UNIVERSITY OF TWENTE

# The usability of the semantic memory

## A Bachelor Thesis

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**Abstract**

The current study examines whether the semantic memory is usable in a real world setting. The study of Huth et al. (2016a) has developed a map on which the semantic memory is projected. By scanning brain activity with an fMRI scanner from participants while the participants listen to natural stories, certain voxels in the brain get activated by hearing certain words. This map is divided into different clusters with corresponding words. The current study examines six clusters on their usability with a card sorting task and a questionnaire. A list of 50 words from the six clusters is made to test their usability outside a laboratory, and is analysed by comparing the results with the study of Huth et al. (2016a). The results of the card sorting task is a heatmap, on which actual numbers like two and three have a clear result. By comparing this result with the study of Huth et al. (2016a) and other literature, it becomes clear that actual numbers from the semantic memory are usable in a real world setting. The questionnaire gives other results, such as that four of the six tested clusters are adequately labelled to be recognized by participants, thus improving their usability. The discrepancy between the card sorting task and the questionnaire can be clarified through a familiarity bias of the participants. Participants have worked in the card sorting task with the same 50 selected words as the words used in the questionnaire.

Keywords: semantics, cluster, card sorting, heatmap, semantic memory

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# 1. Introduction

The human memory consists of two components, the declarative memory and the procedural memory. The procedural memory does not require conscious recall and it can be seen as automated. An example of procedural memory would be to know how to drive a car. Opposite of procedural memory is the declarative memory. This declarative memory does require conscious and active recall. There are two parts of declarative memory, namely episodic and semantic memory. Episodic memory concerns a particular context such as time and place. An example of episodic memory would be to remember a shopping list. The second part of declarative memory is semantic memory. This semantic memory can be seen as the foundation for nearly all human activity with its acquired knowledge and it is independent of context (Binder & Desai, 2011). The focus of this study is the semantic memory, and it represents the meaning of concepts in the cerebral cortex.

## 1.1 Exploring the semantic memory

One theory on the structure and neural basis of semantic memory is the theory of the hub-and-spoke model (Lambon-Ralph, Jefferies, Patterson & Rogers, 2016). The notion of this theory is that when a person experiences an aspect from an object such as the noise it makes, that this person associates other aspects from this object, such as the function of the object. In other words, the semantic representation is partly distributed over the cortex. In this notion, the hub with the different spokes brings conceptualisation of an object. For example, when a person hears the word “camel”, this person generates related information such as how a camel looks and walks, where camels can be found, the famous brand of cigarettes, and so forth. This hub-and-spoke model is visualised in figure 1. In this model, the anterior temporal lobe region is

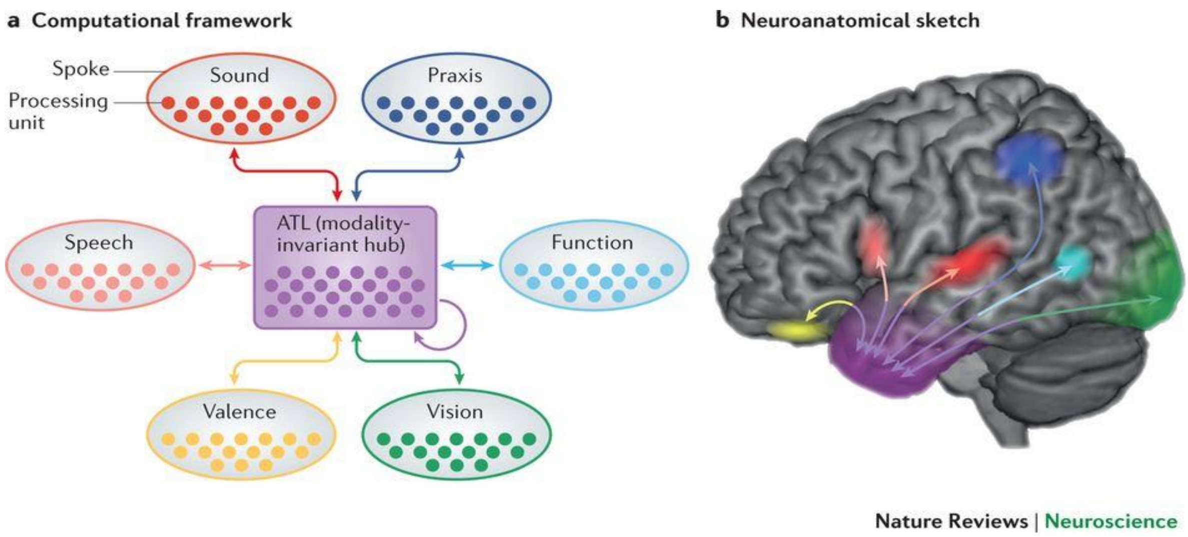




*Figure 1.* Visualisation of the hub-and-spoke model. Adapted from Lambon-Ralph et al. (2016).

the hub by which the different spokes scattered around the brain communicate in a bidirectional way.

Many studies have done inquiries on semantics and the semantic memory. These studies have investigated representation in the semantic memory, which resulted in for example the discovery of the area of frontal and temporal gyrus for concrete or abstract words (Binder, Westbury, McKiernan, Possing, & Medler, 2005; Friederici, Opitz, & Von Cramon, 2000; Noppeney & Price, 2004). This discovery means that concrete or abstract words such as 'table' or 'love' are represented in the frontal and temporal gyrus in the human brain. Another study has discovered the regions of posterior-lateral-temporal cortex for action verbs (Bedny, Caramazza, Grossman, Pascual-Leone, & Saxe, 2008). This discovery means that action verbs such as 'walk' are represented in the posterior-lateral-temporal cortex. A different study has found a region in the temporo parietal junction for social narratives (Saxe & Kanwisher, 2003). This discovery means that social narratives such as a conversation are represented in the temporo parietal junction. Other studies that investigated representation in the semantic system have discovered different areas selective for groups of related concepts such as 'living things', 'tools', 'food', or 'shelter' (Caramazza & Shelton, 1998; Mummery, Patterson, Hodges, & Price, 1998; Just, Cherkassky, Aryal, & Mitchell, 2010; Warrington, 1975; Mitchell et al., 2008; Damasio, Grabowski, Tranel, Hichwa, Damasio, 1996). These discoveries means that groups of related concepts such as 'living things', 'tools', 'food', or 'shelter' are represented in selective similar areas. However, all previous mentioned studies have not produced a comprehensive survey of how semantic information is represented across the entire semantic memory system. An exception is the study from Huth, de Heer, Griffiths, Theunissen and Gallant (2016a), who has studied the semantic memory without specific focus on semantic domains.

