Semantic representations of retrieved memory information depend on cue-modality

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The semantic content (i.e., meaning of words) is the essence of retrieved autobiographical memories. In comparison to previous research, which has mainly focused on phenomenological experiences and age distribution of memory events, the present study provides a novel view on the retrieval of event information by addressing the semantic representation of memories. In the present study the semantic representation (i.e., word locations represented by vectors in a high dimensional space) of retrieved memory information were investigated, by analyzing the data with an automatic statistical algorithm. The experiment comprised a cued recall task, where participants were presented with unimodal (i.e., one sense modality) or multimodal (i.e., three sense modalities in conjunction) retrieval cues and asked to recall autobiographical memories. The memories were verbally narrated, recorded and transcribed to text. The semantic content of the memory narrations was analyzed with a semantic representation generated by latent semantic analysis (LSA). The results indicated that the semantic representation of visually evoked memories were most similar to the multimodally evoked memories, followed by auditorily and olfactorily evoked memories. By categorizing the semantic content into clusters, the present study also identified unique characteristics in the memory content across modalities.

Autobiographical memory refers to the recollection of personally experienced events. Many researchers in the field consider that the memory should originate from a specific event delimited in time and space (e.g., Greenberg & Rubin, 2003) which is relived during recollection by means of mental time travel (Greenberg & Rubin, 2006; Tulving, 2002). Further, since it is a personal experience it is considered to be "an important and strong relation between the self and autobiographical memories" (Conway & Pleydell-Pearce, 2000, p.264). As part of our memory systems Rubin (2006) characterized autobiographical memory as "episodic memory for complex situations" (p.279). A typical example of a memory event could be as personally experienced by the author: 'I remember when I last summer where out riding a warm afternoon. Now, thinking back, I could almost feel the smell of warm horse, newly cut grass, see the ripe golden wheat fields and hear the sound of horseflies circle around'.

The semantic content is a core feature of naturally produced language and as such also in verbally narrated autobiographical memories, still has previous quantitative research mainly focused on autobiographical memories with regard to experiential ratings (e.g., valence) and the age distribution of retrieved events. To the authors knowledge has until now the semantic representation of retrieved memory information per se (i.e., how retrieved information can be represented in terms of its meaning) not been studied. The aim of the present study was therefore to investigate the semantic representation of memory information elicited by unimodal and multimodal retrieval cues by using, for the field, a new analyze method, latent

semantic analysis which makes possible to efficiently and quantitatively analyze large data sets of memory information.

Previous studies on cued retrieval of autobiographical memories have used unimodal cues (words, pictures, sounds, or odors; e.g., Cady, Harris & Knappenberger, 2008; Chu & Downes, 2000, 2002; Goddard, Pring & Felmingham, 2005; Herz, 2004; Herz & Schooler, 2002; Rubin & Schulkind, 1997; Willander & Larsson, 2006, 2007). However, in naturalistic settings individuals most often attend and integrate sensory information pertaining to different sensory modalities simultaneously. Thus, the rationale for comparing unimodally and multimodally cued memories is based on the hypothesis that multimodal retrieval cues map differently onto stored memory information compared to unimodal cues. Further, Willander, Sikström and Karlsson (2011) suggested that there is a cue-hierarchy among the modalities. This hierarchy may be the result of visual dominance, which in the perceptual domain "refers to the observation that in bimodal environments vision often has an advantage over the other senses in humans" (Schmid, Büchel & Rose, 2011, p.304). For example, cognitive and perceptual experiments have observed faster or more frequent responses to visual cues compared to other modalities (e.g., Colavita & Weisberg, 1979; Koppen & Spence, 2007; Willander et al., 2011; Williams, Healy & Ellis, 1999). The significant role of the visual modality has also been addressed in relation to autobiographical memories. Williams et al. (1999) found that the more visually vivid the memory of an event was the more specific it was and the faster it was retrieved. Their results also indicated that the second most significant modality to contribute to these variables was the auditory system. Furthermore, the importance of the visual system for autobiographical memory has been stressed in studies on patients affected by impairment of visual brain areas. In separate case studies it has been found that visual object agnosia is associated with retrograde amnesia (i.e. impaired autobiographical memory; Greenberg et al., 2005; O'Connor et al., 1992; Ogden, 1993).

