**Visual and auditory perceptual strength norms for 3,596 French nouns and their relationship with other psycholinguistic variables.**

*Georges Chedid [1,2], Simona Maria Brambati [1,2], Christophe Bedetti [2], Amandine E. Rey [4], Maximilliano A. Wilson [3], Guillaume T. Vallet [1,2,5]*

1. Department of Psychology, University of Montreal, Montreal, Quebec, Canada,

2. Centre de Recherche, Institut universitaire de gériatrie de Montréal, Montreal, Quebec, Canada

3. Centre de recherche CERVO et Département de réadaptation, Université Laval, Quebec city, Quebec, Canada

4. Laboratoire d'Étude des Mécanismes Cognitifs, Université Lyon 2, Lyon, France

5. Université Clermont Auvergne, CNRS UMR 6024, Laboratoire de Psychologie Sociale et Cognitive, Clermont-Ferrand, France

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Perceptual experience plays a critical role in the conceptual representation of words. Higher levels of semantic variables such as imageability, concreteness, and sensory experience are generally associated with faster and more accurate word processing. Nevertheless, these variables tend to be assessed based mostly on visual experience. This underestimates the potential contribution of other perceptual modalities. Accordingly, recent evidence stresses the importance of providing modality-specific perceptual strength norms. In the present study, we developed French Canadian norms of visual and auditory perceptual strength (i.e., the modalities that have a major impact on word processing) for 3,596 nouns. We then explored the relationship between these newly developed variables and other lexical, orthographic and semantic variables. Finally, we demonstrated the contribution of visual and auditory perceptual strength ratings to visual word processing beyond that of other semantic variables related to perceptual experience (e.g., concreteness, imageability and sensory experience ratings). The ratings developed in this study are a meaningful contribution toward the implementation of new studies that will shed further light on the interaction between linguistic, semantic and perceptual systems.

## Introduction

The sensory/perceptual system processes information from the environment through our different senses. More specifically, the sensory system allows the detection and analysis of the stimuli through the peripheral nervous system (through the receptors specific to different sensory modalities) (Gardner & Martin, 2019). Perception refers to the central processing that transforms sensory information into a meaningful pattern (Keetels & Vroomen, 2012). Perceptual experience based on different sensory modalities (visual, auditory, etc.) is part of our conceptual knowledge (Ernst & Bulthoff, 2004). A large body of evidence has shown that semantics, especially when associated with the perceptual and functional attributes of object concepts, is represented by distributed patterns of activity across multiple modality-specific processing pathways in the brain (Binder & Desai, 2011; Martin, 2007; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). Functional neuroimaging studies in healthy participants have consistently demonstrated that semantic processing of words representing concepts with strong visual, auditory, olfactory and gustatory association activated the brain network involved in the processing of these sensory characteristics (Barros-Loscertales et al., 2012; Goldberg, Perfetti, & Schneider, 2006; Gonzalez et al., 2006; Kiefer, Sim, Herrnberger, Grothe, & Hoenig, 2008; Simmons et al., 2007). These findings suggest that semantic knowledge remains, at least in part, grounded in its sensory and motor features (Barsalou, 1999, 2008; Borghi & Riggio, 2015; Grush, 2004; Vallet, Brunel, & Versace, 2010). Cognition would thus be indivisible from the sensorimotor states of the body as well as the characteristics of the surrounding environment (Glenberg, Witt, & Metcalfe, 2013; Versace et al., 2014). Applied to memory, the different modal sensory components of a single concept are closely related. Thus, the activation of one component should then automatically propagate to the other associated components (Vallet, Simard, Versace, & Mazza, 2013; Versace et al., 2014) from a perceptual prime (Vallet et al., 2013) or even from a conceptual prime (a word, see Rey, Riou, Vallet, & Versace, 2017). Taken together, these findings demonstrate the potential role of perceptual experience in conceptual knowledge.

Thus, one might argue that the conceptual processing of words partially relies on the ability of each modality to be activated (i.e., its perceptual strength). In line with that, Lynott and Connell collected perceptual strength ratings for different sensory modalities (visual, tactile, auditory, olfactory, and gustatory) for approximately 400 nouns and 400 adjectives (Connell & Lynott, 2012; Lynott & Connell, 2009, 2013). More specifically, participants were asked to rate to what extent they experienced each word by seeing, hearing, smelling, tasting, or feeling through touch. Ratings ranged from 0 (not experienced at all through this sense) to 5 (greatly experienced through this sense). More importantly, these authors investigated the impact of perceptual strength in different modalities on word processing. This series of studies yielded two main findings. Firstly, they showed that perceptual strength is a good predictor of both lexical decision and word-naming performance (Connell & Lynott, 2012, 2014). More specifically, words with strong perceptual representations are processed more quickly than words with weaker perceptual representations. This result is in agreement with previous studies reporting that perceptual stimulation leads to faster and/or more accurate conceptual processing in the same modality, i.e., the perceptual-conceptual facilitation effect (Kaschak, Zwaan, Aveyard, & Yaxley, 2006; Van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). Secondly, these studies showed that the strength of perceptual experience predicts word processing performance better than semantic variables such as concreteness or imageability (Connell & Lynott, 2012). Concreteness is defined as the degree to which words refer to objects, individuals, places or things that can be experienced with our senses (Paivio, Yuille, & Madigan, 1968). Concreteness rating norms are based on the degree to which certain words refer to tangible objects, materials or people that can be easily perceived by our senses (Bonin, Meot, & Bugaiska, 2018). A longstanding literature points out that concrete concepts are processed more quickly and accurately than abstract concepts (Allen & Hulme, 2006; Binder, Westbury, McKiernan, Possing, & Medler, 2005; Fliessbach, Weis, Klaver, Elger, & Weber, 2006; Paivio, Yuille, & Smythe, 1966; Romani, McAlpine, & Martin, 2008). According to the dual coding theory (Paivio, 2013), this advantage comes from the fact that both concrete and abstract concepts have a verbal code representation, but only concrete concepts also benefit from an imagistic representation (Crutch, Connell, & Warrington, 2009; Crutch & Warrington, 2005; Holcomb, Kounios, Anderson, & West, 1999; Jessen et al., 2000; Paivio, 1991). In this regard, the concept of concreteness is strongly related to the concept of imageability. Imageability refers to the degree to which a word and/or a concept arouses a mental image. In fact, in the experimental language literature, imageability and concreteness ratings are often used interchangeably because of their high correlation and theoretical relationship (Binder et al., 2005; Fliessbach et al., 2006; Sabsevitz, Medler, Seidenberg, & Binder, 2005).