### 1.2 Exploring the study of Huth et al. (2016a)

The aim of the study of Huth et al. (2016a) was to measure voxels in the brain of the participants. Voxels are 3D elements which can be used for the brain. To map the voxels of the brain, Huth et al. (2016a) have used fMRI scanning technology to measure brain activity from the participants. While being scanned, participants listened to natural stories which are genuine stories told by people. The natural narrations caused brain activity within the participants, which was being measured by the fMRI scanner. The next step was analysing the brain activity and the causation of the brain activity. Huth et al. (2016a) inferred that the brain activity was caused by a total of 10,470 words from the natural stories. Certain words triggered activation in specific voxels, thus meaning that a voxel in the brain contains specific words which relates to each other. By using a tiling technique, Huth et al. (2016a) grouped voxels belonging to a similar cluster in the following brain cortices: lateral parietal cortex, medial parietal cortex, superior prefrontal cortex, lateral temporal cortex, ventral temporal cortex, inferior prefrontal cortex, and the opercular and insular cortex. All of these cortices contain a semantic representation of the 10,470 words that were found. This semantic representation of grouped voxels is the semantic map.

The different tiled cortices can be compared to the spokes of the hub-and-spoke model. The clusters from every cortex can be seen as a spoke because it communicates through a conceptualizing hub that connects with different cortices. A word in a voxel in a cortex can give the rise of another word in another voxel in another cortex. These two words are retrieved in the anterior temporal lobe, where it gets its meaning.

In figure 2, a screenshot from the online interactive semantic map is shown. In this figure, one can see the 11 different clusters spread over a 3D brain. Every voxel is identified with three aspects:

- The exact coordinates in expressed in three numbers, for example [16, 26, 27]. In this coordinate, the first number accounts for whether the voxel is in the higher or lower area of the brain, the second number accounts for whether the voxel is in the frontal or the posterior area of the brain, and the third numbers accounts for whether the voxel is leaning towards the left side of the brain. For the first number applies that the higher the number, the higher the voxel is. For the second number applies that the higher the number, the more towards the posterior of the brain the voxel is. And for the third number applies that the higher the number, the more the voxel can be found towards the left side of the brain.
- A reliability score/model performance. This reliability score is expressed in a range from (1/5) until (5/5). In this range, (1/5) means “Not semantically selective (ignore)” and (5/5) means “Excellent, extremely reliable”. This reliability score is based on the model performance of a voxel. This model performance stands for the accuracy of a voxel, wherein a higher performance means a more accurate voxel. The model performance is expressed into the reliability score.

- The positioning of a voxel in either the left or right hemisphere.

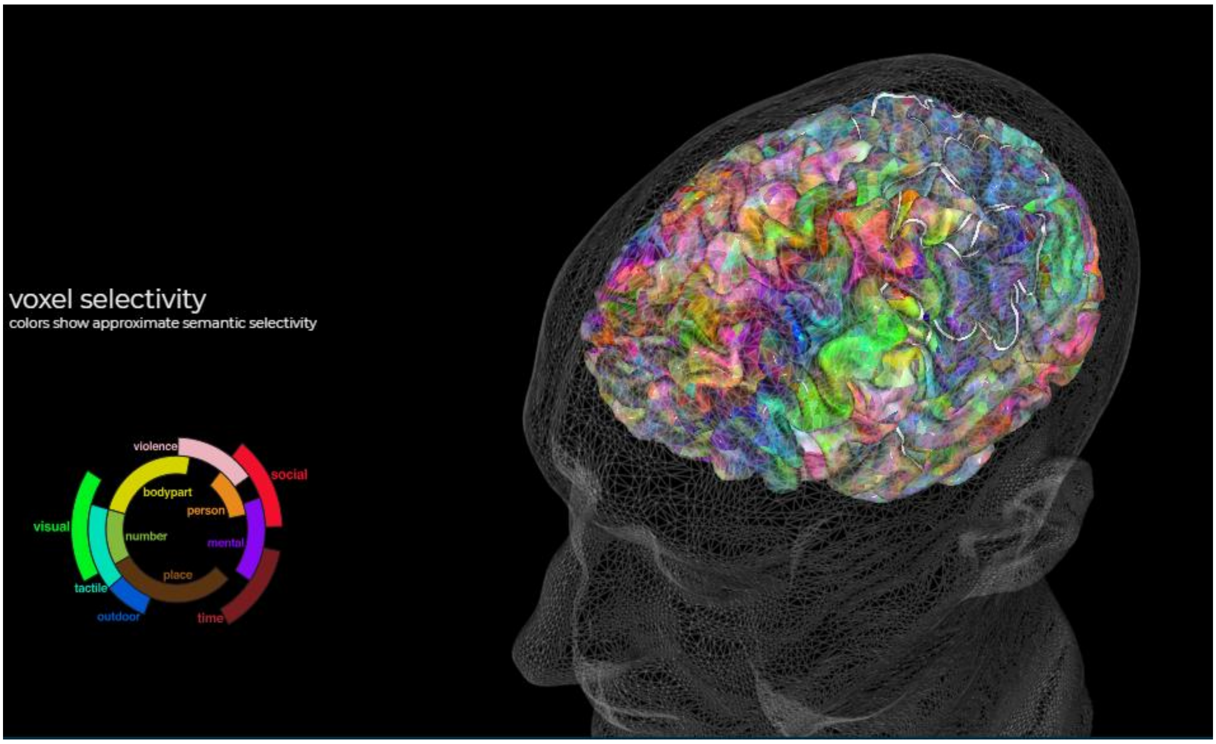


*Figure 2.* Screenshot of the semantic map with corresponding clusters. Adapted from gallantlag.org/huth2016/

### 1.3 The current study

The current study investigates into the usability of the clusters and words from the semantic map of Huth et al. (2016a). Thus it means that the current study investigates how the words from clusters from the semantic map of Huth et al. (2016a) are used by participants outside the laboratory. To investigate into the usability, the relations of concepts from Huth et al. (2016a) need to be analysed. There are multiple ways of analysing the relations of concepts from Huth et al. (2016a). In this study, two analyses will be used in order to investigate the usability with more precision.

The first analysis is that participants make their own categories with the words from corresponding clusters from Huth et al. (2016a). This can be done with a card sorting task. In this task, participants receive an amount of cards and the participants need to sort the cards. There are closed card sorting tasks and open card sorting tasks. In closed card sorting tasks participants need to sort the cards according to one or more criteria set by the researchers. An example of a criterion would be that the participant needs to sort the cards according to the familiarity of the cards; so car brands that the participant knows are in a group and car brands that are unknown to the participant form the other group. On the other hand, in open card sorting tasks the participants are free to make groups of the cards in any way the participants want. An example of open card sorting would be when a participant receives 20 cards with different car brands on it. A participant can sort these 20 cards by the nationality of car brands. Thus the participant makes a group with German cars, another group with French cars, another group with Italian cars, and a final group with Asian cars.