The research on cued retrieval of autobiographical memories have until now mainly been concerned with the age distribution of retrieved events (e.g., Chu & Downes, 2000; Conway & Haque, 1999; Rubin & Schulkind, 1997; Willander & Larsson, 2006; Willander, et al, 2011) or phenomenological qualities (the subjective experience of for example valence and emotion; e.g., Chu & Downes, 2002; Herz, 2004; Herz & Schooler, 2002; Willander & Larsson, 2006, 2007). These studies suggest that memories differ as a function of retrieval cue. More specifically, autobiographical memories retrieved with words or pictures originate mainly from the period between 10-30 years of age (Conway & Haque, 1999; Rubin & Schulkind, 1997; Willander & Larsson, 2006, Willander et al., 2011). In comparison, memories evoked by olfactory cues, typically originate from early childhood (<10 years of age; Chu & Downes, 2000, 2002; Willander & Larsson, 2006, 2007; Willander et al., 2011). To the authors knowledge this is the first study to use multimodal cues to elicit autobiographical memories, Willander et al. (2011) investigated memories evoked by unimodal (i.e. visual, auditory *or* olfactory) or multimodal (i.e., visual, auditory *and* olfactory information in conjunction) cues. Their results indicated that the age distribution of multimodally cued memories took an intermediate position of the three unimodal age distributions, where olfactorily cued memories had a peak at much earlier age and auditorily/visually had a peak at a slightly older age. A further quantitative analysis by modelling the age distributions revealed that multimodal retrieval was mainly driven by the visual and auditory modalities, with a contribution of approximately 91%, whereas olfactory cues contributed to a lesser degree (~9%; Willander et al., 2011). However, auditorily and visually evoked memories could not be discriminated using this method of analyze of age distributions.

Studies of the phenomenological experiences of recollected events have also demonstrated differences as a function of cue modality (e.g., Chu and Downes, 2002; Herz, 2004; Herz & Schooler, 2002; Willander & Larsson, 2006, 2007). Several studies have shown that olfactory evoked memories are more emotional and produce a stronger feeling of being brought back to the original event, than memories retrieved with other cue-types (e.g., Chu and Downes, 2002; Herz, 2004; Herz & Schooler, 2002; Willander & Larsson, 2006, 2007; Willander & Yeshurun, submitted). Willander and Larsson (2007) compared memories evoked by perceptual cues (i.e., odors), semantic cues (i.e., odor-labels) or perceptual-semantic cues (i.e., odors and odors-labels in conjunction). They found that memories retrieved with perceptual cues (i.e., odor-evoked memories) were rated as more emotional and associated with stronger feelings of being brought back in time than memories evoked by semantic cues or combination cues. Likewise, results from Cady et al. (2008) suggested that memories triggered by perceptual cues (i.e., auditory or visual) produced stronger feelings of being brought back in time compared to semantic cues. For the vividness dimension the pattern of findings are somewhat less consistent concerning the influence of cue-modality (e.g., Cady et al., 2008; Chu and Downes, 2002a; Goddard et al., 2005; Hertz, 2004; Herz & Schooler, 2002; Willander & Larsson, 2006, 2007). In a meta-analysis Willander and Yeshurun (submitted) found a relatively small effect size (d=.17) for vividness ratings of autobiographical memories across cue-conditions. However, the results from the meta-analysis results supported the notion that memories evoked by olfactory cues were experienced as more vivid than memories evoked by other modalities.

Previous content analyses of retrieved memories have been based on more classical strategies, such as word frequencies or manual categorization (e.g., Chu & Downes, 2002b; Reese, Haden & Fivush, 1996; Levine et al., 2002; Rasmussen & Berntsen, 2009). However, at least three critical issues may be identified with the classical approach to content analysis: (i) the lack of a data driven quantification of the underlying semantic representation (ii), it is sensitive to individual differences in the coding/analysis process of memory information and (iii) it is labor intensive and as a result highly time consuming. In order to solve these problems in the present study a semantic representation of the memory events was generated based on latent semantic analysis (Deerwester et al. 1990) and this representation was used to study event information. LSA is a content analytic method used to investigate relationships between sets of texts in which semantic co-occurrence and closeness are revealed. Landauer, Foltz and Laham, (1998) has described LSA as "a theory and method for extracting and representing contextual-usage meaning of words by statistical computation applied to a large corpus of text" (p. 259). A full presentation of LSA is out of scope for the present article, but somewhat simplified LSA can be described as a mathematical generalization where the text in the corpus is subjected to singular value decomposition (SVD). SVD is a mathematical decomposition algorithm which has a lot in common with factor analysis and multidimensional scaling (Landauer & Dumais, 1997; Landauer et al., 1998). First, a representation of the text corpus is constructed in the form of a co-occurrence matrix with rows for unique words and columns for text passages (in present study the memory events). Next, the words in the matrix are weighted according to their occurrence and extremely high frequent non-content words are excluded. Once the co-occurrence matrix has undergone the weighting transformation it is factored by the use of SVD. The matrix is then decomposed in such a way that every passage and individual word is re-represented as points (vectors) in a high dimensional abstract space. The final output makes up a semantic representation from which one can calculate similarity measures between all pairs (e.g., word – word, word – context context – context similarities) (Landauer & Dumais, 1997; Landauer et al., 1998; Martin & Berry, 2007). The aim of the present study was to examine with the method of LSA

how uni- and multimodal cueing influence the semantic representation of autobiographical memories. Memories evoked with three unimodal retrieval cues (i.e. auditory, olfactory or visual) and one multimodal retrieval cue (i.e., the three unimodal cues in conjunction) were compared on two levels: 1) semantic closeness of retrieved memories as quantified by latent semantic analysis 2) cue dependent differences in semantic categories investigated by clustering of semantic representations.

