Rubin, 2017 for review).

Even if their theoretical constructs do not overlap, both Kensinger (Kensinger, 2007, 2009) and Mather (Mather, 2007) argued that negative emotional arousal enhances remembering of some features of a memory over others. On the one hand, Kensinger differentiates intrinsic features useful to processing the affective relevance of the information from extrinsic features more distant from the emotional arousal of the event. From this perspective, negative emotional arousal enhances memory for intrinsic features such as spatial details, but it does not enhance and sometimes impairs memory for extrinsic details such as temporal details. On the other hand, Mather's view focuses on fixed properties of the event. She distinguishes memory binding for "within item" that associates the constituent features of the event from memory binding for "between-item" which associates the event to background contextual information and to other events. Unlike Kensinger, Mather considers both spatial and temporal information as "within item," enhanced by negative emotional. On the contrary, according to this view, emotion does not enhance and sometimes impairs binding for "between-item". Despite the advances made through the development of these theories, the influence of emotion on the different features of a flashbulb memory is still poorly understood.

### ***Current study***

In the present study, we investigated changes over 10 years in people's retelling of their 9/11 flashbulb memory. We used textometry, a powerful approach for the analysis of large body of texts (Lebart et al., 1998), to perform quantitative and qualitative bottom-up analysis of individuals' retelling of the circumstances in which they learned about the attacks. Textometry provides a concise view of people's retellings through a detailed

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textual analysis, taking into account the exact wording and the context in which words were used. Moreover, this method operates in a contrastive way, it entirely relies on current lexical data and experiment internal variables (word frequencies, testimony lengths, testing timepoint, participant descriptive features), and does not involve any external resource that could skew observations. We expected it would provide converging evidence for the coding results and allow for a more subtle comprehension of flashbulb memory consolidation (Lebart et al., 1998).

Our study aimed 1) to determine whether the retelling of 9/11 flashbulb memory changed over time, with a particular focus for the use of spatial, temporal, and emotional features; 2) to understand whether the intensity of emotions felt by the participants upon hearing the news influenced the retelling of each feature over time. For such a purpose, we used textometry to analyze individuals' retelling in response to the open-ended probe included in Hirst et al. (2009, 2015)'s study conducted over a 10-year period. However, unlike previous studies, we did not apply any manual coding to the vocabulary before conducting our analyses. This difference may seem trivial, but it is fundamental as individuals' free reconstruction of their flashbulb memory in retellings go beyond the field of possible answers to series of closed or semi-open questions.

In line with Kensinger's work, we hypothesized that the use of "intrinsic" features such as spatial details in retelling would be stable over time whereas the use of "extrinsic" details such as temporal details would decrease. This profile of change should be amplified by the intensity of the emotion felt upon hearing the news, since arousal enhances memory for "intrinsic" but not "extrinsic" features (Kensinger, 2007; Kensinger & Schacter, 2006). We also expected a decrease of the retelling of emotional detail over time since memory for emotions tends to decrease over time (Hirst et al., 2009, 2015; Levine & Pizarro, 2004).

## **Method**

### ***Recruitment, procedure, and surveys***

Data were collected by Hirst et al. (2015, 2009) as part of the study on individual memories of the terrorist attack of the September 11, 2001, 1 week, 11 months, 35 months and 119 months after the event. Recruitment procedure, data collection methods and survey content are detailed in Hirst et al. (2015, 2009). We recruited participants between September 17, 2001 and September 21, 2001 (Survey 1, T1), August 5, 2002 and August



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20, 2002 (Survey 2, T2), August 9, 2004 and August 20, 2004 (Survey 3, T3) and August 1, 2011 and August 15, 2011 (Survey 4, T4). They came from seven locations across the United States: Boston and Cambridge, MA; New Haven, CT; New York, NY; Washington, DC; St. Louis, MO; Palo Alto, CA; Santa Cruz, CA.

For all four investigations, participants were asked to fill out the survey either on-line or on paper and return it within 48 hours. Each survey took about 45 minutes to complete. It included a set of nearly 30 open-ended questions, short-answer questions and rating scales exploring flashbulb and event memories, consequentiality of the event (as assessed by personal loss or inconvenience), as well as intensity of emotional response and rehearsal (as assessed by media attention and ensuing conversation about 9/11).

Analyses reported in previous studies by Hirst et al. (2015, 2009) were based on a manual coding of responses devising separate coding scheme for flashbulb and event memories. Our approach is different and independent in this study since the core of our analyses relies on automatic and bottom-up analyses of participants' full text responses to the first question of the survey: "Please describe how you first became aware of the terrorist attack on America. NOTE: Please do not turn to the next page until you have completed your response to this question."

### ***Selection of participants***

We selected participants from Hirst et al. (2015, 2009), who had answered the four surveys. Thus, 206<sup>1</sup> participants (148 females) aged between 18 and 83 years old on September 11, 2001 (mean age:  $38.44 \pm 1.24$  years) were included in the present study. At the time of the attack, 106 (51.4%) were students. Twenty-two participants (10.7%)

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<sup>1</sup> Four additional participants who had taken all four surveys were discovered subsequent to the publication of Hirst et al, (2009). These participants had used incorrect IDs, but were subsequently identified based on their handwriting, demographic information, and a near match of their IDs. For instance, the ID was required to include a three-letter identification of the participant's place of residence. On one Survey, they used NYC (for New York City) whereas for another survey they used BRO (for Brooklyn).

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were witnesses to the attack, 78 (37.9%) learned about it by word of mouth, 62 (30.1%) via media and 44 (21.4%) by phone call or email. Ten participants reported suffering of psychological condition following the attack (6 participants with post-traumatic stress disorder, 3 with depression or mood disorder and 1 with anxiety disorder). There is no difference between participants who only took Survey 1 and those who took all four surveys (included in the present analyses) in terms of age, sex, country of origin, student membership at the time of the attack, and way to first learn about the attacks (all  $ps > .10$ ).