If the participant wishes to refine a group that the participant made, the participant can make use of hierarchical card sorting (Schettow & Sommer, 2016). This means that the participant sort a group another time, for example sorting the group with Asian cars into a group of Japanese cars and a group of Chinese cars. This gives a refinement of what the participant thinks should be a category. When the sorting of the cards is done, a participant is done with the card sorting task. The open hierarchical card sorting task is going to be used because the participants can make their own groups of words, independent of the known clusters from Huth et al. (2016a).

The second analysis is that participants fill in a questionnaire. In this questionnaire, participants are asked to assess the relation between a cluster label from Huth et al. (2016a) and a word from the same cluster from Huth et al. (2016a). An example of this is with the word ‘Four’ and its corresponding cluster number. The question in this example which is asked would be: how related are the following words with the mentioned category? In this question, the word is ‘Four’ and the mentioned category is number. To answer this question, a Likert scale format will be used. This format let participants choose between in this case five different answers on a scale. The answers are ‘Highly Related’, ‘Related’, ‘Neutral’, ‘Not Related’, and ‘Highly Not Related’, whereas ‘Highly Related’ has a score of 1 and ‘Highly Not Related’ a score of 5. To keep the participants thinking about their answers and alert, filler words are added to the questionnaire. Filler words are words which do not have a relation with the category that is mentioned in the question. In the example given, the word ‘Plastic’ does not have a relation with the category number. The filler words should score more negative due to fact that it is not related to the mentioned category. The questionnaire is going to be used because participants can judge whether the words are considered to be related to its clusters from Huth et al. (2016a).

In this study, 6 of the 11 clusters will be analysed. This division is based on the fact that another researcher is taking care of the other half of the clusters. The six clusters are visual, tactile, outdoor, body part, number, and place. From these six clusters, a selection of 50 words is made. This selection is done by selecting two voxels per cluster, one from the left hemisphere and one from the right hemisphere. Thus 12 voxels are used in this study. Only the voxels with reliability score equal or higher than (3/5) are selected. A voxel contains several words, which match one or more categories. The words which match with one of the six focus categories are put into the list of 50 words the researcher is going to use. However, the total of the words with only one corresponding cluster is below 50. This means that another criterion must be added to come to 50 words. This criterion is that words which correspond with two focus categories are selected. The primary focus category is used to divide to words into the corresponding categories. This primary focus category is assessed by comparing the colour of the voxel with the colour of the most similar category. These words are added to the selected list until the list contains 50 words. An overview of all the clusters, the clusters used in this study and their corresponding words can be found in table 1.

Table 1

*Overview of Cluster from Huth et al. (2016a)*

| **Cluster from Huth et al. (2016a)** | **Used in this study** | **Selected corresponding words** |
|---|---|---|
| Visual | Yes | Plastic, Colored, Steel, Rubber, Clothing, Worn, Jeans, Leather, Coat. |
| Tactile | Yes | Jagged, Flame, Grip, Twisting, Absorb, Melting, Stain, Fabric, Heated. |
| Outdoor | Yes | Atmosphere, Halfway, Cycle, Stream, Roar, Misty, Ride, Climb. |
| Body part | Yes | Bracelet, Purse, Glove, Wear, Garment, Size, Waist, Trousers. |

| | | |
|---|---|---|
| Number | Yes | Nine, Four, Five, Eight, Pounds, Half, Nearly, Length. |
| Place | Yes | Bus, Parking, Airport, Visitors, Packed, Nearest, Motel, Drive. |
| Person | No | n/a |
| Violence | No | n/a |
| Mental | No | n/a |
| Social | No | n/a |
| Time | No | n/a |

To analyse a card sorting task, different ways can be used. One way to analyse card sorting is by using the mismatch score (Schettow & Sommer, 2016). This score represents the degree of discrepancy between the mental model of the participants and the factual model. In this case, the factual model is the cluster-word relations from the semantic map from Huth et al. (2016a). In order to use the mismatch score, similarity measures of both the mental model as well as the factual model are required. However, without the existing heatmap from Huth et al. (2016a), the similarity measure from the semantic map is not applicable. Therefore, another way to analyse the card sorting task is needed. One option would be vector analysis.

Vector analysis makes use of vectors. A vector can be described in association with a word from the card sorting task. This vector contains the relation expressed in numbers between the word that is selected and the other words from the card sorting task. Examples would be the relations of the words Bracelet and Coat, Purse and Jeans, and Glove and Worn. Respectively, the relations are 11.17, 9.17, and 21.09. Two vectors from different words can be compared by calculating the Euclidian distance. This distance can be calculated by using an adaptation of the Pythagorean equation: $(a_1 – a_2)^2 + (b_1 – b_2)^2 + \ldots + (n_1 – n_2)^2 = c^2$. Here is a the first component from the two vectors, b the second, and so forth. In this equation is c the Euclidian distance. The lower the Euclidian distance is, the stronger the relation between vectors and therefore the concepts they represent. If the comparison between vectors and the voxels from Huth et al. (2016a) is made, it becomes clear that the concepts from Huth et al. (2016a) are represented as vectors. Every voxel in the semantic map represents a component of that vector. When the similarities between two concepts as they are represented in the semantic map are being calculated, one should not look at one voxel but at the vectors from the two concepts. Therefore the similarity can be calculated by using the Euclidian distance. As mentioned, the lower this distance is, the stronger the relation between vectors and representing concepts. Thus it means for the card sorting task in this study that the card sorting task is analysed by using vectors.

To analyse the refinement of the hierarchical card sorting, the Jaccard coefficient is used besides the vector analysis (Schettow & Sommer, 2016). With the Jaccard coefficient, the relation between any two items can be measured. This coefficient uses the following formula with the items X and Y: The number of groups to which both X and Y belong / the number of groups to which either X or Y belongs. In here, the '/' stands for divided by. This gives a fraction between 0 and 1, wherein 0 means no relation and 1 means full relation.

Another way of analysing the card sorting task is the analysis based on maximum values. This analysis focuses on the maximum value of every word used in the card sorting. With this analysis the individual differences between the words are neglected, because the individual differences are summed up together. Therefore the results from the analysis based on maximum values can be biased. And a bias in an analysis is something to avoid.

The current study will investigate the usability of the semantic map from Huth et al. (2016a) by answering a question. This question is whether the clusters from Huth et al. (2016a) recur in the judgements from the participants of this study about the relations between the words that occur in the clusters of Huth et al. (2016a). In order to answer the abovementioned question, two sub questions must be answered. The first sub question is whether the same words still belong to the corresponding cluster if participants of this study indicate their own view of the relations between words and corresponding cluster. The second sub question is whether the labels of the clusters used by Huth et al. (2016a) are appropriate according to the judgements of the participants.