To summarize, previous studies of autobiographical memory retrieval have revealed cue-modality differences in the age distribution and phenomenological experiences. However, no previous study has quantified the semantic content of retrieved memories using semantic spaces. In present study it was hypothesized that memories evoked by visual, olfactory, auditory, and multimodal cues differs in their semantic representation. This hypothesis is based on the results from studies indicating visual dominance in perceptual attention (e.g., Colavita & Weisberg, 1979), retrieval latency (Williams et al., 1999) and age distribution of autobiographical memories (Willander et al., 2011). It was further hypothesized that the semantic representations of visually evoked memories will be closer to multimodally evoked memories, followed by auditorily and olfactorily evoked memories. Finally, given that autobiographical memories are semantically related to the self (e.g., Conway & Pleydell-Pearce, 2000; Tulving, 2002), it was also hypothesized that there is an overlap in the semantic representation, such that words related to the self are closest to all memories irrespective of the cue-modality.

Method

Participants

Eighty participants (60 women and 20 men; age range 19-42 years; mean age *M*=25.86, *SD*=6.03), which were students at the Department of Psychology, Stockholm University, participated in the study for course credits.

Design

The design was a four way between-group design, where each participant was randomized to one of the cue conditions (i.e. visual, olfactory, auditory or multimodal).

Materials

The stimuli materials consisted of 15 pictures, 15 sounds, and 15 odors (see Appendix A). Each triad of cues represented a context. The unimodal conditions comprised cues from one modality whereas in the multimodal condition cues from the three modalities (i.e., visual, auditory and olfactory) were presented simultaneously. For example, for the context "indoor swimming bath", participants in the unimodal conditions were presented with either the picture of an indoor swimming bath, the sound of water splashes, laughter, and ambient sounds, or the smell of chlorine. However, in the multimodal condition the picture, sounds and odor were presented in conjunction. The visual cues were presented on a 22 inch LCD computer screen. Sounds were presented with pair of AKG 701 reference headphones connected to the same computer that controlled the visual presentation. Odors were kept in non-translucent glass jars and covered with cotton pads to prevent visual inspection. The participants held the odor-jars themselves and started sniffing when given a start signal.

Procedure

All participants were tested individually. First, the participants were given the following instructions: *You will be presented with a number of memory cues. Your task is to try to remember specific events related to the respective cues. The event may have taken place at any time in your life. Once you remember an event please describe the event verbally as detailed as possible (if possible provide sensory information, feelings and so on). You will be given three minutes to describe the event verbally. You will also be asked to rate the event on some phenomenological dimensions.* Each retrieval cue was presented for a maximum of 30 seconds. In instances of successful memory retrieval, the participants were asked to write down a brief memory title. For each retrieved memory, the participants were given three minutes for verbal narration. Following the verbal narration, participants also rated each memory on five phenomenological dimensions (i.e., emotionality, valence, importance, vividness and feeling of being brought back to the occurrence of the original event). However, these ratings were collected as a part of another study. In case a participant was unable to recall a memory for a given cue during the 30 seconds presentation, the experiment continued with the next cue. After the retrieval phase, the participants dated the recollected memory events based on their age at the time of the event.

Analysis

The verbally narrated memories were recorded and transcribed to text. The corpus of the memory texts (798 memory events) (780 KB) were too small to construct a semantic space with a high quality of the associations. Instead the semantic space was generated from a considerable larger corpus; consisting of approximately 100k Swedish news articles published 2007 in the 100 most common Swedish newspapers. The size of this corpus was approximately 250 Mb. The semantic space was generated by Latent Semantic Analyze method (Deerwester et al., 1990) using the Infomap Software (infomap-nlp.sourceforge.net). The parameters used for constructing the space was: number of words in the semantic space (15k), number of contexts (20k), contexts size (+/- 15 words), number of dimensions in the space (n=100), number of SVD iterations (n=500), where most of these settings are default values in Infomap. The quality of the semantic space was measured by a synonym test, where the medium rank order of the semantic closeness between two synonyms were approximately 4% of the ranked order of semantic closeness of randomly generated pairs of words.

Each autobiographical narration was summarized in the semantic space by summing the semantic vector representing each word in the narration. The resulting vector was, similarly to all word vectors in the space, normalized to a length of one. Each condition was further summarized by summing all narrations in the condition, and normalizing the length of the resulting vector to one. The semantic closeness between conditions was (following the convention in the literature, e.g., Martin & Berry, 2007) measured as the cosines of the angle between the two vectors representing the conditions. To establish whether the semantic representation differed significantly between conditions, a bootstrapping technique (Monte Carlo) was used (with following the convention in the litterateur 10k iterations), where the semantic closeness measures between the conditions was compared to the same measure using random assignment to the conditions. See Arvidsson, Werbart and Sikström (2011) for a more detailed description of this method. Z–values were produced by z–transforming the semantic closeness score by using the mean and the standard deviation of the semantic closeness score received during the random assignment.