Both concreteness and imageability are based on properties of the mental representation evoked by a word, and therefore, they do not reflect the actual perceptual experience associated with the concept represented by the word. In addition, concreteness and imageability ratings are not explicitly based on the personal sensory experience of the raters. For this reason, both variables tend to be assessed based on visual experience, neglecting or underestimating the contribution of other modalities (Connell & Lynott, 2012). This is probably the reason why perceptual strength in multiple modalities was found to be a better predictor of word processing performance than concreteness and imageability (Connell & Lynott, 2012). More recently, Winter (2016) conducted a study in order to investigate the relationship between perceptual strength and emotional valence. The results of this study indicated that words associated with taste and smell (e.g., "pungent" or "delicious") had higher absolute emotional valence compared to words associated with other sensory modalities (e.g., the visual word "yellow" or the auditory word "echoing") (Winter, 2016). In summary, altogether these data clearly show the key role of perceptual strength on word processing. These results highlight the necessity to make available databases of perceptual strength ratings in different modalities of concepts. These ratings could allow for researchers 1) to control for potential variables influencing concept processing when designing factorial experiments and 2) to test specific hypotheses on the impact of perceptual strength on concept processing. In English, in addition to the ratings for single words (van Dantzig, Cowell, Zeelenberg, & Pecher, 2011), ratings of perceptual strength of different sensory modalities are available for object-property pairs (e.g., TUBA-LOUD, or TUBA-SHINY) (van Dantzig et al., 2011). In this study, participants were asked to rate to what degree object-property pairs were experienced by seeing, hearing, feeling by touch, tasting and smelling (van Dantzig et al., 2011). However, these norms are recommended for studies employing tasks using specific concept-property combinations, such as memory tasks (van Dantzig et al., 2011). Ratings based on single words such as those of Lynott and Connell (2009, 2013) are preferred for more general studies, as single word processing (van Dantzig et al., 2011).

The creation of language-specific norms is important because ratings to the same stimulus can vary considerably, not only in different languages (Sanfeliu & Fernandez, 1996), but also in different cultures (e.g., French in Canada and in France) (see Sirois, Kremin, & Cohen, 2006).

Consequently, it has been recommended that normative data should be collected for each culture separately (Bonin, Peereman, Malardier, Meot, & Chalard, 2003).

Until now, no database of modality perceptual strength has been available in French. There is only one database that includes a similar but more general concept of perceptual norms based on sensory experience ratings (SERs) (Bonin, Meot, Ferrand, & Bugaiska, 2015). These authors define the SERs as indicating the degree to which a word evokes a sensory and/or perceptual experience in the mind of the participant, independently of a specific sensory/perceptual modality (Bonin et al., 2015; Juhasz & Yap, 2013; Juhasz, Yap, Dicke, Taylor, & Gullick, 2011). The semantic nature of SERs has been confirmed in both French and English by revealing the significant association between SERs and other semantic variables such as imageability and age of acquisition (Juhasz & Yap, 2013; Juhasz et al., 2011). In addition, it has been demonstrated that SERs critically contribute to word processing above and beyond the contribution of other lexical and semantic variables (Juhasz et al., 2011). Although the SERs are an important step forward in the study of cognition, further perceptual strength ratings in French, specific to the different sensory modalities, are necessary to conduct studies addressing questions on the role of perceptual strength in specific sensory modalities on cognition, as such ratings are available in English (Lynott & Connell, 2009).

The aim of the present study is threefold. The first and main aim is to provide modality-specific perceptual strength ratings for a large set of 3,596 French nouns for which norms of subjective frequency, imageability and concept familiarity are already available (Chedid et al., 2018; Desrochers & Thompson, 2009) (Study 1). This will represent the largest database for which perceptual strength ratings are available in French. Due to the number of words to rate, the present work focused on two modalities of perceptual strength, i.e., visual and auditory perceptual strength. These two modalities have been chosen because vision and audition have a major impact on word processing (Lynott & Connell, 2013; van Dantzig et al., 2011). Additionally, they are the most studied human senses (Colavita, 1974; Hecht & Reiner, 2009), and they are the most widely represented in the human cortex (Glasser et al., 2016). To this aim, we performed an online rating task following the procedures adopted in our previous work on concept familiarity using the same dataset of words (Chedid et al., 2018). In a similar manner to previous studies in English, participants were asked to separately rate to what extent they visually or auditorily experienced each word (Juhasz, Lai, & Woodcock, 2015; Lynott & Connell, 2009, 2013). The second aim was to explore the relationship of our newly developed variables with other well-studied semantic variables (Study 2). Our main hypothesis assumes that our visual and auditory perceptual strength ratings are semantic in nature. This stems from their relationship with other semantic variables, such as concept familiarity, age of acquisition and imageability, as in Connell and Lynott (2012), Juhasz and Yap (2013); Juhasz et al. (2011), and Bonin et al. (2015). The third aim was to demonstrate that the ratings of the strength of visual and auditory perceptual experience are not merely another form of imageability, concreteness or SERs (Study 3). To this aim, we extracted the RTs for lexical decision from Ferrand et al. (2010) and used them in a linear regression to demonstrate the contribution of visual and auditory perceptual strength over and above the contribution of conceptually related semantic variables such as imageability, concreteness and SERs.

**STUDY 1**

The aim of the study was to collect norms for the visual and auditory perceptual strength of a large set of words. We achieved this through two steps: 1) data collection of visual and auditory perceptual strength for a large set of French words and 2) norm verification through intra- and inter-study reliability.

## Method

### Participants

Three hundred four participants (198 women, 106 men), 18-35 years of age (mean age= 25.3, SD= 3.9; mean education in years= 14.1, SD= 3.3), took part in this study. We recruited participants by email invitations sent to a panel of students from the University of Montreal. The inclusion criteria were as follows: 1) to be between 18 and 35 years old, 2) to have normal or corrected-to-normal vision, 3) to not have hearing loss (due to the nature of the task), and 4) to not have a previous history of reading and/or mental problems. Participants received a 10 CAD$ gift card as compensation after completing the experiment.

Based on the study of Sirois et al. (2006), we decided to include a homogeneous group of French Canadian native speakers. The language (and its variant) spoken by each participant was assessed using an online questionnaire. Indeed, Sirois et al. (2006) showed that ratings of some variables, such as name agreement, visual complexity and conceptual familiarity, showed differences between French Canadian and European French.

The study was reviewed and approved by the local ethics committee (*Comité d'éthique de la recherche vieillissement-neuroimagerie* CER IUGM 15-16-33). This committee follows the guidelines of the Tri-Council Policy Statement of Canada, the civil code of Quebec, the Declaration of Helsinki, and the Nuremberg Code.

### Stimuli

We selected the 3,596 French nouns taken from Desrochers and Thompson (2009). The list of 3,596 words was randomly split into 24 lists of approximately 150 words each and presented to participants for perceptual strength ratings. In each list, five randomly selected words appeared twice in a semi-random order to compute the test-retest reliability of each participant's ratings, as previously described (Chedid et al., 2018). Thus, a total of 155 words (including the five repeated words) were presented in each list.