## 2. Methods

### 2.1 Participants

In total, 27 people participated in the study. The age of the participants ranged from 19 to 28 years (M = 21.93, SD = 1.94). The number of male participants is 13 and the number of female participants is 14. 19 participants have the Dutch nationality, six participants have the German nationality, one participant has the Bulgarian nationality, and one participant has the Italian nationality. The participants were recruited using a convenience sample and through Sona Systems.

### 2.2 Part 1: Card sorting

The first part is a card sorting task. This is an empirical method that clarifies the mental model of participants, and makes it understandable within a domain of concepts. Participants in card sorting categorise cards in a way that the cards in a group share something similar; an example is shown in figure 3. This similarity is left open for interpretation by the participant.

*Figure 3.* An example of the outcome of a card sorting task.

There are two ways of conducting card sorting tasks, one being the closed card sorting and the other the open card sorting. With closed card sorting, participants will work with pre-defined categories, made by the researchers in advance. Whereas with open card sorting, participants are free to make whatever groups they wish and how many ever groups the participants think they need. In this study, a type of open card sorting is used, namely hierarchical open card sorting. In this way of card sorting, participants start with an initial deck of cards and are asked to divide this deck into groups. After the first division of the deck, participants are asked to create a subgroup. When this subgroup is created, participants have another chance to create another subgroup. A way to measure the relation between any two items is the Jaccard coefficient. This coefficient uses the following formula with the items X and Y: The number of groups to which both X and Y belong / the number of groups to which either X or Y belongs. In here, the '/' stands for divided by. This gives a fraction between 0 and 1, wherein 0 means no relation and 1 means full relation.

### 2.2.1 Materials.

To conduct the card sorting task, cards are required. 50 cards are used in this card sorting task. These 50 cards are based on the 50 selected words, which can be seen in Appendix A. These 50 words are selected from a set of 10,470 English words from the study of Huth et al. (2016a). This selection is done by selecting two voxels per category, one from the left hemisphere and one from the right hemisphere. Thus 12 voxels are used in this study. Only the voxels with a reliability score, see introduction section for details, equal or higher than (3/5) are selected. A voxel contains several words, which match one or more categories. The words which correspond with one of the six focus categories are put into the list of 50 words the researcher is going to use. However, the total of the words with only one corresponding cluster is below 50. This means that another criterion must be added to come to 50 words. This criterion is that words which correspond with two focus categories are selected. The primary focus category is used to divide to words into the corresponding categories. This primary focus category is assessed by comparing the colour of the voxel with the colour of the most similar category. These words are added to the selected list until the list contains 50 words. After having completed the list of 50 selected words, each word is made into a card. The cards are printed and laminated to be ready for the participants. A photo camera is used to record the outcomes of every round of card sorting.

### 2.2.2 Procedure.

Before the task starts, a participant was asked to give demographic information. Specifically, participants have answered what their sex is, what their age is, and what their nationality is. According to the General Data Protection Regulation (GDPR), private information such as demographic information needs to be processed and treated with care (European Commission, 2018). To ensure the safety of participants, the data is made anonymous so that no person can trace back the data to any of the participants. Furthermore, every hardcopy and digital data is stored behind a lock. After finishing this study, all sensitive information will be destroyed.

After this, the participant received the 50 cards and the researcher explained how card sorting works. The participant can start now with dividing the 50 cards into categories which made sense to the participant. If the participant is done with dividing, the researcher took a photograph of the result. The following step is that the participant can choose any category to divide further, to get a refinement of a group of similar cards. The result is again recording by a camera taking a photograph. If the participant wishes to divide any category even further, then the participant is allowed to do that. And again is the result captured by a photograph. This was the last step of the first part. The researcher will shuffle the cards three times for the next participant to randomise the groups made by the last participant.

### 2.2.3 Analysis.

To analyse the card sorting task, the vector approach has been used. As mentioned, this approach is used because the concepts from Huth et al. (2016a) are represented as vectors. For every participant, a blank fifty-by-fifty table is made in Excel. Every word from the list of the selected 50 words is placed in the row and column of this table. By using the Jaccard coefficient, the vector scores can be calculated for every word pair from every participant. This will created 27 different tables, and will be transformed into one fifty-by-fifty table. This table consists of all the scores from all the participants, where the maximum score is 27. By using R and R studio, a heatmap is generated from the data gathered. This is done by converting the table to .csv file, which is usable with R. After running a program in R studio, a heatmap of the table will be made. With this heatmap, clusters can be seen. The noticeable clusters will be compared to the six clusters from the study of Huth et al. (2016a), which are the focus of this study.

A way to quantify the heatmap, is calculating the means of the clusters from the heatmap. To calculate such means, the relative differences of the words in the cluster are important. This means that the distance between words needs to be calculated. For example, the cluster with the words A B C D in that order exists. The distance between A-B is 1, as is with B-C and C-D. The distance between A-C is 2, as is with B-D. And the distance between A-D is 3. These different distances for this cluster needs to be added with each other, and then the mean needs to decided. In this case, the distances need to be divided with 6 because there are six distances with this cluster. If this is done for all the clusters from the generated heatmap, one mean for the clusters from the heatmap can be calculated. This can be compared to the mean from the clusters from Huth et al. (2016a), which is generated by calculating the distances from the clusters that follows from the heatmap. Thus the same order is kept from the clusters from the heatmap, but calculated with the order from the selected 50 words that is used in this study. Therefore the same steps as described above are followed to get a mean from the means of the distances. By comparing the different means, inferences can be made.

## 2.3 Part 2: Questionnaire

### 2.3.1 Materials.

The questionnaire consists of a question about the 50 selected words, plus 20 filler words. These 20 words were selected from categories from the study of Huth et al. (2016a) which are not in the focus area of this study. The purpose of the filler words is to keep the participant alert. If for example a filler word scored equal to any of the other 50 selected words, this participant's data would be deemed unusable. The filler words let participants think about their answers. The 70 words were divided according to the six selected categories. The 20 filler words were randomly divided between the six categories. With every category, the following question was asked: how related are the following words with the mentioned category? To answer this question, a Likert scale format has been used. This format let participants choose between in this case five different answers on a scale. The answers were 'Highly Related', 'Related', 'Neutral', 'Not Related', and 'Highly Not Related', whereas 'Highly Related' has a score of 1 and 'Highly Not Related' a score of 5. These answers are processed into scores which can be used in the analysis of the questionnaire.