The semantic representations were categorized into clusters using the k-means cluster method. Despite the fact that the k-mean analyses tries to maximize the differences between the

clusters, the resulting centroids were so similar that the most words which had the highest semantic closeness measure largely overlapped. To establish meaningful interpretation of each clusters following method was applied: First a vector best describing the difference between one cluster compared to all other clusters were generated by subtracting the cluster centroid vector with a vector describing all other clusters (i.e., the sum of the centroids, normalized to the length of one). All analysis of the semantic space was conducted using the Semantic program, which is a software specially designed for analyzing semantic representations that runs in the Matlab environment.

Results

Closeness analysis

The semantic closeness measure analysis (stated in cosines) followed by a bootstrap significance test indicated that multimodally retrieved memories had a semantic representation that was significantly different from the unimodal representations. However, the visually cued memories were closest to the multimodally condition ($z = 1.96$, $p = 0.025$), followed by the auditorily ($z = 2.1$, $p = 0.003$) and thereafter by the olfactorily ($z = 3.69$, $p = 0.000$) retrieved memories. The visually retrieved memories were closer to the auditorily ($z = 7.16$, $p = 0.000$) than to the olfactorily ($z = 11.03$, $p = 0.000$) retrieved memories. There were no significant difference between the auditorily and the olfactorily ($z = 0.67$, $p = 0.52$) retrieved memories distances in the semantic representation. All closeness measures between the conditions are presented in Table 1, and Figure 1-3.

Cluster analysis

The words having the highest semantic closeness to the centroids (semantic associates to all autobiographical memories) generated by the k-mean analyses overlapped across clusters. This indicates that all autobiographical memories had a similar representation, even when they are grouped so that they are maximally different from each other. This empirical fact made the identification of the semantic content of the clusters difficult. To resolve this issue, as described in the method section, words were identified that best describe the differences between clusters (semantic associates to differences between clusters).

Semantic associates to all autobiographical memories.

The words best describing all the autobiographical memories was identified by examining the words with the highest semantic closeness to all autobiographical narrations. Given that autobiographical memories concern the *self*, it was hypothesized that the semantically closest word to all memories is *I*. This hypothesis was confirmed. The following word associates are examples from this "*I*"-cluster: *I, me, mine, thought, mine, self, felt, feel, to think, amusing, fun, is felt, was felt, difficult, said, wanted, talked, people, remember, you*. These words were translated from Swedish and some of these required a two-word English translation.

Semantic associates to differences between clusters.

A Chi-square test showed a significant difference in the number of memories pertaining to the different cue-modalities (i.e., visual, olfactory, auditory, multimodal) across the four clusters, χ^2 (2, $N = 798$) = 22.28 ($p<.008$). See Table 2 for frequencies and proportions of memories pertaining to the respective cues across the four clusters.

Table 1. Pairwise semantic closeness measures between the four conditions (measured as the cosines of the angle between the two vectors representing the conditions).

	Multimodal	Visual	Auditory	Olfactory
Multimodal	1.000	.9993*	.9991*	.9988**
Visual		1.000	.9984***	.9977***
Auditory			1.000	.9993
Olfactory				1.000

*p<.05,**p<.01,***p<.001

Note that cosines range from -1 to 1 (Landauer, 2007, p.17). Typically, for randomly paired words the cosine values range from -.01 to + .03 (Dennis et al., 2003, referred to in Lenton, Sedikides & Bruder, 2009).