**Procedure**

The timing, sequencing, presentation of stimuli, response recording, and response latencies were controlled by a web application created by Beau and Rey (2015) and previously used in Rey et al. (2017, https://github.com/sebastienbeau/aphrodite-survey) and Chedid et al. (2018). Participants completed the rating study on an online platform where they submitted their personal information and filled out a screening questionnaire to determine their eligibility to participate. After completing the consent form, they accessed a session consisting of a list of stimuli for which they had to rate the visual and the auditory perceptual strength of 155 words. As in Chedid et al. (2018), each participant could complete a single session or divide the rating task into two or more sessions. Participants were not allowed to complete the same session more than once. The ratings were automatically saved by the server in a secure database (PostgreSQL). The session started with an instruction page where participants received explanations about and examples of rating perceptual strength. Explanations and instructions for ratings followed the method used by Lynott and Connell (2009). After these instructions, the rating task began. The order of the 155 words was randomized across participants. Each word was separately presented to the participants, who had to rate to what extent the meaning of the word could be experienced in each of the two perceptual modalities in the following order: visual (in French :"*Dans quelle mesure CE MOT vous fait ressentir une experience visuelle?*", English translation: "To what extent do you visually experience WORD?"), then auditory (in French: "*Dans quelle mesure CE MOT vous fait ressentir une experience auditive?*", English translation: "To what extent do you audibly experience WORD?"). Underneath these questions, a horizontal visual analogue scale was displayed for the ratings. Participants were asked to move the cursor on this uncalibrated line according to their subjective judgment. To estimate the perceptual strength, the left side of the line corresponded to "very low", and the right side, to "very high". The cursor always appeared in the center of the line (equal to 50), and the participant had to give his or her estimation of the strength of his or her experience of the concept represented by the current word by moving the cursor to the left (extreme left coded as 0) or to the right (extreme right coded as 100). In addition, the rating latencies were also recorded. In the present study, we used visual analogue rating scales (VAS) and not Likert scales as used by Connell and Lynott (2010) for two main reasons. Firstly, Likert scales should be considered as ordinal variables. Conversely, VAS are considered continuous variables (e.g. Howell, 1992; Parker, McDaniel, & Crumpton-Young, 2002). Unlike continuous variables, ordinal data preclude or limit the array of possible analyses. Secondly, multiple studies have found advantages of VAS over Likert scales, notably regarding sensitivity and reliability (e.g. Pfennings, Cohen, & van der Ploeg, 1995) and also for other psychometric parameters (e.g. Voutilainen, Pitkaaho, Kvist, & Vehvilainen-Julkunen, 2016).

**Data screening for outliers**

Before proceeding to the statistical analysis, the data were screened for outliers within each session (per participant) and then for each item (across participants). The data of 12 participants were removed due to lack of variability in responses (i.e., the same rating was given for all words in the list, for example, 50 or 100) (Brysbaert, Warriner, & Kuperman, 2014; Chedid et al., 2018).

For further data trimming, the mean and the standard deviation of all the participants' ratings in each list were calculated. Participant mean scores falling outside ±3.5 standard deviations from the group mean of his/her list were excluded in order to attenuate the possible influence of outliers on ratings (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012). Comparable procedures of detection of outliers have been employed in similar studies providing ratings for word databases (Chedid et al., 2018; Lynott & Connell, 2009). After the screening of all the sessions, the data of 24 participants were discarded because the majority of their ratings were spread out around the mean (the overall ratings of 3 participants were under 3.5 SD of the mean ratings of the group of the same list, and 21 participants gave extreme ratings above 3.5 SD compared to other participants' ratings of the same list). Thus, the data obtained from 268 participants were used in the statistical analyses. Each session was evaluated by a mean of 25 participants (minimum raters per session= 20; maximum raters per session= 29).

In addition, response latencies were used as a lower bound criterion below which responses could be considered invalid. Based on previous studies that used the same criterion, visual inspection of the reaction times distribution suggested that response latencies below 300 ms were derived from a distinct distribution and were extracted (Desrochers & Thompson, 2009; Tsaparina, Bonin, & Meot, 2011). Only .0032% of visual and .0027% of auditory perceptual strength samples were discarded (number of ratings lost (± SD), respectively: 92 ± 6; 74 ± 4). To set an upper-bound criterion, the mean reaction time of all answers given for each item was calculated, and a standard deviation of 2.5 was set as a cut-off for delayed responses. On average, .0118% of visual and .0076% of auditory perceptual strength samples were rejected (number of ratings lost (± SD), respectively: 437 ± 8; 266 ± 5).

**Results**

The overall mean of perceptual strength rating for the visual modality was 61.4 (SD=18.0, Min=2.5, Max=94.2) and for the auditory modality was 32.1 (SD=16.1, Min= 0.6, Max= 95.4).

**Intra- and inter-study rating reliability**

Firstly, we measured the internal consistency of the ratings by calculating the split-half reliability coefficient. This coefficient was calculated by splitting the ratings of the participants into two groups according to even and odd participant numbers and by computing a correlation between the even and odd data of each variable separately. If the ratings of the two halves are highly correlated, it means that they provide similar results and, consequently, that the ratings have good internal consistency reliability. The corrected Pearson correlations were significant for both visual perceptual strength, $r$ (3,596) = .779, $p < .001$, and auditory perceptual strength, $r$ (3,596) = .745, $p < .001$, indicating good internal consistency reliability. The good reliability between raters has also been confirmed by a Cronbach's alpha of .875 for visual perceptual strength and of .854 for auditory perceptual strength. The correlation analysis was corrected with the Holm-Bonferroni method for multiple comparisons.

Secondly, we measured response consistency within participants. To that end, we ran a correlation between the responses to the 120 words that received a double rating (the 5 words repeated within each of the 24 sessions). High correlations indicate that participants gave similar ratings to the same word presented twice. Consequently, this is an indicator of good internal reliability. Pearson's correlation between the two responses given for the 120 repeated words across all sessions was computed and showed a strong significant correlation between the first and the second rating of the same words both for visual perceptual strength, $r$ (120) = .968, $p < .001$, and for the auditory perceptual strength, $r$ (120) = .972, $p < .001$. These strong correlations between the ratings of repeated items are associated with excellent internal consistency, with Cronbach's alpha equal to .983 and .984 for visual and auditory ratings on the repeated items, respectively.

Inter-study reliability was calculated by correlating visual and auditory perceptual strength ratings with the perceptual variables already available for French. The only available French variable is sensory experience ratings or SERs (Bonin et al., 2015). We ran inter-study correlations on stimuli common to our database and that of SERs. A significant and positive correlation would provide evidence of convergent validity of our ratings. The results of the correlation analysis showed a significant and positive correlation for the 542 common words for visual perceptual strength, $r$ (542) = .461, $p < .001$, and for auditory perceptual strength, $r$ (542) = .332, $p < .001$ (Table 2).

**Relationship between both modalities**

In order to test the relationship between visual and auditory ratings, we tested the correlation between these two variables. In previous studies on perceptual strength, authors reported a significant negative correlation between visual and auditory perceptual strength (Connell & Lynott, 2012). Consistently, we expected to observe a negative correlation between visual and auditory perceptual ratings. In agreement with our predictions, a negative and significant correlation was observed, $r$ (3,596) = -.61, $p < .001$. This means that weaker visual perceptual strength is generally associated with stronger auditory strength, and vice versa. A significant negative correlation between visual and auditory perceptual strength ratings has been previously reported in English (Connell & Lynott, 2012; Lynott & Connell, 2009). Most objects are multimodal in nature, as revealed by modality exclusivity perceptual strength ratings obtained in previous studies (Lynott & Connell, 2013; Speed & Majid, 2017). Most common objects like "cat" could be identified through both the visual and auditory modalities. This double association may lead participants to evaluate both perceptual strengths as strong. Consistently, the word "chat" (English translation: "cat") was rated 87.1 for visual and 74.9 for auditory. On the other side, highly visual objects, such as "wall", or highly auditory concepts, such as "whistling", are more rarely associated with the other modality. Consistently, the word "mur" (English translation: "wall") was rated 85.4 for visual and 18.7 for auditory, while the word "sifflement" (English translation: "whistling") was rated 36.8 for visual and 87.9 for auditory. Therefore, the most extreme perceptual strengths in one modality should be negatively associated with the other modality. This result is in agreement with Connell and Lynott (2012, 2014), who observed that auditory and visual perceptual ratings were negatively correlated.