### ***Textometry analysis***

Textometry analysis was performed with TXM 0.7.8 software (Heiden, 2010; Heiden et al., 2018) and DtmVic 6.0 (Lebart & Piron, 2016). Textual corpus included the testimonies the 206 participants provided to the first question at the 4 timepoints. In all, there were 824 texts made up of 58,972 words (see Table 1 for number of occurrences by timepoint). We used two complementary statistical methods to process textometry analysis:

(1) Correspondence analysis (Benzécri, 1973), which is a multivariate statistic method providing the two-dimensional representation of data which explains the maximum of variance. In the context of our study, CA allowed us to test the existence of a temporal (chronological) organization of the testimonies that would reflect changes in retelling over time. We used CA to analyze words (or class of words corresponding to temporal, spatial, and emotional details as described below) composing the corpus to examine the overall organization of testimonies in relation to each other. Our data are presented as contingency tables where rows are observations (here words or classes of words written by the participants), and columns are variables (here the timepoint). Note that in contingency tables, both rows and columns are categorical variables (i.e., a set of words and a set of timepoints) playing symmetric roles which means they can be swapped without changing the mathematical properties of the matrix. Thus, structurally this is a two-way table, also named cross tabulation, or contingency table. Overall, CA is specifically designed and relevant for the analysis of contingency tables, for which it proves getting better results than PCA (Lebart et al., 1998). We also tested the stability of the visualized pattern with a bootstrap validation (Lebart, 2004, 2007), so as to evaluate if these results were powerful enough to draw reliable conclusions on it.

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(2) Specificity analysis (Lafon, 1980; Lebart et al., 1998; Salem, 1988) is an application of Fisher-Yates's exact test to textual data (Gries, 2014; McEnery & Hardie, 2012). In the context of our study, specificity analysis allowed us, in a similar way to a post hoc analysis, to precise the changes in retelling over time and to identify which words (or class of words) were statistically overused and underused at each timepoint, solely considering word distribution among testimonies. Specificity analysis relies on a hypergeometric probability model to provide a specificity score, either positive or negative. A positive (negative) score indicates the order of magnitude of the probability of a word  $w$  appearing  $f$  times or more (or less) in a part containing  $n$  words, given  $w$  appears  $F$  times in the whole corpus of  $N$  words. Specificity scores equal to or higher than 3 (1 chance in 1000 to obtain the frequency  $f$  or more if the words were randomly distributed among parts), or lower than -3 (1 chance in 1000 to obtain the frequency  $f$  or less randomly) were considered significant. Such a very low  $p$ -value (1%) is necessary because of two reasons. First, language is essentially non-random, so that many probabilities are low, and we have to focus on very low ones to get relevant results. Second, from a statistical point of view, specificity measures involve multiple comparisons. It is very common to use a stricter threshold in this type of analysis to narrow Type 1 errors (Lebart, 2004).

### *Changes in the content of retelling over time (word-based analysis)*

We tested if vocabulary used in individuals' retelling changes over time, using both correspondence and specificity analyses of all the words reported in retellings. We did not conduct any semantic classification of words for this analysis. Only spelling variants such as "10:00 am"/"10:00 A.M."/ "10am.", "About/about", "World Trade Center"/"world trade center"/"WTC", "+"/"&"/"and"/"And" were grouped because they have the same meaning and the presence of such variations could mainly be owe to neglects when entering the data in the digital repository. Nonetheless, we purposefully selected to keep inflection variations (number, gender, tense, etc.) in order not to reduce data and lose any information that may be significant. Then, to reduce noise in the analyses, we selected word (lexical entries) that occur 5 times or more in the corpus (corresponding to all testimonies), so that we worked on a total vocabulary composed of about a thousand different words, excluding low frequency words.

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### *Changes over time in the retelling of spatial, temporal, and emotional details*

We tested if temporal, spatial, and emotional details of retellings change over time. Each word was automatically tagged (categorized) as temporal, spatial, or emotional details using regular expressions as detailed below. A regular expression is a string of characters expressing a linguistic pattern. It allows to automatically screen a corpus and to return all the words that follow the specific linguistic pattern coded by the regular expression. For example the regular expression of an hour written in digital form (e.g., 8:50) is “\d{1,2}\:\d{1,2}” read as 1 or 2 decimals followed by a colon and again 1 or 2 decimals. The following regular expressions were used to tag words of the corpus:

- (1) Temporal details corresponding to hours reported as clock time (n = 230):

```
\d{1,2}(\:{0,1}\d{1,2})\{0,1}(\s)\{0,1}(((a|A|p|P)(\.)\{0,1}(m|M)(\.)\{0,1})ish|so.cloc  
k|\snoon)
```

```
\d{1,2}\:\d{1,2}
```

- (2) Spatial details corresponding to names of NYC’s streets, avenues, squares, neighbourhoods or bridges (n = 520):

```
\d{1,3}([a-z])\{2}\s(st([retsaiou])\{0,5}|ave([nues])\{0,4})
```

```
(Astor|Audobon|Bank|Barclay|Bleecker|Broad|Broome|Canal|Christopher|Church|C  
lark|Cortlandt|Dey|Empire|Exchange|Fulton|Grand|Greenwich|Grove|Houston|Huds  
on|Huston|John|Jones|Lafayette|Liberty|(\sM)|Macdougall|Mercer|Murray|Nassau|Or  
ange|Park|Pine|South|Sullivan|Thompson|University|Wall|Warren|Water|Waverly|W  
hite|Wooster|Thompson|Wall|Warren|Water|White|Wooster)\s(st([rets])\{0,5})
```

```
(West\sEnd|Fifth|Graham|Greenwich|Metropolitan|Second|Sixth|Whitney|Wisconsi  
n)\s(ave([nues])\{0,4})
```

```
(Thompson|Times|Prospect|Union|University|Washington|Hall|City\sHall|Boro|Batt  
ery|Central|Brooklyn)\s(sq\square)(\spark)\{0,1}
```

```
(59th\sSt|Bayonne|Bklyn|Brooklyn|Key|Manhattan|George\sWashington)\s(br([idge  
])\{0,5})
```

```
(Rockefeller\s(Center|Plaza)|Union\sStation|Silver\sSpring|Astor\sPlace|Broadway(  
\sPlace)\{0,1}|Brooklyn\s(Heights)\{0,1}(Promenade)\{0,1}|Chinatown|(Greenwich\s  
)\{0,1}Village|Manhattan|Midtown|The\sBronx|Soho|SoHo|Staten\Island|Williamsb  
urg|Harlem|Red\sHook|Exchange\sPlace|Clark\sPlace|Park\sPlace|University\sPlace  
|Waverly\sPlace)
```

```
(Brooklyn|New\sYork(\sCity)\{0,1}|New Jersey|Jersey City)
```