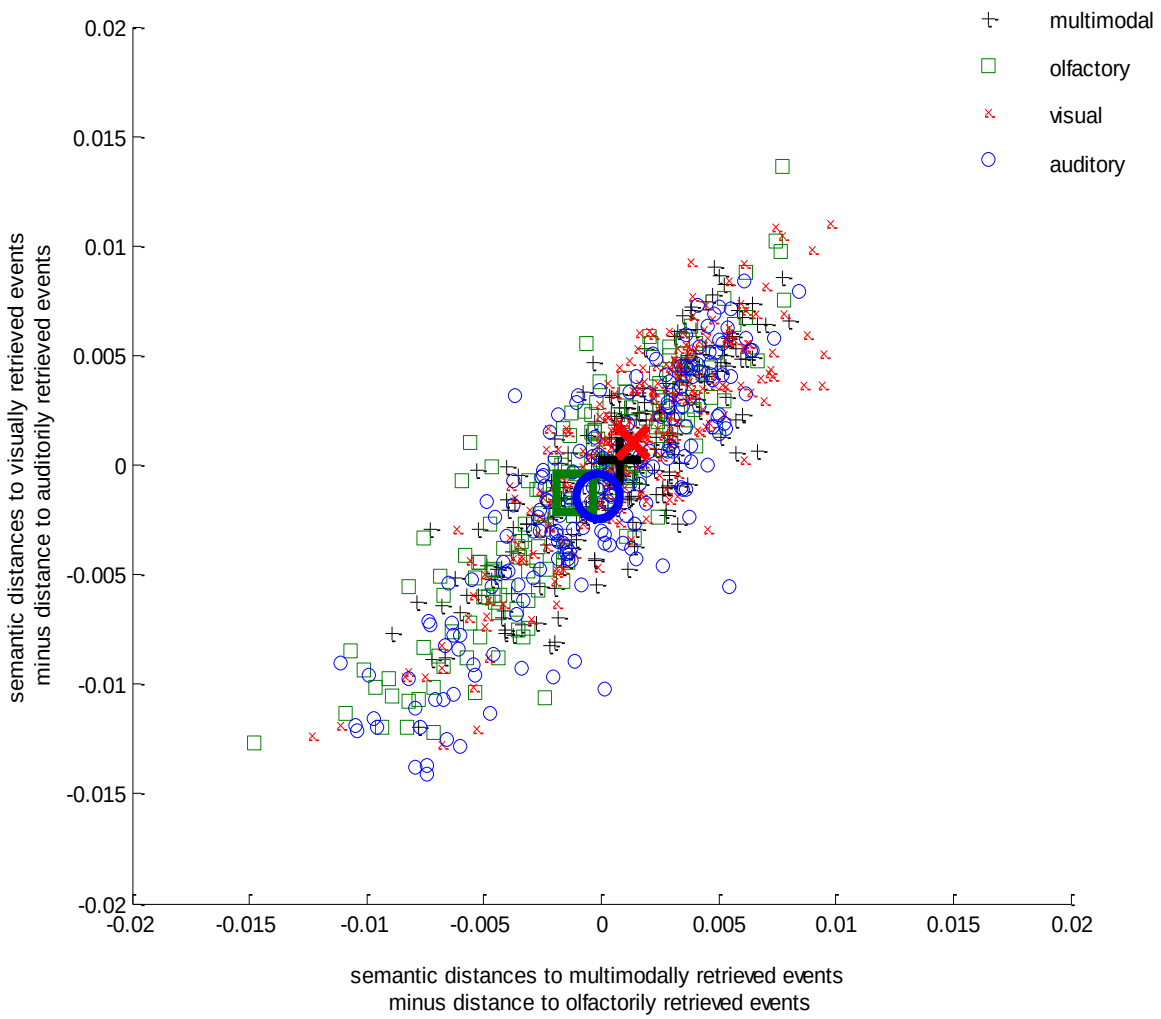

Figure 1. Centroid distances. On the x-axis: semantic distance between multimodally retrieved events (black upright cross) and olfactorily retrieved events (green square). On the Y-axis: semantic distance between visually retrieved events (red tilted cross) and auditorily retrieved events (blue circle).

Note, for or all figures, each marker represents one participant's memory event narration. The larger markers represent the groups mean. The values on the x-axis are calculated by first computing the semantic distances from an event narration to the mean of each condition, where the x-axis represents the semantic differences between these distances. The values on the y-axis are calculated by first computing the semantic distances from an event narration to the mean of each condition, where the y-axis represents the semantic differences between these distances. The semantic differences for both axes are corrected for the selection bias that is introduced by the selection of the two conditions, i.e. by removing the distance that occurs when memory narrations are randomly assigned to the conditions (compare with the bootstrap method).