## STUDY 2

Visual and auditory perceptual strength ratings are associated with the conceptual dimensions of the words and they are thus considered semantic in nature (Connell & Lynott, 2012; Juhasz & Yap, 2013). The aim of the present study was to establish the relationship between the newly developed visual and auditory perceptual strength ratings and other well-known psycholinguistic semantic variables that have been previously shown to affect word processing (Bonin et al., 2015; Connell & Lynott, 2012; Juhasz & Yap, 2013). We hypothesize a semantic correlation between visual and auditory ratings and other semantic variables like imageability, concreteness, age of acquisition, conceptual familiarity and SERs.

## Methods

The significant association between the visual and auditory perceptual strength scores and other semantic variables was tested using correlations. These semantic variables included concreteness, imageability, conceptual familiarity, age of acquisition and SER. The complete list of variables and the databases used to obtain them are reported in Table 1. Unfortunately, norms for the semantic variables were not always available for all the words included in the present study. Ratings of concreteness for 542 words were taken from Bonin et al. (2018). Imageability ratings for 3,596 words were taken from Desrochers and Thompson (2009). Concept familiarity refers to the degree to which people come in contact with or think about a specific concept. Concept familiarity ratings for 3,596 words were extracted from Chedid et al. (2018). Age of acquisition (AoA) refers to the age at which a word was first learned. The 425 AoA ratings were extracted from Ferrand et al. (2008).

## Results

### *Relationship between visual perceptual strength and other semantic variables*

Table 2 shows the results of the correlation analyses between all variables. We found significant and positive correlations between visual perceptual strength and the other semantic variables: concreteness, $r$ (537) = .763, $p < .001$, imageability, $r$ (3,596) = .862, $p < .001$, concept familiarity, $r$ (3,596) = .544, $p < .001$, SER, $r$ (542) = .461, $p < .001$. The positive correlations indicate that as visual perceptual strength increased, the values of the other semantic variables also increased. This means that stronger visual perceptual strength also meant more imageable, more concrete, more conceptually familiar and stronger perceptual (SER) words. We found a negative correlation for AoA, $r\ (420) = -.558$, $p < .001$. This means that the earlier a word was learned, the stronger is its visual perceptual strength.

***Relationship between auditory perceptual strength and other semantic variables***

Auditory perceptual strength significantly correlated with the five semantic variables: concreteness, $r\ (537) = .100$, $p = .02$, imageability, $r\ (3{,}596) = .182$, $p < .001$, concept familiarity, $r\ (3{,}596) = .298$, $p < .001$, SER, $r\ (542) = .332$, $p < .001$. The positive correlations indicate that as auditory perceptual strength increased, the values of the other semantic variables also increased. In other words, stronger auditory perceptual strength also meant more imageable, more concrete, more conceptually familiar and stronger perceptual (SER) words. We also found a negative correlation for AoA here, $r\ (420) = -.218$, $p < .001$: earlier acquired words tended to be stronger in their auditory perceptual strength. Compared to visual perceptual strength, the correlations for auditory perceptual strength were weaker.

The visual and auditory perceptual strength ratings should be related to the conceptual sensory dimensions of the words and are therefore semantic in nature. It is logical that the perceptual strength of a given concept should also depend on its sensory characteristics, that should in turn be among its conceptual properties. The results showed that visual and auditory perceptual strength strongly correlated with other semantic variables, such as imageability, AoA, concreteness and conceptual familiarity. These correlations with semantic variables confirm that visual and auditory perceptual strength variables index one aspect of the semantic representation of words.

## STUDY 3

Concreteness, imageability and SER ratings refer to sensory and perceptual aspects of concept representation. This could raise the question as to whether our newly developed variables are merely another form of these variables or if they independently contribute to explain the variability in word processing. To address this issue, we conducted a hierarchical regression analysis using lexical decision reactions times (RTs) to determine the contribution of the two newly developed variables over and beyond concreteness, imageability and SER, once controlled for orthographic and lexical variables known to have an impact on lexical decision task (Bonin et al., 2015; Connell & Lynott, 2012; Juhasz et al., 2011). We hypothesize that both visual and auditory perceptual strength will show a significant contribution to lexical decision RTs variability, above and beyond the contribution of other lexical and semantic variables.

### Stepwise regression

We used a stepwise regression analysis to determine the proportion of the variance of reaction times (RTs) in lexical decision that could be explained by concreteness, imageability, SER, and visual and auditory perceptual strength (Connell & Lynott, 2012). We followed previous similar literature (Boukadi, Zouaidi, & Wilson, 2016; Cortese & Khanna, 2007; Cortese & Schock, 2013; Sanchez-Gutierrez, Mailhot, Deacon, & Wilson, 2018) and ran several hierarchical regression models in which each of the two modality-specific perceptual variables (auditory and visual) were added separately in the last step of these regression models. This allows testing the contribution of each of the new variables once the variability of all the other variables entered in the previous step(s) has been controlled for.

We obtained the values for the dependent variable (RTs) from the lexical decision latencies in Ferrand et al. (2010) (http://brm.psychonomic-journals.org/content/supplemental). As control variables, we extracted the values of the following orthographic and lexical psycholinguistic variables for the 3,596 nouns from the French online database Lexique (New, Pallier, Brysbaert, & Ferrand, 2004) (www.lexique.org): word length in number of syllables (N-syllables; e.g., concept = 2); objective lexical frequency calculated from books (FreqBooks) (e.g., concept = 7.63 occurrences per million); and orthographic Levenshtein distance 20 (OLD20) (i.e. the minimum number of insertions, deletions, and substitution required to turn one word into the 20 nearest neighbors) (Yarkoni, Balota, & Yap, 2008). We also obtained the values for subjective frequency from Desrochers and Thompson (2009). There were large differences in the amount of overlap between the words in our database and those present in databases for which ratings of concreteness (537), SER (538) and imageability (3,124) were available. Thus, we ran six separate regression models for each of the variables (see Table 3).

In the first model, we entered the lexical and orthographic variables (i.e., N-syllables, FreqBooks, OLD20 and subjective frequency), imageability and auditory perceptual strength in the first step. We entered visual perceptual strength in the second step. In the second model, we entered visual perceptual strength in step 1 and auditory perceptual strength in the step 2. These models would allow to test the contribution of each of the two modality-specific perceptual variables above the contribution of the semantic variable of imageability in the prediction of lexical decision RTs.

In the third model, we entered the lexical variables, concreteness and auditory perceptual strength in step 1. We entered visual perceptual strength in step 2. In the fourth model, we entered visual perceptual strength in step 1 and auditory perceptual strength in the step 2. These models would allow to determine the contribution of each of the two modality-specific perceptual variables above that of the semantic variable of concreteness in the prediction of lexical decision RTs.