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(3) Emotional details corresponding to negative emotional feelings based on synonyms of ‘horror’, ‘afraid’, ‘agitated’, ‘worried’, ‘terrible’, ‘astonished’, ‘sad’ listed using Collins<sup>2</sup> and Oxford<sup>3</sup> synonym dictionaries in different declensions (verb, adjective, noun, etc; n = 383):

afraid|agitate(d){0,1}|alarmed|angry|anxious|astonish(ing|ed){0,1}|awe|awful(ly){0,1}|bad(ly){0,1}|bother(ed){0,1}|burst(\sout){0,1}|calm|choke(d){0,1}|concerned|confus(e|ed|ing|ion)|crazy|cried|cry(ing){0,1}|curious|deprese(d){0,1}|devastating|disast(er|rous)|disbelief|distraught|distressed|emotional(ly){0,1}|excit(e|ed|ing)|fine|flipping|frantic(ally){0,1}|freak(ing){0,1}|frighten(ed|ing)|gasp(ed){0,1}|gawk(ing){0,1}|guilty|hop(e|ed|ing)|horr(or|ible|ified)|hysterical|implausible|incomprehensible|inconceivable|incredulous|injured|love(ly)|mayhem|mesmerize(d){0,1}|nervous|nightmare|numb|okay|panic(ked|kingly|(-\s)stricken){0,1}|puzzl(ed|ing)|quiet|sad(ness){0,1}|scar(y|e|ed)|safe(ty){0,1}|scream(ed|ing){0,1}|shaken|shock(ed){0,1}|shout(ing){0,1}|skeptical|spell(-){0,1}|bound|struggling|stunned|suffering|surprised|surreal|tear(s){0,1}|terrible|terrif(y|ied|ying)|terror|trauma(tized){0,1}|unbelievable|upset|weird|worr(ied|ying)|wors(e|t)|yell(ed|ing){0,1}

For this detail-based study, all other words were compiled in a class called ‘#REST#’.

We explored the overall organization of these details (see Table 1 for number of occurrences by timepoint) from T1 to T4 using a correspondence analysis, and their overuse or underuse at each timepoint using a specificity analysis.

### *Influence of intensity of emotions felt upon hearing the attack on retelling details*

We explored whether the intensity of emotions felt by individuals upon hearing the news about the attack (emotion-intensity) affected the amount of temporal, spatial and emotional details they reported over time. For each participant, we calculated an emotion-intensity score corresponding to the average of his responses to the six questions for

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<sup>2</sup> <https://www.collinsdictionary.com/dictionary/english-thesaurus>

<sup>3</sup> <https://www.lexico.com/synonyms/>

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which they had to rate the intensity of sadness, anger, fear, confusion, frustration, and shock felt upon hearing about 9/11 (Survey 1, Questions 13–18). Inter-correlations among scores of emotional intensities are presented in Table 2.

The effect of a continuous variable cannot be directly tested (such as correlation analyses) with the textometry method. To simplify the interpretations of the textual analysis and the presentation of the results, we transformed the continuous variable of emotion-intensity into a categorical variable with “high” and “low” groups as recommended by DeCoster et al. (2011). This method seemed optimal to us since it tends to give the best results when the initial variable (emotion-intensity) has a symmetric distribution, which is the case in our study. Moreover, we have selected this method rather than a 3 groups analysis (with “high”, “middle” and “low” groups) or an extreme group analysis (mostly done by selecting the upper and lower quarters of the distribution excluding the middle 50%) that would have strongly reduced the statistical power of analyses. This decrease would have been especially problematic in our study since textual analysis is based on very restrictive significance thresholds. Thus, we conducted a median-split of the group of 206 participants based on their emotion-intensity score: Participants with a score lower than or equal to the median (3.5) were affected to the ‘Low emotional intensity’ group and those with a score higher than 3.5 in the ‘High emotional intensity’ group. There are no differences between the two sub-groups of participants in terms of age, sex, country of origin, student membership at the time of the attack, the way to first learn about the attacks (all  $ps > .07$ ). Furthermore, as the median-split prevents to consider all the variability of the emotion-intensity, we developed a new exploratory method inspired by adjacent characteristic elements analysis (Lebart et al., 1998; Salem, 1988) to explore the full continuum of the effect of emotion-intensity on details reported by the participants over time using iterative specificity analysis (see supplemental material).