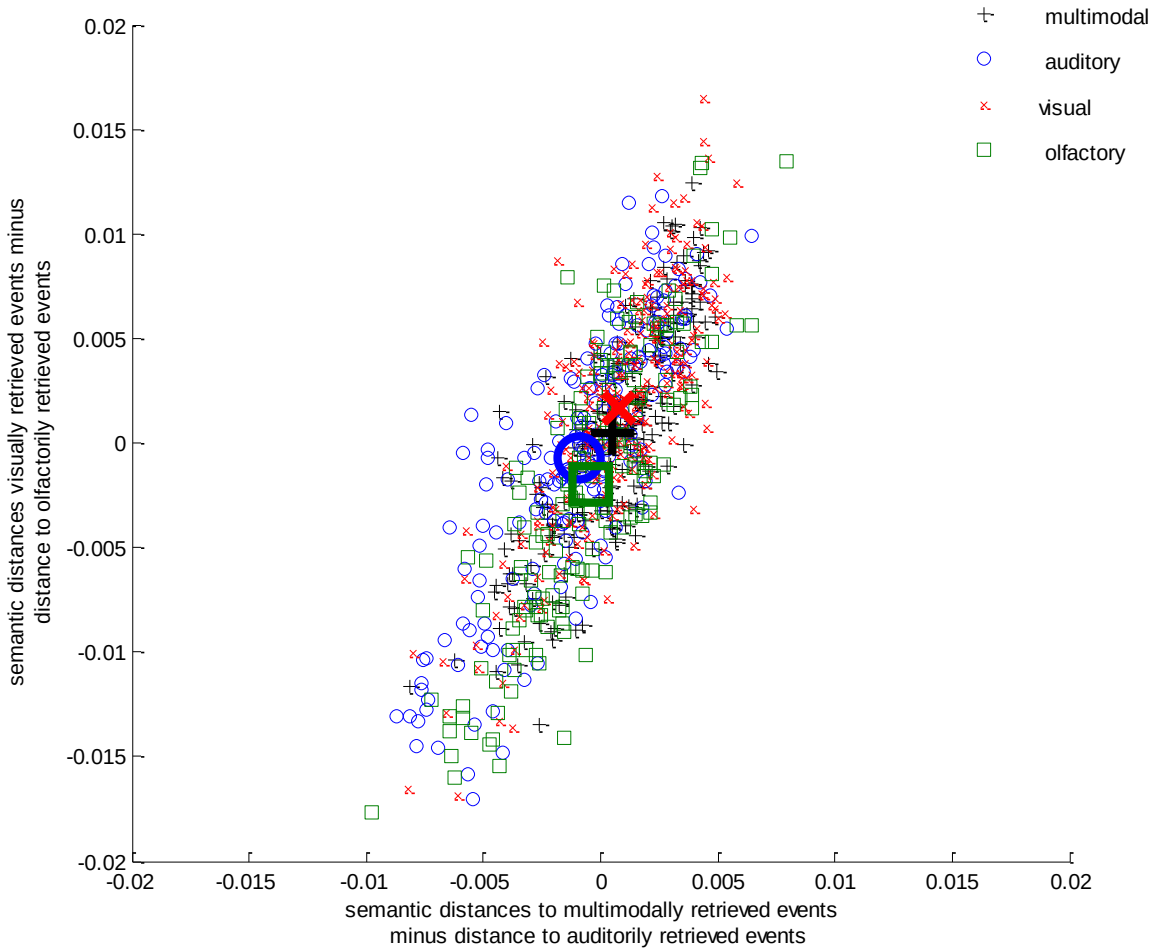

Figure 2. Centroid distances. On the x-axis: semantic distance between multimodally retrieved events (black upright cross) and auditorily retrieved events (blue circle). On the Y-axis: semantic distance between visually retrieved events (red tilted cross) and olfactorily retrieved events (green square).

The possibility of generating meaningful labels to the cluster were facilitated by examining the words associated with the differences between the clusters. The words closest to the respective cluster centroids, when examining cluster differences concerned mainly in cluster 1) cognitive and sensory perceptual information, in cluster 2) largely related to emotions and communication in social interaction, in cluster 3) mostly related to activity and in cluster 4) associated to challenges and risks. Words having the highest semantic closeness measure to the resulting vector are presented in Table 3.