In the fifth model, we entered the lexical variables, SER and auditory perceptual strength in step 1. In the sixth model, we entered visual perceptual strength in step 1 and auditory perceptual strength in the step 2. These models would allow to determine the contribution of each of the two-modality specific perceptual variables above the contribution of the more general semantic variable SER in the prediction of lexical decision RTs.

**Results**

Table 3 shows the standardized regression coefficients of the six models used in Study 3. In the first and second models (all tolerance values > 0.2 and VIF values < 4), we observed a significant contribution of visual perceptual strength, $F$ (3124) = 36.94, $p < .001$, $R^2 = .007$, and auditory perceptual strength, $F$ (3124) = 15.44, $p < .001$, $R^2 = .003$, to lexical decision RTs. This contribution was beyond that of imageability. In the third and fourth models (all tolerance values > 0.3 and VIF values < 3), both visual and auditory perceptual strength significantly contributed to explain the variance in lexical decision RTs beyond the contribution of concreteness (visual: $F(537) = 15.24$, $p < .001$, $R^2 = .017$; auditory: $F(537) = 5.27$, $p = .022$, $R^2 = .006$). In the fifth and sixth models (all tolerance values > 0.5 and VIF values < 2), we found a significant contribution of visual perceptual strength above that of SER, $F(537) = 4.28$, $p = .039$, $R^2 = .005$. Nevertheless, auditory perceptual strength did not significantly contribute to explain RTs decisions, $F(537) =$ 2.56, $p = .110$, $R^2 = .003$. In conclusion, these results demonstrated for the first time in French the critical role of the visual and auditory perceptual strength evoked by a word, above and beyond the contribution of other semantic variables such as imageability, concreteness and SERs.

**Discussion**

This study provided ratings for 3,596 French nouns for two semantic variables that are based on the perceptual experience of individuals: visual and auditory perceptual strength. The intra-study reliability analysis showed that our new ratings were reliable between raters. The inter-study reliability analysis revealed that our ratings were consistent with those contained in the French database by Bonin et al. (2015). Bonin et al. collected ratings for a more general sensory experience variable, i.e., sensory experience ratings (SER) (Bonin et al., 2015). Thus, we produced reliable norms for two specific modalities, visual and auditory, of perceptual strength in French. These are freely available at http://lingualab.ca/en/projects/norms-of-visualperceptualstrength and http://lingualab.ca/en/projects/norms-of-auditoryperceptualstrength. In addition, our study provided critical evidence that visual and auditory perceptual strength are not mere by-products of other semantic variables related to the perceptual experience evoked by a concept, such as concreteness, imageability and SER. In fact, we demonstrated that visual and auditory perceptual strength contribute to lexical decision latencies during word processing over and beyond the contribution of concreteness, imageability and SER. This result confirms previous findings obtained in English (Connell & Lynott, 2012) and highlights the key role of perceptual experience in semantics. According to Bonin et al. (2015), high visual scores are attributed to more-imageable words and to an earlier age of acquisition of the word. In our Study 2, we reproduced these results. Indeed, the association between visual perceptual strength and imageability stresses the richness of conceptual representations. Both perceptual strength and imageability are thought to be subjective semantic variables as they are based on the personal experiences and knowledge of the individual. On the other hand, AoA is also considered to have a semantic component as it affects lexical decisions and word naming (Brysbaert & Ghyselinck, 2006; Cuetos & Barbón, 2006; Davies, Wilson, Cuetos, & Burani, 2014; Ghyselinck, Lewis, & Brysbaert, 2004; Wilson, Cuetos, Davies, & Burani, 2013). Accordingly, we found that the earlier a word is learned, the stronger its visual perceptual strength. Visual perceptual strength was strongly associated with imageability, suggesting that visual perceptual strength and imageability share some semantic visual/imageable representations. The association between visual perceptual strength and concreteness, such as the one we found here, has been explained in terms of the verbal and imagistic representations of concepts (Crutch et al., 2009; Crutch & Warrington, 2005; Holcomb et al., 1999; Jessen et al., 2000). It has been demonstrated that concrete concepts have more direct connections to imagistic representations, whereas abstract concepts have only indirect connections to images via other verbal codes (Binder et al., 2005; Crutch et al., 2009; Crutch & Warrington, 2005).

On the other hand, auditory perceptual strength was weakly related to other semantic variables. This is not surprising. The instructions used to obtain concreteness ratings do not explicitly mention that the raters should consider any sensory experience as a form of concreteness. On the other side, the instructions used to obtain imageability ratings explicitly mention that raters should mainly rely on the 'mental image' aroused by the word. These instructions are likely to create a bias towards the visual perceptual modality. This would explain the results of Study 2 for auditory perceptual strength. Indeed, the association between imageability and auditory perceptual strength ratings was weaker that the one found for visual perceptual strength and imageability. The same pattern was observed for concreteness. Taken together, these results appear to support the view that concreteness and imageability ratings mainly capture the visual aspects of sensory experience, confirming the previous findings (Bonin et al., 2015; Juhasz & Yap, 2013). Moreover, the relationship between the two modalities, visual and auditory, confirm the multimodality of noun concepts. Strongly auditory nouns frequently refer to things that can also be seen (e.g., *chanteuse* (singer): visual = 72.5, auditory = 77) (Lynott & Connell, 2013). Although the vast majority of noun concepts in our sample were visually dominant, the correlation analysis indicated that many of these words also had high auditory perceptual strength, and should therefore be characterized as bimodal (e.g., *ambulance*: visual = 89.40, auditory = 87.14).

Why should future research use these new semantic variables related to perceptual strength? What is the added value of visual and auditory perceptual strength compared to concreteness and imageability, the two most widely used semantic variables? The results of Study 3 showed that visual and auditory perceptual strength have a role beyond that of concreteness and imageability in the explanation of lexical decision RTs. This effect was already reported in an English-language study by Connell and Lynott (2012). However, it must be noted that they used a similar but slightly different perceptual strength variable, i.e., the strength in the dominant perceptual modality of a concept (maximum perceptual strength) as a measure of perceptual strength. Regarding SER, another semantic variable related to the perceptual experience, visual perceptual strength increased the percentage of explained variance in lexical decision RTs, while auditory perceptual strength did not. The significant result for visual perceptual strength is extremely important because it shows that a modality-specific perceptual strength could significantly increase the explained variance of lexical decision RTs when added to a general perceptual rating score (SER). The absence of a significant effect produced by auditory perceptual strength could be due to different factors. Firstly, the analysis was run on a small subset of words of our database since SER ratings were available for only 542 words. Secondly, another possible explanation may come from the distribution of these 542 words in terms of their visual and auditory properties. To test this hypothesis, we conducted a cluster analysis (see Supplementary data) to determine whether there were different patterns of words in our database based on their visual and auditory perceptual strength ratings. The results of the cluster analysis showed that the words were distributed in three clusters. Cluster 1 (n = 787) included words with high visual and low auditory perceptual strength. Cluster 2 (n = 1,283) regrouped the words with weak visual and auditory perceptual strength. Finally, Cluster 3 (n = 1,061) was composed of words with strong visual but weak auditory perceptual strength. These results are congruent with those of other studies that found that visual and haptic modalities tend to be grouped together, and the auditory modality was not included in either groups (Lynott & Connell, 2013; Tsaparina et al., 2011). If we consider the subset of 542 words with SER ratings, 445 words (82% of the total) belonged to Cluster 1 (i.e., high visual and low auditory perceptual strength). Thus, the fact that the great majority of the words included in the database by Bonin and colleagues for SERs had low auditory perceptual strength could partly explain why auditory perceptual strength did not increase the percentage of the prediction of lexical decision RTs. Future studies on a larger database including concepts more grounded in auditory features would help to better understand the role of auditory perceptual strength in word processing

This study represents a first necessary step to provide French Canadian norms of perceptual strength in the most studied perceptual modalities (i.e. visual and auditory). Our results showed the critical role of these variables for word processing. This highlights the importance of further collecting norms for the other three perceptual modalities (olfactory, gustatory and haptic). Future studies should address this issue.