### 2.3.2 Procedure.

After being done with the card sorting task, the participant got a laptop from the researcher. On this laptop, the website to conduct and complete the questionnaire was open. There was no limit on duration of the questionnaire. A participant must answer for every word in a category how related this word is with the corresponding category. As mentioned, a participant had the choice between five different answers. This is done for all six categories. After assessing the relationship of 70 words and their corresponding category, the participant was thanked for his participation and given a debriefing. In this debriefing, the participant was informed that he or she could ask at any time any question about the research, for example by sending an e-mail. The participant could also contact the researcher if there is an interest in results of the study.

### 2.3.3 Analysis.

To analyse the answers from the participants, the means will be calculated from every word. First the means of the 50 selected words plus the 20 filler words will be compared to the 50 selected words by using One-Sample T Test. Secondly, the means are going to be used in the comparison of the study of Huth et al. (2016a) to see how related each word is with its corresponding category. Only means lower than 2.5 is taken in consideration, because these score are according to the participants related or highly related with the corresponding category. Means of or above 2.5 will be discarded for further analysis.

# 3. Results

## 3.1 Part 1: Card sorting

The generated heatmap is displayed in Figure 4. To get an equal amount of clusters as the study of Huth et al. (2016a), a cut-off line is used. With this cut-off line, six clusters are noticeable in this heatmap. These six clusters with the corresponding words are divided into table 2 and table 3. Here, table 2 contains the words and clusters that occur in one cluster from Huth et al. (2016a). While in table 3 the words and clusters occur in two or more clusters form Huth et al. (2016a).

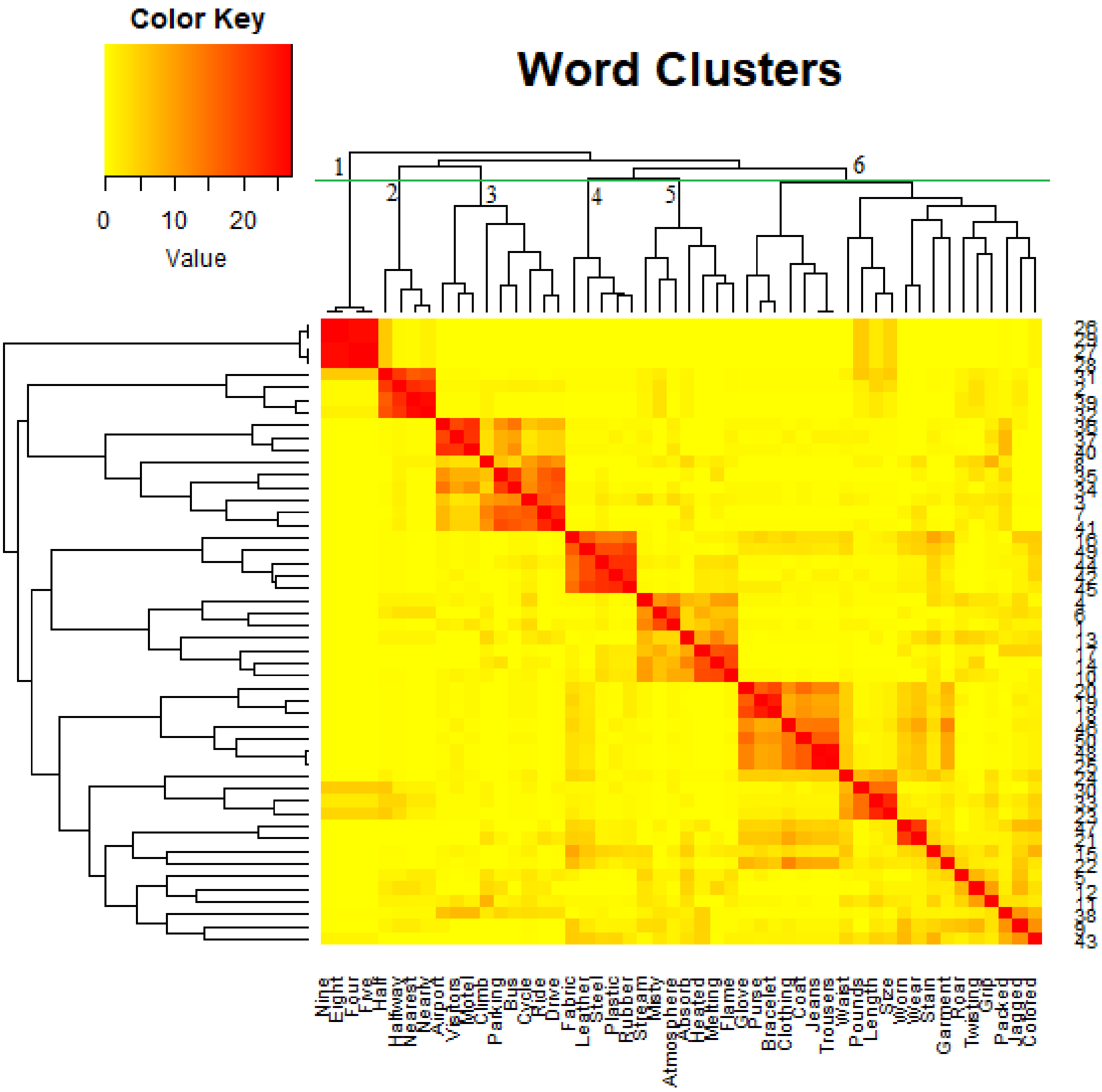


*Figure 4.* The generated heatmap. The green line in the top dendrogram is the cut-off line to get six clusters. The six clusters are enumerated along the green line.

In table 2, the words from the clusters from this study are similar with one cluster from Huth et al. (2016a). For example, cluster 1 from this study contains the words ‘Nine’, ‘Eight’, ‘Four’, and ‘Five’. These four words can be found in one cluster from Huth et al. (2016a), namely the cluster numbers.

Table 2

*Overview of Noticeable Cluster with Words in one Cluster from Huth et al. (2016a)*

| Cluster in this study | Words | Clusters in Huth et al. (2016a) |
|---|---|---|
| 1 | Nine; Eight; Four; Five. | Numbers |

However, in table 3 the words from the clusters from this study are similar with multiple clusters from Huth et al. (2016a). For example, cluster 3 from this study contains the words ‘Airport’, ‘Visitors’, ‘Motel’, ‘Bus’, Drive’, ‘Parking’, ‘Climb’, Ride’, and ‘Cycle’. The words ‘Airport’, ‘Visitors’, ‘Motel’, ‘Bus’, Drive’, and ‘Parking’ are from the cluster place from Huth et al. (2016a), while the words ‘Climb’, Ride’, and ‘Cycle’ are from the cluster outdoor from Huth et al. (2016a).