## Results

### *Changes in the content of retelling over time (word-based analysis)*

The chi-square test between the two variables (timepoint and words) of the correspondence analysis revealed a significant association ( $\chi^2(176,913) = 3055.39; p = .019$ ). Correspondence analysis plot showed that the points corresponding to the timepoint described a horseshoe pattern and are organized in a chronological order from T1 to T4 on the axis 1 which represents 44.11 % of the total variance (Figure 1A). This

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pattern is ascertained by bootstrap analysis (a partial bootstrap processed on word occurrences (Lebart, 2007)): small confidence ellipses shows that we have enough data to get a stable and reliable configuration we can interpret. This pattern is consistent with what is known as the Guttman effect, which reveals a unidimensional structure of data dominated by the presence of a gradation (Lebart et al., 1998; Salem, 1988). In his method for the lexical analysis of chronological textual series, Salem (1988) suggests that in the case of the Guttman effect, the traditional interpretation of correspondence analysis results (i.e., progressive interpretation of axes, one-by-one, commenting on the oppositions observed on each one) must be replaced by an overall interpretation. Thus, our result reflects that words have evolutionary profiles from one timepoint to another.

Specificity analysis of words at the four timepoints was performed to characterize the changes in vocabulary from T1 to T4. Significant specificity scores (higher than 3 or lower than -3) were observed at T1 and T4. Five words were statistically overused at T1 (Figure 1B): Quotes (“”)<sup>4</sup>, ‘explosion’, ‘collapse’, ‘minute’ and ‘Tuesday’. At T4, clock times were significantly underused, and two words, ‘remember’<sup>5</sup> and ‘dorm’<sup>6</sup>, were significantly overused (Figure 1B). No significant specificity score was observed for T2 and T3.

Overall, these results revealed a chronological organization of the testimonies that suggests changes (evolution) in the content of retelling over time. At T1, retellings seem rich in details, which may reflect a greater vividness of the flashbulb memory early after the event.

### ***Changes over time in the retelling of spatial, temporal, and emotional details***

The chi-square test of independence between the two variables (timepoint and details) of the correspondence analysis revealed a significant association ( $\chi^2(9) = 69.71; p < .001$ ). A correspondence analysis on details (i.e., words classed as spatial, temporal or emotional details, or #REST# if corresponding to none of these features) reveals that a Guttman

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<sup>4</sup> Words repeated as heard or spoken.

<sup>5</sup> 29 occurrences at T4, all in contexts like "I (do not) remember", "I can (not) remember".

<sup>6</sup> Main use in context: "my dorm (room)". **Mostly used by younger participants.**

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effect (with points corresponding to timepoint) described a horseshoe pattern and is organized in a chronological order from T1 to T4 on the axis 1 which grasps 85.35 % of the total variance (Figure 1C). The bootstrap analysis also validates the pattern (partial bootstrap on detail occurrences (Lebart, 2007)): confidence ellipses are larger than in the previous case, but they neither overlap, nor include the center of the graph, so that results are conclusive even if the amount of data is not that big.

Specificity analysis of details reported at the four timepoints allows exploring whether these details are reported from T1 to T4. At T1, spatial details were significantly underused, whereas temporal and emotional details were significantly overused (Figure 1D). No significant specificity score was observed for T2 and T3. At T4, spatial details were overused, temporal details were underused, and emotional details were neither overused, nor underused. Visually, the result suggests a constant increase in the report of spatial details, and a constant decrease in the report of temporal and emotional (except for time 4) details over time, which is consistent with the chronological organization suggested by the correspondence analysis. However, at T2 and T3, specificity scores are non-significant, this evolution is therefore not statistically assessed within the specificity analysis.

Overall, these results revealed a temporal evolution of spatial, temporal, and emotional details reported in retellings from T1 to T4. Over time, spatial details are more likely to be reported, whereas temporal and emotional details are less likely.

#### ***Influence of intensity of emotions felt upon hearing the attack on retelling details***

Specificity analysis on details with both timepoints and emotion-intensity as variables revealed that participants in the low emotion-intensity score group significantly overused temporal details at T1, whereas participants in the high emotion-intensity score group significantly overused emotional details at T1 only (emotional details were not anymore significantly overused as soon as T2) and, to a lesser extent, spatial details at T4 (close to the significance threshold [2.97]; Figure 2). Overall, the results suggest that the influence of the emotions felt upon hearing the attack on report for details was mostly observed at T1. As the corpus is divided into 8 parts (4 timepoints \* 2 levels of emotion-intensity), each part is quite small, so that the statistical test points out few significant results.

The iterative specificity analysis of the full continuum of emotion-intensity values provided similar results and substantiate spatial details overuse by high emotion-intensity



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subjects at T4. Furthermore, they refine the results for emotional details at T1, suggesting that within the high emotion-intensity group, participants with extreme high emotion-intensity underused emotional details (see supplemental material).

### **Discussion**

This study is the first using textual analysis to examine time-related changes of the use of characteristic features in individuals' retelling of their flashbulb memories for the attack of September 11, 2001. We showed differential changes in the retelling of temporal, spatial and emotional features of these flashbulb memories over time. More precisely, individuals were more likely to report temporal and emotional details early after the event and spatial details at the long-term investigation. Finally, we also highlighted that intensity of the emotion felt when they first heard the news of the attacks influenced people's way of retelling their 9/11 flashbulb memories over time.

Overall, we found a relative increase in the use of spatial details versus a relative decrease in the use of temporal details in individuals' retelling over time. This finding corroborates Kensinger's view that emotional arousal enhances memory over time for intrinsic features of an event such as spatial details but for not extrinsic features such as temporal details (Kensinger, 2007, 2009; see also Mather, 2007). Interestingly, the accessibility of these contextual details has been proposed to drive the subjective recollection of an event (Johnson & Raye, 1981). One possibility is that since learning about the attacks disrupted the normal course of their day, individuals were more likely to use temporal details as landmarks to organize their first retelling in a chronological order. Thus, rarefaction of temporal details in individuals' retelling over time could reflect a decrease of the accessibility of these features in memory. The increasing use of spatial details as landmarks in the following retellings might be an attempt to compensate this phenomenon all the more so recollection is mainly based on visual imagery for which spatial details are prominent and temporal details are scarce. Besides, as proposed by some authors (Butler et al., 2016), the repeated retrieval of this visual information may explain the maintenance of the exceptional vividness of flashbulb memories recollection reported by individuals over time. Finally, greater use of spatial landmarks in later retellings may also arise from the ubiquity of visual images in our society that become powerful memory shapers over time. Indeed, the occurrence of an event such as the attack of September 11, 2001 is followed by repeated broadcast of shocking images of the event in the media (i.e., television, newspapers, social media etc.). A huge amount of

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individuals share access to these images whose memorization is likely to interfere with flashbulb memory and influence its recollection. Thus, flashbulb memory seems to occupy a special place at the intersection of individual and collective memories and its study may help to shed light on the co-construction and evolution of these memories over time.