One limitation of our study concerns the fact that participants could not say if they did not know a word they had to rate. Notwithstanding, and according to the available French Canadian familiarity ratings, none of these words were of extremely low familiarity to the raters (Chedid et al., 2018). This suggests that most participants might have known these words. However, we cannot rule out the possibility that words that received low ratings on perceptual strength for both modalities were indeed unknown to certain participants.

In conclusion, our results confirm and expand upon previous findings that demonstrate that visual and auditory perceptual strength ratings cannot be considered another form of concreteness, imageability or SER since visual and auditory perceptual strength make independent contributions to the prediction of latencies in word processing. These findings are in line with grounded cognition models, indicating the importance of perceptual experience in concept representation. Further studies should be carried out to test the specific impact of these variables on word processing. We are confident that the new ratings of visual and auditory perceptual strength for the large set of French nouns that we presented here will help enable new studies to investigate the role of perceptual experience on the representation of concepts.

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## References

Alario, F. X., & Ferrand, L. (1999). A set of 400 pictures standardized for French: norms for name agreement, image agreement, familiarity, visual complexity, image variability, and age of acquisition. *Behav Res Methods Instrum Comput, 31*(3), 531-552.

Allen, R., & Hulme, C. (2006). Speech and language processing mechanisms in verbal serial recall. *Journal of Memory and Language, 55*(1), 64-88. doi:10.1016/j.jml.2006.02.002

Barros-Loscertales, A., Gonzalez, J., Pulvermuller, F., Ventura-Campos, N., Bustamante, J. C., Costumero, V., . . . Avila, C. (2012). Reading salt activates gustatory brain regions: fMRI evidence for semantic grounding in a novel sensory modality. *Cereb Cortex, 22*(11), 2554-2563. doi:10.1093/cercor/bhr324

Barsalou, L. W. (1999). Perceptual symbol systems. *Behav Brain Sci, 22*(4), 577-609; discussion 610-560.

Barsalou, L. W. (2008). Grounded cognition. *Annu Rev Psychol, 59*, 617-645. doi:10.1146/annurev.psych.59.103006.093639

Beau, S., & Rey, A. (2015). Github repository, https://github.com/sebastienbeau/aphrodite-survey.

Binder, J. R., & Desai, R. H. (2011). The neurobiology of semantic memory. *Trends Cogn Sci, 15*(11), 527-536. doi:10.1016/j.tics.2011.10.001

Binder, J. R., Westbury, C. F., McKiernan, K. A., Possing, E. T., & Medler, D. A. (2005). Distinct brain systems for processing concrete and abstract concepts. *J Cogn Neurosci, 17*(6), 905-917.

Bonin, P., Meot, A., & Bugaiska, A. (2018). Concreteness norms for 1,659 French words: Relationships with other psycholinguistic variables and word recognition times. *Behav Res Methods*. doi:10.3758/s13428-018-1014-y

Bonin, P., Meot, A., Ferrand, L., & Bugaiska, A. (2015). Sensory experience ratings (SERs) for 1,659 French words: Relationships with other psycholinguistic variables and visual word recognition. *Behav Res Methods, 47*(3), 813-825. doi:10.3758/s13428-014-0503-x

Bonin, P., Peereman, R., Malardier, N., Meot, A., & Chalard, M. (2003). A new set of 299 pictures for psycholinguistic studies: French norms for name agreement, image agreement, conceptual familiarity, visual complexity, image variability, age of acquisition, and naming latencies. *Behav Res Methods Instrum Comput, 35*(1), 158-167.

Borghi, A. M., & Riggio, L. (2015). Stable and variable affordances are both automatic and flexible. *Front Hum Neurosci, 9*, 351. doi:10.3389/fnhum.2015.00351

Boukadi, M., Zouaidi, C., & Wilson, M. A. (2016). Norms for name agreement, familiarity, subjective frequency, and imageability for 348 object names in Tunisian Arabic. *Behav Res Methods, 48*(2), 585-599. doi:10.3758/s13428-015-0602-3

Brysbaert, & Ghyselinck, M. (2006). The effect of age of acquisition: Partly frequency related, partly frequency independent. *Visual Cognition, 13*(7-8), 992-1011. doi:10.1080/13506280544000165

Brysbaert, Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. *Behav Res Methods, 46*(3), 904-911. doi:10.3758/s13428-013-0403-5

Chedid, G., Wilson, M. A., Bedetti, C., Rey, A. E., Vallet, G. T., & Brambati, S. M. (2018). Norms of conceptual familiarity for 3,596 French nouns and their contribution in lexical decision. *Behav Res Methods*. doi:10.3758/s13428-018-1106-8

Connell, L., & Lynott, D. (2010). Look but don't touch: Tactile disadvantage in processing modality-specific words. *Cognition, 115*(1), 1-9. doi:10.1016/j.cognition.2009.10.005

Connell, L., & Lynott, D. (2012). Strength of perceptual experience predicts word processing performance better than concreteness or imageability. *Cognition, 125*(3), 452-465. doi:10.1016/j.cognition.2012.07.010

Connell, L., & Lynott, D. (2014). I see/hear what you mean: semantic activation in visual word recognition depends on perceptual attention. *J Exp Psychol Gen, 143*(2), 527-533. doi:10.1037/a0034626

Cortese, M. J., & Khanna, M. M. (2007). Age of acquisition predicts naming and lexical-decision performance above and beyond 22 other predictor variables: an analysis of 2,342 words. *Q J Exp Psychol (Hove), 60*(8), 1072-1082. doi:10.1080/17470210701315467

Cortese, M. J., & Schock, J. (2013). Imageability and age of acquisition effects in disyllabic word recognition. *Q J Exp Psychol (Hove), 66*(5), 946-972. doi:10.1080/17470218.2012.722660

Crutch, S. J., Connell, S., & Warrington, E. K. (2009). The different representational frameworks underpinning abstract and concrete knowledge: evidence from odd-one-out judgements. *Q J Exp Psychol (Hove), 62*(7), 1377-1388, 1388-1390. doi:10.1080/17470210802483834

Crutch, S. J., & Warrington, E. K. (2005). Abstract and concrete concepts have structurally different representational frameworks. *Brain, 128*(Pt 3), 615-627. doi:10.1093/brain/awh349

Cuetos, F., & Barbón, A. (2006). Word naming in Spanish. *European Journal of Cognitive Psychology, 18*(3), 415-436. doi:10.1080/13594320500165896