Table 3

*Overview of Noticeable Clusters with Words in Multiple Clusters from Huth et al. (2016a)*

| Cluster in this study | Words | Clusters in Huth et al. (2016a) |
|---|---|---|
| 2 | Halfway; Half; Nearly; Nearest. | Outdoor, Numbers, Place |
| 3 | Airport; Visitors; Motel; Bus; Drive; Parking; Climb; Ride; Cycle. | Place, Outdoor |
| 4 | Fabric; Leather; Steel; Plastic; Rubber. | Tactile, Visual |
| 5 | Stream; Misty; Atmosphere; Absorb; Heated; Melting; Flame. | Outdoor, Tactile |
| 6 | Roar; Jagged; Grip; Twisting; Stain; Glove; Purse; Bracelet; Trousers; Wear; Garment; Size; Waist; Pounds; Length; Packed; Colored; Clothing; Coat; Jeans; Worn. | Outdoor, Tactile, Body part, Numbers, Place, Visual |

To quantify the heatmap, different means were calculated. An overview of the different cluster from the heatmap with the according means is displayed in table 4. In this table, the means from the heatmap are from the clusters found in the heatmap. These clusters have a different order in the study of Huth et al. (2016a) which might increase the distance and therefore the mean. The last row in the table is the overall mean from both the means of the heatmap and the means from the clusters from Huth et al. (2016a).

Table 4

*Overview of Clusters with Corresponding Words and Calculated Means, Both from this Study and the Study from Huth et al. (2016a)*

| Cluster from this study | Words | Means Heatmap | Means Huth et al. (2016a) |
|---|---|---|---|
| 1 | Nine; Eight; Four; Five | 10/6 = 1.67 | 10/6 = 1.67 |
| 2 | Halfway; Half; Nearly; Nearest. | 10/6 = 1.67 | 112/6 = 16.67 |
| 3 | Airport; Visitors; Motel; Bus; Drive; Parking; Climb; Ride; Cycle. | 120/36 = 3.33 | 622/36 = 17.28 |
| 4 | Fabric; Leather; Steel; Plastic; Rubber. | 20/10 = 2 | 138/10 = 13.8 |
| 5 | Stream; Misty; Atmosphere; Absorb; Heated; Melting; Flame. | 56/21 = 2.67 | 150/21 = 7.14 |
| 6 | Roar; Jagged; Grip; Twisting; Stain; Glove; Purse Bracelet; Trousers; Wear; Garment; Size; Waist; Pounds; Length; Packed; Colored; Clothing; Coat; Jeans; Worn. | 1.540/210 = 7.33 | 3.382/210 = 16.10 |
| | | ((10/6) + (10/6) + (120/36) + (20/10) + (56/21) + (1.540/210)) / 6 = 3.11 | ((10/6) + (112/6) + (622/36) + (138/10) + (150/21) + (3382/210)) / 6 = 12.66 |

### 3.2 Part 2: Questionnaire

To check whether the filler words were effective, a One-Sample T Test has been conducted. With this test, a test value of 2.5 has been used because 2.5 is a threshold between whether a word is considered to be relevant or not relevant; a score lower than 2.5 is considered to be relevant. In table 5, the outcome of the One-Sample T Test is displayed. Both lists with and without the filler words are significant. And because the list without the filler words, in the table known as MeanSelected, has a negative Mean Difference, it means that the filler words had a desirable effect namely keeping the participant alert.

Table 5

*The Statistical Output of the One-Sample T Test. MeanAll is the selected 50 words including filler words, whereas MeanSelected is just the 50 selected words.*

| | **One-Sample Test** | | | | | |
|---|---|---|---|---|---|---|
| | Test Value = 2.5 | | | | | |
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| MeanAll | 4,513 | 26 | ,000 | ,25686 | ,1399 | ,3738 |
| MeanSelected | -4,829 | 26 | ,000 | -,23778 | -,3390 | -,1366 |

The means from the questionnaire are divided according to the six clusters this study uses from Huth et al (2016a). If a mean is lower than 2.5, then this word is considered to be relevant or highly relevant. In table 6 with the cluster outdoor, the words ‘Atmosphere’, ‘Cycle’, ‘Stream’, ‘Misty’, ‘Ride’, and ‘Climb’ are considered related or highly related according to the participants.

Table 6

*Cluster Outdoor. The means are between 1 and 5. SD means Standard Deviation.*

| Word | Atmosphere | Halfway | Cycle | Stream | Roar | Misty | Ride | Climb |
|---|---|---|---|---|---|---|---|---|
| Mean | 1.41 | 3.52 | 1.93 | 1.52 | 2.56 | 1.41 | 1.85 | 1.52 |
| SD | .501 | 1.014 | 1.107 | .802 | .934 | .572 | .77 | .509 |
| Minimum | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Maximum | 2 | 5 | 5 | 4 | 4 | 3 | 4 | 2 |

In table 7 with the cluster tactile from Huth et al. (2016a), only the word 'Grip' is considered related according to the participants

Table 7

*Cluster Tactile. The means are between 1 and 5. SD means Standard Deviation.*

| Word | Jagged | Flame | Grip | Twisting | Absorb | Melting | Stain | Fabric | Heated |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 2.56 | 2.93 | 1.89 | 2.81 | 3.37 | 3.07 | 3.04 | 2.26 | 2.52 |
| SD | 1.121 | 1.107 | 1.086 | 1.302 | 1.043 | 1.141 | 1.224 | 1.228 | .935 |
| Minimum | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Maximum | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 4 |

In table 8 with the cluster body part from Huth et al. (2016a), the words 'Size' and 'Waist' are considered related or highly related according to the participants.

Table 8

*Cluster Body part. The means are between 1 and 5. SD means Standard Deviation.*

| Word | Bracelet | Purse | Glove | Wear | Garment | Size | Waist | Trousers |
|---|---|---|---|---|---|---|---|---|
| Mean | 2.88 | 3.48 | 2.7 | 2.89 | 3.19 | 1.96 | 1.19 | 2.63 |
| SD | 1.177 | 1.156 | 1.265 | 1.219 | 1.21 | .808 | .396 | 1.115 |
| Minimum | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 |
| Maximum | 5 | 5 | 5 | 5 | 5 | 4 | 2 | 5 |

In table 9 with the cluster numbers from Huth et al. (2016a), the words 'Nine', 'Four', 'Five', 'Eight', 'Pounds', and 'Length' are considered related or highly related according to the participants.

Table 9

*Cluster Numbers. The means are between 1 and 5. SD means Standard Deviation.*

| Word | Nine | Four | Five | Eight | Pounds | Half | Nearly | Length |
|---|---|---|---|---|---|---|---|---|
| Mean | 1 | 1 | 1 | 1 | 2.48 | 2.59 | 3.67 | 2.33 |
| SD | 0 | 0 | 0 | 0 | 1.189 | 1.083 | 1.074 | 1.109 |
| Minimum | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| Maximum | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 5 |

In table 10 with the cluster place from Huth et al. (2016a), the words ‘Parking’, ‘Airport’, ‘Visitors’, ‘Nearest’, and ‘Motel’ are considered related or highly related according to the participants.