The decline in the use of emotional words over time is consistent with the decrease in both the intensity and the consistency of the emotional responses over time highlighted by Hirst et al. (2009, 2015). This result is also in line with studies of verbal recollection of past emotions suggesting that emotion does not persist in memory (Holland & Kensinger, 2010; Robinson & Clore, 2002). It might also reflect a change of visual perspective during individuals' recollection of their flashbulb memory over time. Indeed, when recollecting a recent autobiographical memory, individuals are usually spontaneously adopting an own eye perspective (i.e. within the body) whereas they are more likely to adopt an observer perspective (i.e. outside the body) for older memories (Rice & Rubin, 2009). Moreover, switching from one perspective to another is likely to modify the content and phenomenology of recollection (St. Jacques et al., 2017). For instance, switching from an own eye to an observer visual perspective has been proven to reduce the emotional intensity associated to recollection of the memory. Some authors suggested that this phenomenon increases detachment and distance between the individual and the event (Wallace-Hadrill & Kamboj, 2016). Thus, decreasing use of emotional words over time in our study might reflect a reduction in the emotional intensity of recollection due to switching from an own eye perspective to an observer view over time. Future investigations of flashbulb memory could integrate questions about this aspect of retrieval in order to better understand how the perspective adopted by individuals affects the use of emotional words in their retelling, and more generally how it modulates the phenomenological experience of recollection. Of note, the current conclusion is limited to the emotional vocabulary included in the analyses. Indeed, automatic tag of emotional word is subject to variability and dependent on the strategy used to define the vocabulary.

Interestingly, we found that the intensity of emotions felt upon hearing the news of the 9/11 attack influenced the use of emotional and temporal words in individuals' retellings. As expected, participants who reported feeling a high initial emotional arousal recollected more emotional details than other in their first retelling one week after 9/11.

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Conversely those who reported feeling a low initial emotional arousal recollected more temporal details in their first retelling. Altogether, these findings suggest that high emotional arousal during a negative emotional event leads to attention focus on emotionally salient intrinsic features at the expense of peripheral extrinsic features such as temporal details (Kensinger, 2007; Loftus et al., 1987; Mather, 2007). This change in attention allocation also modifies the way in which various components of the flashbulb memories are encoded and recollected as can be observed in individuals' lines of retellings. However increased use of spatial terms at T4 in individuals who experienced high emotional arousal also demonstrates that it was still possible for them to allocate attention to intrinsic features, and to memorize and consolidate their representations in memory.

Beyond considerations on the theoretical of flashbulb memory, this study underscores that a methodology based on longitudinal analysis of retellings is particularly relevant to explore the dynamic of mnemonic processes. Indeed textometry analysis allows a data-driven exploration of textual data released from bias associated with manual coding such as inter-judge reliability issues or lack of consideration of the context in which the words are used (Lebart et al., 1998). Above all, this method has the advantage of preserving the identity and meaning of every sub-part and sub-unit that keep determined by the overall context of the corpus (Pincemin, 2011). In the case of the investigation of human memory, it allows to study key features of memories considering the context in which they are reported.

### ***Future studies***

Our study showed that individuals reported more temporal and emotional details in their retelling early after the event, and significantly more spatial details in their long-term recollection. In addition, intensity of emotions felt upon hearing the 9/11 news modulated how individuals reported their flashbulb memories over time. Understanding the entanglement between flashbulb memory, described by many authors as a highly emotional autobiographical memory, and collective memory could be investigated in future studies. More specifically, it would be interesting to study the influence of memory practices such as media attention and ensuing conversation, commemorations, and memorials, on reconsolidation and integration of each feature of flashbulb memory, especially since a correlation between some of these elements and accuracy of event

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memories has been found in a previous study (Hirst et al., 2009). Indeed, understanding how individuals crystallize common representations of their flashbulb memory would help to highlight the construction processes of individual and collective identity. Moreover, some studies showed that flashbulb memory is shared across generations through conversations between parents and their children and participates in the construction of their social identity (Meyler, 2017). For Bohleber (2007), this transgenerational dynamic of maintaining the representation of the memory across generations allows the catastrophic and potentially traumatic nature of the event to persist across generations. Future studies could try to understand whether the particularities of reconsolidation that we highlighted is linked to this intergenerational transmission. Finally, given the conceptual proximity between flashbulb memory and collective traumatic memory, it might be relevant to study the characteristics of the evolution of the narratives of the flashbulb memory over time in individuals who have developed a post-traumatic stress disorder following learning about a potentially traumatic event. A study conducted within our laboratory, the transdisciplinary and longitudinal research project "*Programme 13 Novembre*" has precisely as main objective to better understand the interactions between individual and collective memory (Eustache & Peschanski, 2017; Mary et al., 2020). This program focuses on the attacks that occurred in Paris and Saint-Denis on the evening of November 13, 2015. In particular, it aims to better understand the influence of interpersonal interactions on individual memory, the conditions that allow an event to become part of collective memory, as well as the evolution of these two types of memory over time. For the past five years, this project has been following people who were directly or indirectly exposed to the Paris attacks and who are invited, every two years, to testify about these events. Analysis of these interviews could allow a better understanding of the specificities of the reconsolidation of these events over time and the construction processes of individual and collective identity in post-traumatic stress disorder patients in comparison to resilient individuals.