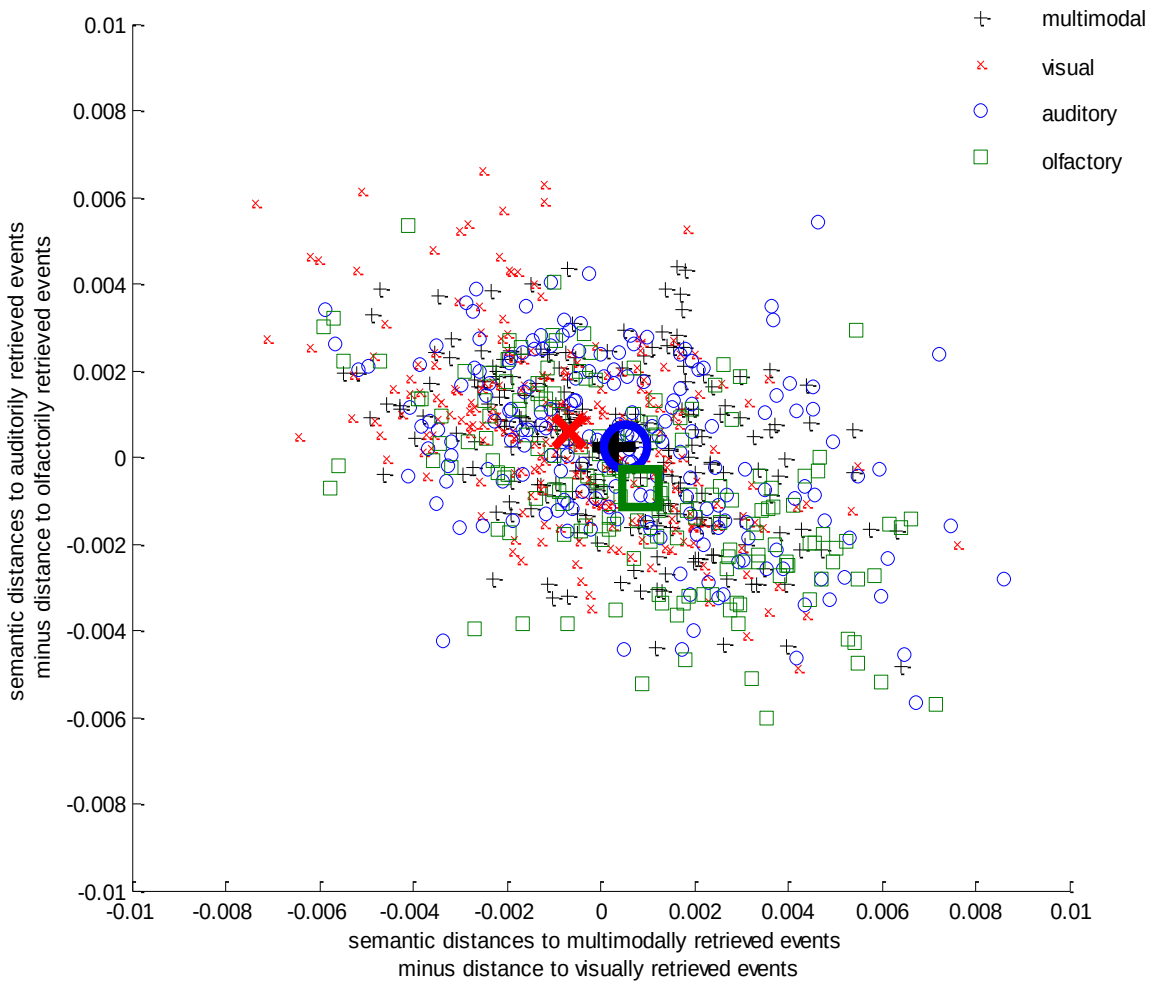

Figure 3. Centroid distances. On the x-axis: semantic distance between multimodally retrieved events (black upright cross) and visually retrieved events (red tilted cross). On the Y-axis: semantic distance between auditorily retrieved events (blue circle) and olfactorily retrieved events (green square).

Table 2. Frequencies of events retrieved by the four cue-modalities (and their respective proportion in percentages) across the four clusters.

Cue-modality	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Visual	105 (36.33)	46 (21.10)	57 (28.94)	21 (22.34)	229
Auditory	64 (22.15)	57 (26.15)	45 (22.84)	25 (26.60)	191
Olfactory	52 (17.99)	53 (24.31)	33 (16.75)	26 (27.66)	164
Multimodal	68 (23.53)	62 (28.44)	62 (31.47)	22 (23.40)	214
Total	289	218	197	94	798

Table 3. Words association per cluster. All words are translated from Swedish. Note, some Swedish words required a two-word English translation.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
felt	I	was	one
considered	happy	walked	disappear
learnt	you	showed	takes
read	angry	stood	gets
depended	you	existed	stays
was	me	took	starts
did help	something	did	proceeds
lived	yours	led	works
remember	change	got	pulls
realized	your	followed	memory
thought	self	ended up	preparedness
wanted	sad	hit	we
saw	bribe	succeeded	to risk
understood	your	reached	travels
perceived	determined	managed	is forced
resulted	god	could	is done
it felt	tell	met	end up
seemed	asked	gave	drive
asked	feels	stayed	oxygen
meant	dares	broke	prepared

Discussion

The present study investigated the semantic representation of autobiographical memories cued by unimodal or multimodal cues. It was found that the semantic representation of memory information is dependent on the cue-modality. Previous studies aimed at analyzing the content of retrieved memories have used more classical approaches (e.g., Chu & Downes, 2002b; Reese et al., 1996; Levine et al., 2002; Rasmussen & Berntsen, 2009). However, the application of latent semantic analysis in the present study allowed a quantitative analyze of the retrieved events.

Given that previous research have observed differences in event recollection as a function of cue-modality (e.g., Chu & Downes, 2000, 2002; Conway & Haque, 1999; Herz, 2004; Herz & Schooler, 2002; Rubin & Schulkind, 1997; Willander & Larsson, 2006, 2007; Willander et al., 2011) it was of interest to study whether these differences would be reflected in the semantic representation of retrieved memory information. By modelling the age distribution of autobiographical memories, Willander et al. (2011) found that multimodal cuing of autobiographical memories was largely driven by visual and auditory information and to a lesser degree by olfactory information. Although, Willander et al. (2011) were unable to differentiate the visual and auditory contribution, it was in present study hypothesized that in the case of multimodal cuing, visual information contributed to a higher degree than did auditory information. The present study confirmed the hypothesis and extended the

conclusions of Willander et al. (2011) by analyzing the semantic representation of memory information with LSA.

The main finding of the present study was that the distance between the centroids for the four cue-modalities followed a specific pattern. That is, memories retrieved with visual cues were located closer to the multimodal memories in the semantic space than were auditorily or olfactory cued memories. Auditorily cued memories were located closer to the multimodally retrieved memories compared to olfactory cued memories. This is in agreement with present study's hypotheses and may be interpreted as follows. If the visual system is dominant in relation to other sensory system and there is a modality hierarchy, one should expect that memory information retrieved with multimodal cues would reflect this hierarchy. This is because when all sensory systems contribute to the memory retrieval and information selection to different degrees, the semantic representation of multimodally cued memories should be closer to the semantic representation of the most dominant representation, second closest to the second most contributing and so on. Thus, it was expected that the distance between the semantic representation of multimodally cued memories and the unimodally cued memories to be a function of the relative contribution of the respective (uni)modality. This is exactly the pattern which was observed in the present data, suggesting that the semantic representation of memory information is dependent on cue-modality and that memory information is accessed based on meaning. Although, the pairwise closeness may seem rather small it should be noted that given the type of data material and its size, the closeness is substantial and reliable.

The conclusion that the meaning of memory information is of importance in the study of autobiographical memories is further highlighted by the variation in proportions of retrieved events cued by the different modalities in the four clusters. The most prevalent cue-modality differed across all four clusters. In relation to existing models of autobiographical memory, for example the self-memory system model (Conway & Pleydell-Pearce, 2000, the basic-systems model (Rubin, 2005) and the social-culture development model (Nelson & Fivush, 2004), the present data suggests that binding of autobiographical information is not only done at the level of event but information may also be organized on higher abstract level based on similarities and differences in meaning.