Table 10

*Cluster Place. The means are between 1 and 5. SD means Standard Deviation.*

| Word | Bus | Parking | Airport | Visitors | Packed | Nearest | Motel | Drive |
|---|---|---|---|---|---|---|---|---|
| Mean | 2.78 | 1.7 | 1.22 | 2.37 | 3.07 | 1.85 | 1.26 | 2.59 |
| SD | 1.086 | .724 | .424 | 1.305 | 1.174 | .534 | .447 | .971 |
| Minimum | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 |
| Maximum | 5 | 4 | 2 | 5 | 5 | 3 | 2 | 5 |

In table 11 with cluster visual from Huth et al. (2016a), the words ‘Colored’, ‘Steel’, ‘Rubber’, ‘Clothing’, ‘Jeans’, ‘Leather’, and ‘Coat’ are considered related or highly related according to the participants.

Table 11

*Cluster Visual. The means are between 1 and 5. SD means Standard Deviation.*

| Word | Plastic | Colored | Steel | Rubber | Clothing | Worn | Jeans | Leather | Coat |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 2.52 | 1.19 | 2.15 | 2.19 | 1.93 | 3.15 | 2.44 | 2.19 | 2.41 |
| SD | 1.087 | .396 | 1.027 | 1.001 | 1.072 | 1.406 | 1.086 | 1.001 | 1.118 |
| Minimum | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Maximum | 5 | 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

## 4. Discussion

When the results of this study are being compared with the study of Huth et al. (2016a), some similarities but also differences can be discovered. One similarity is the representation of the cluster from this study with the words ‘Nine’, ‘Four’, ‘Five’, and ‘Eight’. This cluster contains words from just one cluster from Huth et al. (2016a), namely the cluster numbers, which is made clear with the heatmap and the calculated means. The questionnaire also brought forward this similarity, by considering the words to be highly related to the cluster numbers. Besides this study, other literature also brought forward this semantic representation of numbers. According to Amalric and Dehaena (2018), calculations, numbers, and other quantities are activating parietal electrodes when mentioned in natural speech.

Another similarity is the representation of the cluster visual. According to the results of the questionnaire, seven of the nine words are considered to be related or highly related. This means that the cluster visual is quite semantically represented. However, such evidence cannot be supported by the heatmap. The cluster visual is represented separately across two different clusters from this heatmap.

One difference between this study and the study from Huth et al. (2016a) is the representation of the cluster tactile. The words from the cluster tactile from the study Huth et al. (2016a) is spread over three clusters from the heatmap of this study. Besides the spread of representation of the one cluster tactile from Huth et al. (2016a) across three different clusters, are all the words but one in the cluster tactile not relevant to the cluster according to the participants. This means that the cluster tactile differs in representation in this study.

Another difference between this study and the study from Huth et al. (2016a) is the representation of the cluster body part. In the heatmap the cluster body part is represented in one cluster, namely the last cluster. However, other words from other clusters from Huth et al. (2106a) are as well in the same cluster in the heatmap. The difference is also supported by evidence from the questionnaire; two words from total of eight words are considered to be relevant.

The next difference between this study and the study from Huth et al. (2016a) is the representation of the cluster outdoor. This cluster from Huth et al. (2016a) is represented across four different clusters from the heatmap of this study. However, the questionnaire resulted in a disagreement. The results from the questionnaire are six out of the eight words are relevant to the cluster outdoor. Nevertheless, the cluster outdoor is different represented in this study than in the study of Huth et al. (2016a).

The last cluster, place, is represented differently in this study than in the study of Huth et al. (2016a). In the heatmap, the words from the cluster place from Huth et al. (2016a) are represented in three different clusters. Besides this, the questionnaire resulted in the consideration of five out of eight words to be relevant to the cluster of place from Huth et al. (2016a).

If we look at the literature, other differences from the comparison to the study of Huth et al. (2016a) can be found. When looking at the study of Barsalou (2017), it concludes that in the study of Huth et al. (2016a) cortical surface responses have been found. However, the actual mechanisms are still unclear. Thus it means that voxel-wise modelling, which has been done by Huth et al. (2016a), only tells what parts of the brain become active. And it tells nothing about the mechanisms behind the activation of the brain. Besides this, Barsalou (2017) concludes that in the case of using other narratives, other observed semantic selectivity of an area might occur.

Another study by Huth, Lee, Nishimoto, Bilenko, Vu and Gallant (2016b) has done a similar study as Huth et al. (2016a), but instead of using natural speech, natural movies has been used. However, the results are different from each other. In the study of Huth et al. (2016a), as mentioned earlier, there are relations between general categories and atypical examples, such as number and pounds. But in the study with natural movies from Huth et al. (2016b), such relations are not found.

A study from Van Vliet, Van Hulle, and Salmelin (2018) mention correctly that the study from Huth et al. (2016a) focuses on same natural semantic categories that produces similar brain activity. However, although some semantic categories activate similar unique mental activity patterns, it is not certain that this activation works for all the categories. Nor is it certain that other types of relationships that are important to the semantic systems in our brain would work with the mentioned activation.

## 5. Conclusion

The aim of the current study has been to investigate the usability of the semantic map from Huth et al. (2016a). This has been done by answering the questions whether the clusters from Huth et al. (2016a) recur in the judgements from the participants of this study about the relations between the words that occur in the clusters of Huth et al. (2016a). This question is divided into two sub questions. The first sub question is whether the same words still belong to the corresponding cluster if participants of this study indicate their own view of the relations between words and corresponding cluster. The second sub question is whether the labels of the clusters used by Huth et al. (2016a) are appropriate according to the judgements of the participants.

The first sub question can be answered with help from the card sorting task. Only the words from the cluster body part from Huth et al. (2016a) is considered to belong to its corresponding cluster. But in the cluster from this study that contains the words from the cluster body part from Huth et al. (2016a) is also other words from other clusters from Huth et al. (2016a). This cluster from this study contains a larger number of words in comparison to the other clusters from this study due to the fact of the cut-off line. Was this line somewhere else, the clusters would have changed. The other words from the clusters of Huth et al. (2016a) are spread over the found clusters from the heatmap. However, actual numbers such as three and four are correctly assigned to the cluster numbers of Huth et al. (2016a). Therefore, only actual numbers are usable as they are semantically represented in the brain.