### ***Conclusion***

In conclusion, using for the first time textual analysis to explore longitudinal changes in individuals' retelling of a flashbulb memory, the present study suggests a switch from a greater use of temporal and emotional features early after the event to a greater use of spatial details 10 years later. Moreover, the intensity of emotions felt upon hearing the

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news influenced the use of these features in individuals' retellings over time. These findings provide further support for theories suggesting focal enhancement of memory for intrinsic but not extrinsic features of an emotional arousal event due to specific attention allocation to these intrinsic features (Kensinger, 2007, 2009; Mather, 2007). They also extend the work of Rimmele, Davachi, and Phelps (2012) showing that individuals tend to better remember the spatial features of their flashbulb memory than any other features. Finally, this study highlights the relevance of textometry analyses of retellings to provide a more fine-grained exploration of the adaptive and flexible characteristics of memories over time.

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**Table 1: Occurrence of words and details by timepoint.**

	<b>1 week</b>	<b>1 year</b>	<b>3 years</b>	<b>10 years</b>
<b>Words - Total</b>	16,750	12,732	12,855	16,635
<b>(mean [range])</b>	(81.3 [0-493])	(61.8 [1-337])	(62.4 [0-378])	(80.7 [0-1006])
<b>Spatial details</b>	113	90	134	183
<b>Temporal details</b>	93	53	50	34
<b>Emotional details</b>	143	80	61	99

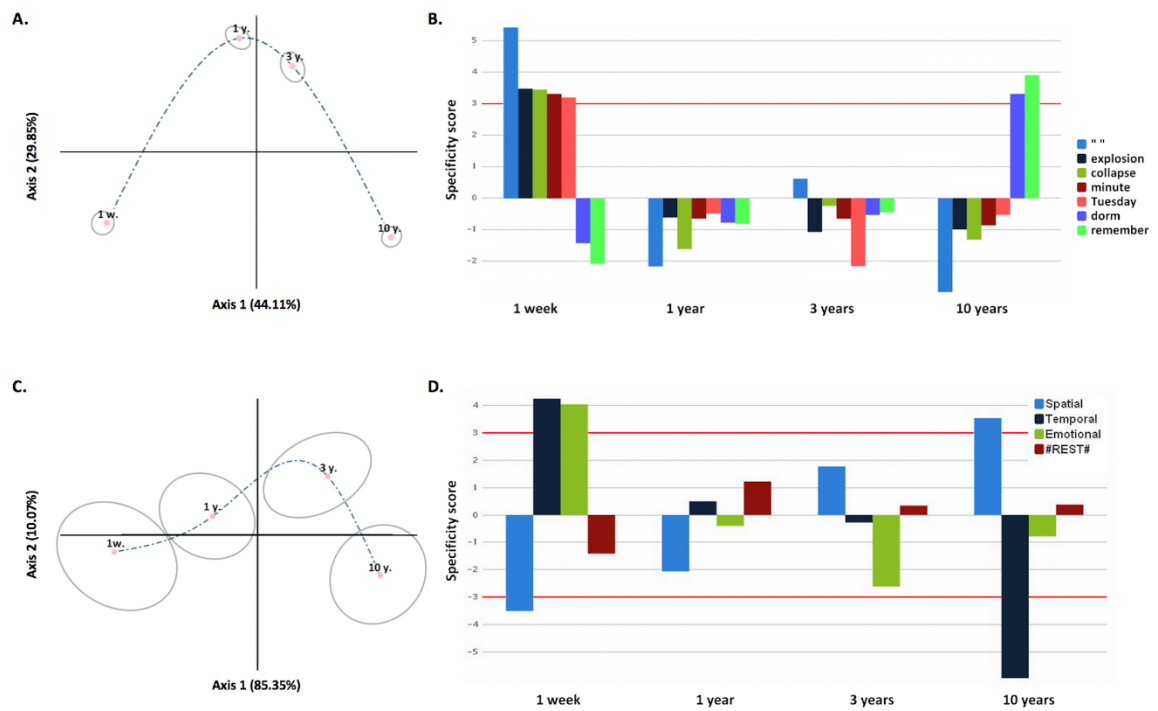
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**Table 2: Inter-correlations among scores of emotion-intensity felt by participants upon hearing the news about the attack.** Emotion-intensity score corresponds to the average responses of a participant to the six questions for which he had to rate the intensity of sadness, anger, fear, confusion, frustration, and shock felt upon hearing about 9/11 (Survey 1, Questions 13–18). \* indicates  $p < .05$ . \*\* indicates  $p < .01$ .

		<b>Sadness</b>	<b>Anger</b>	<b>Fear</b>	<b>Confusion</b>	<b>Frustration</b>	<b>Shock</b>
<b>Sadness</b>	Pearson Correlation	1					
	Sig, (2-tailed)						
	N	206					
<b>Anger</b>	Pearson Correlation	.266**	1				
	Sig, (2-tailed)	.000					
	N	206	206				
<b>Fear</b>	Pearson Correlation	.304**	.395**	1			
	Sig, (2-tailed)	.000	.000				
	N	206	206	206			
<b>Confusion</b>	Pearson Correlation	.158*	.157*	.366**	1		
	Sig, (2-tailed)	.023	.024	.000			
	N	205	205	205	205		
<b>Frustration</b>	Pearson Correlation	.164*	.415**	.283**	.419**	1	
	Sig, (2-tailed)	.019	.000	.000	.000		
	N	206	206	206	205	206	
<b>Shock</b>	Pearson Correlation	.399**	.315**	.304**	.318**	.326**	1
	Sig, (2-tailed)	.000	.000	.000	.000	.000	
	N	206	206	206	205	206	206