Davies, R., Wilson, M., Cuetos, F., & Burani, C. (2014). Reading in Spanish and Italian: effects of age of acquisition in transparent orthographies? *Q J Exp Psychol (Hove), 67*(9), 1808-1825. doi:10.1080/17470218.2013.872155

Desrochers, A., & Thompson, G. L. (2009). Subjective frequency and imageability ratings for 3,600 French nouns. *Behav Res Methods, 41*(2), 546-557. doi:10.3758/BRM.41.2.546

Ernst, M. O., & Bulthoff, H. H. (2004). Merging the senses into a robust percept. *Trends Cogn Sci, 8*(4), 162-169. doi:10.1016/j.tics.2004.02.002

Ferrand, L., Bonin, P., Meot, A., Augustinova, M., New, B., Pallier, C., & Brysbaert, M. (2008). Age-of-acquisition and subjective frequency estimates for all generally known monosyllabic French words and their relation with other psycholinguistic variables. *Behav Res Methods, 40*(4), 1049-1054. doi:10.3758/BRM.40.4.1049

Ferrand, L., New, B., Brysbaert, M., Keuleers, E., Bonin, P., Meot, A., . . . Pallier, C. (2010). The French Lexicon Project: lexical decision data for 38,840 French words and 38,840 pseudowords. *Behav Res Methods, 42*(2), 488-496. doi:10.3758/BRM.42.2.488

Fliessbach, K., Weis, S., Klaver, P., Elger, C. E., & Weber, B. (2006). The effect of word concreteness on recognition memory. *Neuroimage, 32*(3), 1413-1421. doi:10.1016/j.neuroimage.2006.06.007

Gardner, E., & Martin, J. (2019). *Coding of Sensory Information*.

Ghyselinck, M., Lewis, M. B., & Brysbaert, M. (2004). Age of acquisition and the cumulative-frequency hypothesis: a review of the literature and a new multi-task investigation. *Acta Psychol (Amst), 115*(1), 43-67.

Glasser, M. F., Coalson, T. S., Robinson, E. C., Hacker, C. D., Harwell, J., Yacoub, E., . . . Van Essen, D. C. (2016). A multi-modal parcellation of human cerebral cortex. *Nature, 536*(7615), 171-178. doi:10.1038/nature18933

Glenberg, A. M., Witt, J. K., & Metcalfe, J. (2013). From the Revolution to Embodiment: 25 Years of Cognitive Psychology. *Perspect Psychol Sci, 8*(5), 573-585. doi:10.1177/1745691613498098

Goldberg, R. F., Perfetti, C. A., & Schneider, W. (2006). Perceptual knowledge retrieval activates sensory brain regions. *J Neurosci, 26*(18), 4917-4921. doi:10.1523/JNEUROSCI.5389-05.2006

Gonzalez, J., Barros-Loscertales, A., Pulvermuller, F., Meseguer, V., Sanjuan, A., Belloch, V., & Avila, C. (2006). Reading cinnamon activates olfactory brain regions. *Neuroimage, 32*(2), 906-912. doi:10.1016/j.neuroimage.2006.03.037

Grush, R. (2004). The emulation theory of representation: motor control, imagery, and perception. *Behav Brain Sci, 27*(3), 377-396; discussion 396-442.

Hecht, D., & Reiner, M. (2009). Sensory dominance in combinations of audio, visual and haptic stimuli. *Exp Brain Res, 193*(2), 307-314. doi:10.1007/s00221-008-1626-z

Holcomb, P. J., Kounios, J., Anderson, J. E., & West, W. C. (1999). Dual-coding, context-availability, and concreteness effects in sentence comprehension: an electrophysiological investigation. *J Exp Psychol Learn Mem Cogn, 25*(3), 721-742.

Howell, D. C. (1992). *Statistical methods for psychology, 3rd ed*. Boston, MA, US: PWS-Kent Publishing Co.

Jessen, F., Heun, R., Erb, M., Granath, D. O., Klose, U., Papassotiropoulos, A., & Grodd, W. (2000). The concreteness effect: evidence for dual coding and context availability. *Brain Lang, 74*(1), 103-112. doi:10.1006/brln.2000.2340

Juhasz, B. J., Lai, Y. H., & Woodcock, M. L. (2015). A database of 629 English compound words: ratings of familiarity, lexeme meaning dominance, semantic transparency, age of acquisition, imageability, and sensory experience. *Behav Res Methods, 47*(4), 1004-1019. doi:10.3758/s13428-014-0523-6

Juhasz, B. J., & Yap, M. J. (2013). Sensory experience ratings for over 5,000 mono- and disyllabic words. *Behav Res Methods, 45*(1), 160-168. doi:10.3758/s13428-012-0242-9

Juhasz, B. J., Yap, M. J., Dicke, J., Taylor, S. C., & Gullick, M. M. (2011). Tangible words are recognized faster: the grounding of meaning in sensory and perceptual systems. *Q J Exp Psychol (Hove), 64*(9), 1683-1691. doi:10.1080/17470218.2011.605150

Kaschak, M. P., Zwaan, R. A., Aveyard, M., & Yaxley, R. H. (2006). Perception of auditory motion affects language processing. *Cogn Sci, 30*(4), 733-744. doi:10.1207/s15516709cog0000_54

Keetels, M., & Vroomen, J. (2012). Perception of Synchrony between the Senses. In M. M. Murray & M. T. Wallace (Eds.), *The Neural Bases of Multisensory Processes*. Boca Raton (FL).

Kiefer, M., Sim, E. J., Herrnberger, B., Grothe, J., & Hoenig, K. (2008). The sound of concepts: four markers for a link between auditory and conceptual brain systems. *J Neurosci, 28*(47), 12224-12230. doi:10.1523/JNEUROSCI.3579-08.2008

Kuperman, V., Stadthagen-Gonzalez, H., & Brysbaert, M. (2012). Age-of-acquisition ratings for 30,000 English words. *Behav Res Methods, 44*(4), 978-990. doi:10.3758/s13428-012-0210-4

Lynott, D., & Connell, L. (2009). Modality exclusivity norms for 423 object properties. *Behav Res Methods, 41*(2), 558-564. doi:10.3758/BRM.41.2.558

Lynott, D., & Connell, L. (2013). Modality exclusivity norms for 400 nouns: the relationship between perceptual experience and surface word form. *Behav Res Methods, 45*(2), 516-526. doi:10.3758/s13428-012-0267-0

Martin, A. (2007). The representation of object concepts in the brain. *Annu Rev Psychol, 58*, 25-45. doi:10.1146/annurev.psych.57.102904.190143

Meteyard, L., Cuadrado, S. R., Bahrami, B., & Vigliocco, G. (2012). Coming of age: a review of embodiment and the neuroscience of semantics. *Cortex, 48*(7), 788-804. doi:10.1016/j.cortex.2010.11.002

New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). Lexique 2: a new French lexical database. *Behav Res Methods Instrum Comput, 36*(3), 516-524.

Paivio, A. (2013). Dual coding theory, word abstractness, and emotion: a critical review of Kousta et al. (2011). *J Exp Psychol Gen, 142*(1), 282-287. doi:10.1037/a0027004

Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. *J Exp Psychol, 76*(1), Suppl:1-25.