Of further interest, differences in event recollection as a function of cue-modality were in present study observed concerning proportion in the four clusters. The visually retrieved memories had the largest proportion in cluster 1, were the words were mainly associated with perceptual and cognitive reflections. Multimodally retrieved memories had the largest proportion in cluster 2 and 3. The word in cluster 2 was mainly associated with social interaction, communication and emotions and the words in cluster 3 were all associated with activity. Olfactorily had the largest proportion in cluster 4, were the words were mainly associated with challenge and risk. These tendencies of differences between retrieved events as a function of cue modality are in accordance with the present and previous research (e.g., Chu & Downes, 2000, 2002; Conway & Haque, 1999; Herz, 2004; Herz & Schooler, 2002; Rubin & Schulkind, 1997; Willander & Larsson, 2006, 2007; Willander et al., 2011). Cluster 1 was the largest cluster of the four and most memoires pertaining to it were visually retrieved, following the notion of visual information selection dominance. In the clusters were one could expect individuals to attend and integrate different sensory information the most, as in social interaction (cluster 2) and dealings with the surrounding world (cluster 3), the proportion of multimodally retrieved was the highest. Further, the proportion of olfactorily retrieved memories was highest in clusters (2 and 4) containing word associated with

emotions. Although, there were observed differences across memories cued by the different modalities in the present study, a substantial part of the memory information was similar across the four cue-modalities and concerned the *self*. This is in line with Conway and Pleydell-Pearce (2000) self-memory system model stating that autobiographical memories are regarded as "transitory mental constructions within a self-memory system". Based on the results from the present study it is suggested that the pivotal role of the self can be observed as latent information in all autobiographical memories.

For future studies it would be of interest to further study semantic representations of autobiographical memories in relation to results from studies postulating functions of autobiographical memories. For example, out of the results in a qualitative content analyze study Rasmussen and Berntsen (2009) divided autobiographical memories into three types based on their function: directive, social, or self. The directive function was conceptualized as guiding present and future thinking and behavior. The social function was conceptualized as sharing memories for the purpose of social bonding. Finally, the self-function was conceptualized as maintaining self-continuity. Post hoc, a resemblance between the postulated three dimensions of function in Rasmussen and Berntsens study (2009) and the content in the data-driven clusters formed in present study were identified. A resemblance between the word content in cluster 1 and cluster 4 and the conceptualization of the directive function could be observed, and further between cluster 2 and 3 and the social function. The words in cluster 1 concerned mainly cognitive and perceptual information and the words in cluster 4 were at large associated to challenges and risks. Both of these clusters of words could be interpreted as the content created when the self process information which could guide and direct future behavior and as such maintain the self's goal-orientation. In cluster 2 the words closest to the cluster centroid largely concerned emotions and communication in social interaction, which could be interpreted as content about the self in relation with its social environment. The content in cluster 3 could be interpreted as the individual orienting itself in its social environment and physical surrounding. To verify this indication of a connection between semantic content in autobiographical memories and their postulated functions further study are needed.

In conclusion, the present study demonstrated that the semantic content of retrieved events depends on cue-modality, and further that retrieved memory information is organized in terms of meaning. The semantic representations of the visually evoked memoires were closer to the multimodally than the auditorily and olfactorily evoked memories. Finally, an overlap in the semantic representation was observed, such that words related to the self were closest to all memories irrespective of cue-modality.

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Appendix A

Context	Pictures	Sounds	Odors
Bar	Bar table with a glass of beer	Typical bar sounds (no music)	Beer
Café	Café table with a cup of coffee	Typical café sounds (no music), plates, spoons and cups colliding, coffee being poured in to a cup	Coffee
Camp fire	Camp fire	The sound of a burning camp fire	Burned-smell
Cigarette	Cigarette, cigarette smoke, ashtray	Lightning a cigarette, inhale/exhale sounds	Smoked cigarette
Cooking	Chopping onion	Chopping onion	Onion
Dentist	A dentist with a drill	Dentist drill and saliva suction	Eugenol
Eating an apple	Half-eaten apple	Biting and chewing an apple	Apple
Garden	Garden with flowers	Bees, ambient outdoor sounds	Flower
Gas station	Car being filled with gasoline at a gas station	Typical gas station sounds, gas pump	Gasoline
Harbor	Harbor by the sea with boats	Boat, water and seabirds	Fish
Indoor swimming bath	Indoor swimming bath	Water splashes, laughter, ambient sounds	Chlorine
Mopping a floor	Mop and bucket	Mop swirl, dipping a mop in a bucket with water	Soft soap
Painting	Partly painted wood panels	Opening a jar of paint, stirring, brush strokes	Wall paint
Walk in a forest	Pine forest	Walking in a forest, wooden sticks breaking	Pine
Washing clothes	Washing machine	Washing machine in action	Washing powder