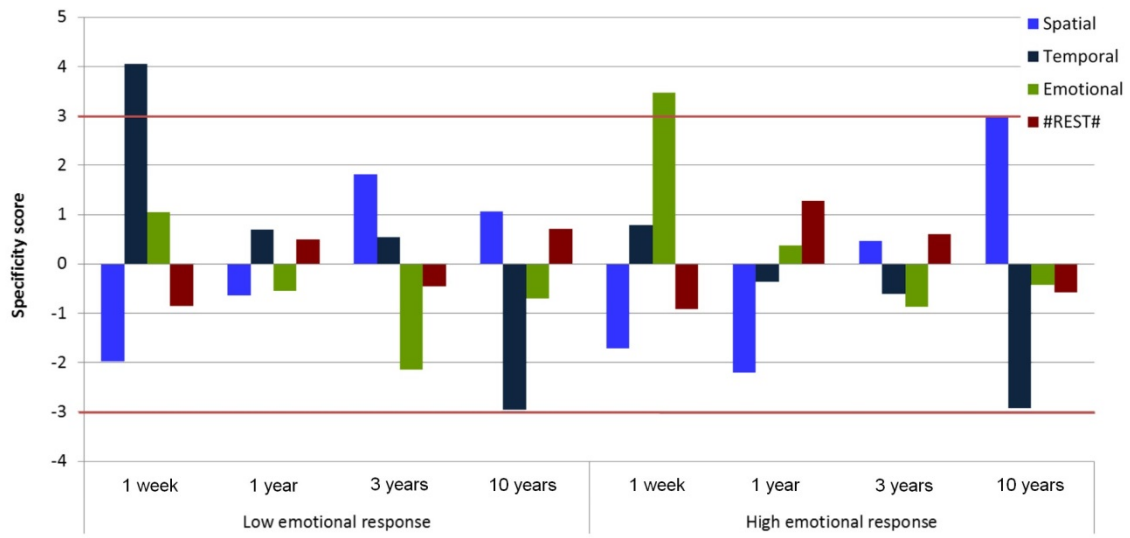
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**Figure 1**



Changes over 10 years in the retelling of the flashbulb memories of the attack of September 11, 2001

**Figure 2**



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**Figure 1: Changes in the content of retelling over time (word-based analysis).** A) Correspondence analysis map of Words (not plotted) and Timepoint (red dots) along the first and second dimensions, with confidence ellipses (grey circles). B) Plot of specificity scores of Words by Timepoint, for the 7 words statistically significant at one timepoint or more. C) Correspondence analysis map of Details (not plotted) and Timepoint (red dots) along the first and second dimensions, with confidence ellipses (grey circles). D) Plot of specificity scores of Details by Timepoint. Red line: significance threshold.

**Figure 2: Influence of intensity of emotions felt upon hearing the attack on report for details.** Plot of specificity scores of Details by (Timepoint \*Emotion-intensity). Red line: significance threshold.

**Supplemental material.**

**Iterative specificity analysis of the effect of emotion-intensity on the retelling of spatial, temporal, and emotional details.**

The effect of a continuous variable cannot be directly tested (such as correlation analyses) with the textometry method. Therefore, we developed a new exploratory method partly inspired by chronological or adjacent characteristic elements analysis (Salem, 1988; Lebart et al, 1998) to explore the full continuum of the effect of emotion-intensity on details reported by the participants over time using iterative specificity analysis. For each value of an emotion-intensity threshold - from the minimum (1.17) to the maximum (5.00; 41 values) - the 206 participants were split into two groups: participants with a score lower than or equal to the given value in one group ( $\leq$  emotion-intensity threshold, low emotion-intensity group) and those with a score higher than the given value in the other group ( $>$  emotion-intensity threshold, high emotion-intensity group). Specificity analysis was then conducted for each group, by varying emotion-intensity threshold within every given detail type and timepoint (Figure S1).

***Interpretation key of the iterative specificity analysis graphs***

At the extreme low and high emotion-intensity values, all the participants (N = 206) are within the high emotion-intensity group and the low emotion-intensity group respectively. The curve of the high emotion-intensity group starts at the specificity score corresponding to the whole sample analysis presented in Figure 1D (e.g., 4.00 for emotional details at T1) and ends at zero. At the contrary, the curve of the low emotional-intensity group starts at zero and ends at a specificity score corresponding to the whole sample analysis conducted on all participants presented in Figure 1D. Since the total frequency of a detail type (emotional, temporal, or spatial) is fixed within a given timepoint, the curves of the two groups evolve complementarily along the emotion-intensity threshold axis, either converging or diverging from each other.

If the average frequency of the detail is identical in the two groups, meaning that the detail is not emotion-intensity dependent, the two curves fit their reference curve computed for a constant and uniform distribution of the detail in the group.

If the detail is emotion-intensity dependent, the average frequency of the detail differs between the two groups, and the two curves deviate from their reference. The curve is



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above its reference curve when the detail is overused in the group defined by the current threshold, and below its reference curve when the detail is underused.

If the two curves meander around their reference curve or intersect each other several times, the detail frequency in the two groups is not monotonically related to emotion-intensity.

### ***Results***

Emotional details: At T1, the two curves deviated from their reference from the emotion-intensity value of 3.17, suggesting that below this value the report of emotional detail was not emotion-intensity dependent. Between the emotion-intensity values of 3.17 and 3.42, the participants with an emotion-intensity score higher than the threshold significantly overused emotional details. Then, from the median (3.5) the curve of the high emotion-intensity group decreased and deviated below its reference, suggesting that participants with extreme high emotion-intensity scores underused emotional details in their retelling. There is no significant result at T2, T3 and T4 (all the specificity scores  $> -3$  or  $< 3$ ).

Temporal details: At T1, the low emotion-intensity group curve showed an overall overuse of temporal details compared to the high emotion-intensity group. The participants significantly divided into two groups around the value of 3.5 (corresponding to the median) with the participants with lower emotion-intensity scores significantly overused temporal details. At T2 and T3, there is no significant result (all the specificity scores  $> -3$  or  $< 3$ ). At T4, group curves fit their reference curve, meaning that the report of temporal details was not emotion-intensity dependent. All the participants significantly underused temporal details which is consistent with the analyses performed on the whole sample (Figure 1).