The second sub questions can be answered through the questionnaire. The clusters outdoor, numbers, place, and visual from Huth et al. (2016a) are considered to be appropriate by the participants. The other clusters, body part and tactile, are considered to be not appropriate by the participants. Therefore, according to the results from the questionnaire, the clusters outdoor, numbers, place, and visual from Huth et al. (2016a) are usable as they are semantically represented in the brain.

In conclusion, this study tries to answer whether the clusters from Huth et al. (2016a) recur in the judgements from the participants of this study about the relations between the words that occur in the clusters of Huth et al. (2016a). For the card sorting, the clusters from Huth et al. (2016a) recur not fully in the judgements from the participants of this study. Only actual numbers are correctly assigned. However for the questionnaire, the clusters from Huth et al. (2016a) recur more but also not fully than the card sorting task in the judgements from the participants of this study. Four of the six clusters are in comparison with what the participants have said. The reason why the questionnaire has more similarities than the card sorting task can be traced back to a bias from the participants.

Looking at this study, one limitation can be found. Participants were biased when beginning with the questionnaire, due to the fact that participants already have seen the words that were also used in the questionnaire. Participants have mentioned for example that they interpreted words differently after seeing which category a word can belong to. Although the effect of the bias is not directly visible, it is deemed favourable that participants are not biased while doing the tasks or experiments. There is the possibility that the questionnaire had different results in the case of non-biased participants.

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# 7. Appendix A

List of 50 Selected Words

**Outdoor:**

1. Atmosphere (voxel [19, 23, 34] RH)
2. Halfway (voxel [19, 23, 34] RH)
3. Cycle (voxel [19, 23, 34] RH)
4. Stream (voxel [19, 23, 34] RH)
5. Roar (voxel [18, 83, 54] LH)
6. Misty (voxel [18, 83, 54] LH)
7. Ride (voxel [18, 84, 54] LH)
8. Climb (voxel [18, 84, 54] LH)

**Tactile:**

1. Jagged (voxel [24, 78, 62] LH)
2. Flame (voxel [ 24, 78, 62] LH)
3. Grip (voxel [24, 78, 62] LH)
4. Twisting (voxel [24, 78, 62] LH)
5. Absorb (voxel [13, 23, 32] RH)
6. Melting (voxel [ 13, 23, 32] RH)
7. Stain (voxel [13, 23, 32] RH)
8. Fabric (voxel [13, 23, 32] RH)
9. Heated (voxel [13, 23, 32] RH)

**Body part:**

1. Bracelet (voxel [13, 78, 66] LH)
2. Purse (voxel [13, 78, 66] LH)
3. Glove (voxel [13, 78, 66] LH)
4. Wear (voxel [16, 31, 25] RH)
5. Garment (voxel [16, 31, 25] RH)
6. Size (voxel [16, 31 ,25] RH)
7. Waist (voxel [16, 31, 25] RH)
8. Trousers (voxel [16, 31, 25] RH)

**Numbers:**

1. Nine (voxel [14, 89, 59] LH)
2. Four (voxel [14, 89, 59] LH)
3. Five (voxel [14, 89, 59] LH)
4. Eight (voxel [14, 89, 59] LH)
5. Pounds (voxel [18, 31, 28] RH)
6. Half (voxel [18, 31, 28] RH)
7. Nearly (voxel [18,31, 28] RH)
8. Length (voxel [18, 31, 29] RH)

**Place:**

1. Bus (voxel [7, 63, 61] LH)
2. Parking (voxel [7, 63, 61] LH)
3. Airport (voxel [7, 63, 61] LH)
4. Visitors (voxel [7, 63, 61] LH)
5. Packed (voxel [21, 43, 38] RH)
6. Nearest (voxel [21, 43, 38] RH)
7. Motel (voxel [21, 43, 38] RH)
8. Drive (voxel [21, 43, 38] RH)

**Visual:**

1. Plastic (voxel [ 19, 33, 73] LH)
2. Colored (voxel [19, 33, 73] LH)
3. Steel (voxel [19, 33, 73] LH)
4. Rubber (voxel [19, 33, 73] LH)
5. Clothing (voxel [16, 26, 27] RH)
6. Worn (voxel [16, 26, 27] RH)
7. Jeans (voxel [16, 26, 27] RH)
8. Leather (voxel [16, 26, 27] RH)
9. Coat (voxel [16, 26, 27] RH)

## 8. Appendix B

The syntax from SPSS to calculate the means from every cluster and to calculate the T Test.

```
FREQUENCIES VARIABLES=Q1_1 Q1_2 Q1_4 Q1_5 Q1_6 Q1_8 Q1_10 Q1_11
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=Q3_1 Q3_3 Q3_4 Q3_5 Q3_7 Q3_8 Q3_10 Q3_12 Q3_13
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=Q5_2 Q5_3 Q5_4 Q5_5 Q5_7 Q5_8 Q5_10 Q5_11
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=Q6_1 Q6_2 Q6_4 Q6_6 Q6_7 Q6_8 Q6_10 Q6_11
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=Q7_1 Q7_2 Q7_3 Q7_6 Q7_7 Q7_8 Q7_10 Q7_11
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=Q8_1 Q8_3 Q8_4 Q8_5 Q8_7 Q8_8 Q8_10 Q8_11 Q8_13
  /STATISTICS=STDDEV MINIMUM MAXIMUM MEAN
  /ORDER=ANALYSIS.
```

```
T-TEST
  /TESTVAL=2.5
  /MISSING=ANALYSIS
  /VARIABLES=MeanAll MeanSelected
  /CRITERIA=CI(.95).
```

## 9. Appendix C

The syntax from R and R studio to generate the heatmap from the card sorting task

```
# R script to generate a heatmap based on concepts from Huth et al. (2016)

install.packages("gplots")
install.packages("RColorBrewer")

# Call these libraries. They need to be installed as packages
library(gplots)
library(RColorBrewer)

# Read the data file (.csv format)
#data <- read.csv("path/filename")
data <- read.csv("full analysis V4.csv")

# Transform data in numerical format
mat_data <- data.matrix(data[,1:ncol(data)])

# Define colors of heatmap: red for high numbers
my_palette <- colorRampPalette(c("yellow","red"))(n = 299)

# Call heatmap function (from gplots), with these arguments
# See: https://www.rdocumentation.org/packages/gplots/versions/3.0.1/topics/heatmap.2
# Note: argument 'main=' gives name of plot
```

```
heatmap.2(mat_data, col = my_palette, density.info="none", trace="none",
      revC = TRUE, main="Word clusters")

# For fruit concepts data file use:
heatmap.2(mat_data, col = my_palette, density.info="none", trace="none",
        revC = TRUE, main="Word clusters", margin=c(10, 10))

# Export figure (png or pdf) from Plots screen (bottom-right panel)
```