Spatial details: At T1, the two curves meandered around their reference and intersected each other several times, suggesting no monotonical association with emotion-intensity. At T2 and T3, there is no significant result (all the specificity scores  $> -3$  or  $< 3$ ). At T4, the high emotion-intensity group curve showed an overall overuse of spatial details compared to the low emotion-intensity group (the curve deviated above its reference and the significance threshold). The specificity value computed for the median-split (Figure 2) was attenuated by the fact that participants with emotion-intensity above the mean but

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below the median value (emotion-intensity between 3.00 and 3.33) strongly overused spatial details, as much as those with highest emotion-intensity ( $>3.75$ ). The observation of the complete curve allowed to highlight an overuse of spatial details by the high emotion-intensity group at T4.

Overall, these results are consistent with findings revealed by the median-split analyses (Figure 2) and substantiate spatial details overuse by high emotion-intensity subjects at T4. Furthermore, they refine the results for emotional details, suggesting an underuse of these details at T1 by the participants with extreme high emotion-intensity.

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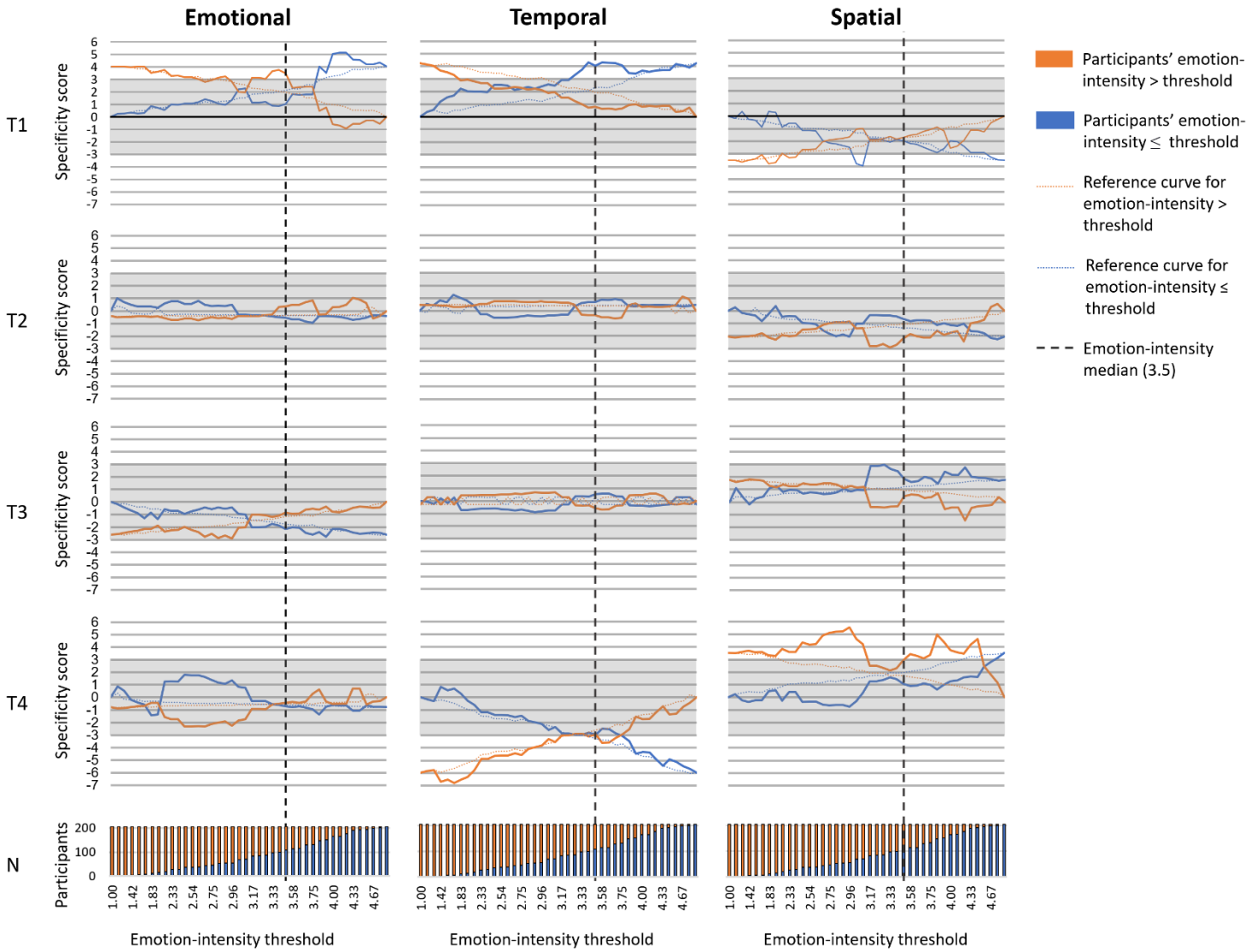


Figure S1

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Figure S1: **Iterative specificity analysis of the effect of emotion-intensity on details.**

Plot of specificity scores of emotional, temporal, and spatial details at each timepoint (T1, T2, T3, T4) for each emotion-intensity threshold from the minimum (1.17) to the maximum (5.00; 41 values). Number of participants in each group (orange / blue) for each emotion-intensity threshold is plot on the bottom line. Grey zone: non-significant score. Orange line: participants with a score higher than the given value in the other group ( $>$  emotion-intensity threshold). Orange dotted line: reference curve for emotion-intensity higher than the threshold. Blue line: participants with a score lower than or equal to the given value in one group ( $\leq$  emotion-intensity threshold). Blue dotted line: reference curve for emotion-intensity lower than or equal to the threshold.

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