Paivio, A., Yuille, J. C., & Smythe, P. C. (1966). Stimulus and response abstractness, imagery, and meaningfulness, and reported mediators in paired-associate learning. *Can J Psychol, 20*(4), 362-377.

Parker, P. L., McDaniel, H. S., & Crumpton-Young, L. L. (2002). Do Research Participants Give Interval or Ordinal Answers In Response to Likert Scales? *In IIE Annual Conference. Proceedings (p. 1). Institute of Industrial and Systems Engineers (IISE).*

Pfennings, L., Cohen, L., & van der Ploeg, H. (1995). Preconditions for sensitivity in measuring change: visual analogue scales compared to rating scales in a Likert format. *Psychol Rep, 77*(2), 475-480. doi:10.2466/pr0.1995.77.2.475

Rey, A. E., Riou, B., Vallet, G. T., & Versace, R. (2017). The automatic visual simulation of words: A memory reactivated mask slows down conceptual access. *Can J Exp Psychol, 71*(1), 14-22. doi:10.1037/cep0000100

Romani, C., McAlpine, S., & Martin, R. C. (2008). Concreteness effects in different tasks: implications for models of short-term memory. *Q J Exp Psychol (Hove), 61*(2), 292-323. doi:10.1080/17470210601147747

Sabsevitz, D. S., Medler, D. A., Seidenberg, M., & Binder, J. R. (2005). Modulation of the semantic system by word imageability. *Neuroimage, 27*(1), 188-200. doi:10.1016/j.neuroimage.2005.04.012

Sanchez-Gutierrez, C. H., Mailhot, H., Deacon, S. H., & Wilson, M. A. (2018). MorphoLex: A derivational morphological database for 70,000 English words. *Behav Res Methods, 50*(4), 1568-1580. doi:10.3758/s13428-017-0981-8

Sanfeliu, M. C., & Fernandez, A. (1996). A set of 254 Snodgrass-Vanderwart pictures standardized for Spanish: Norms for name agreement, image agreement, familiarity, and visual complexity. *Behavior Research Methods, Instruments, & Computers, 28*(4), 537-555. doi:10.3758/bf03200541

Simmons, W. K., Ramjee, V., Beauchamp, M. S., McRae, K., Martin, A., & Barsalou, L. W. (2007). A common neural substrate for perceiving and knowing about color. *Neuropsychologia, 45*(12), 2802-2810. doi:10.1016/j.neuropsychologia.2007.05.002

Sirois, M., Kremin, H., & Cohen, H. (2006). Picture-naming norms for Canadian French: name agreement, familiarity, visual complexity, and age of acquisition. *Behav Res Methods, 38*(2), 300-306.

Speed, L. J., & Majid, A. (2017). Dutch modality exclusivity norms: Simulating perceptual modality in space. *Behav Res Methods, 49*(6), 2204-2218. doi:10.3758/s13428-017-0852-3

Tsaparina, D., Bonin, P., & Meot, A. (2011). Russian norms for name agreement, image agreement for the colorized version of the Snodgrass and Vanderwart pictures and age of acquisition, conceptual familiarity, and imageability scores for modal object names. *Behav Res Methods, 43*(4), 1085-1099. doi:10.3758/s13428-011-0121-9

Vallet, Brunel, L., & Versace, R. (2010). The perceptual nature of the cross-modal priming effect: arguments in favor of a sensory-based conception of memory. *Exp Psychol, 57*(5), 376-382. doi:10.1027/1618-3169/a000045

Vallet, Simard, M., Versace, R., & Mazza, S. (2013). The perceptual nature of audiovisual interactions for semantic knowledge in young and elderly adults. *Acta Psychol (Amst), 143*(3), 253-260. doi:10.1016/j.actpsy.2013.04.009

van Dantzig, S., Cowell, R. A., Zeelenberg, R., & Pecher, D. (2011). A sharp image or a sharp knife: norms for the modality-exclusivity of 774 concept-property items. *Behav Res Methods, 43*(1), 145-154. doi:10.3758/s13428-010-0038-8

Van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2008). Perceptual processing affects conceptual processing. *Cogn Sci, 32*(3), 579-590. doi:10.1080/03640210802035365

Versace, R., Vallet, G. T., Riou, B., Lesourd, M., Labeye, É., & Brunel, L. (2014). Act-In: An integrated view of memory mechanisms. *Journal of Cognitive Psychology, 26*(3), 280-306. doi:10.1080/20445911.2014.892113

Voutilainen, A., Pitkaaho, T., Kvist, T., & Vehvilainen-Julkunen, K. (2016). How to ask about patient satisfaction? The visual analogue scale is less vulnerable to confounding factors and ceiling effect than a symmetric Likert scale. *J Adv Nurs, 72*(4), 946-957. doi:10.1111/jan.12875

Wilson, M. A., Cuetos, F., Davies, R., & Burani, C. (2013). Revisiting age-of-acquisition effects in Spanish visual word recognition: the role of item imageability. *J Exp Psychol Learn Mem Cogn, 39*(6), 1842-1859. doi:10.1037/a0033090

Winter, B. (2016). Taste and smell words form an affectively loaded and emotionally flexible part of the English lexicon. *Language, Cognition and Neuroscience, 31*(8), 975-988. doi:10.1080/23273798.2016.1193619

Yarkoni, T., Balota, D., & Yap, M. (2008). Moving beyond Coltheart's N: a new measure of orthographic similarity. *Psychon Bull Rev, 15*(5), 971-979. doi:10.3758/PBR.15.5.971

Table 1. Sources and number of words, as well as the means and standard deviations, minimums and maximums for the psycholinguistic variables used in Studies 2 and 3.

| | Code | Source | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|---|
| ***Orthographic variables*** | | | | | | | |
| Number of syllables | N-syllables | Ferrand et al, 2010 | 3576 | 2.36 | 0.95 | 1 | 6 |
| Orthographic Levenshtein Distance | OLD20 | Yarkoni et al, 2008 | 3576 | 2.21 | 0.67 | 1 | 6.35 |
| ***Lexical variables*** | | | | | | | |
| Word frequency in books | FreqBooks | Lexique 3 | 3576 | 19.25 | 93.34 | 0.00 | 4696.15 |
| Subjective Frequency | Subjective frequency | Desrochers et al, 2009 | 3596 | 3.56 | 1.12 | 1.07 | 6.45 |
| ***Semantic variables*** | | | | | | | |
| Imageability | Imageability | Desrochers et al, 2009 | 3596 | 4.15 | 1.50 | 1.08 | 7.00 |
| Concept Familiarity | Concept Familiarity | Chedid et al, 2018 | 3596 | 81.48 | 16.07 | 4.50 | 98.57 |
| Concreteness | CONC | Bonin et al, 2018 | 537 | 3.97 | 0.94 | 3.97 | 5.00 |
| Age of acquisition | AoA | Ferrand et al, 2008 | 420 | 7.21 | 2.14 | 3.57 | 14.05 |
| Sensory experience ratings | SER | Bonin et al, 2015 | 542 | 3.39 | .97 | 1.27 | 6.13 |

Table 2. Correlation values for visual and auditory perceptual strength and the semantic variables of Study 2.

| Variables | Visual Perceptual Strength | Auditory Perceptual Strength |
|---|---|---|
| Imageability | .862** | .182** |
| Concept familiarity | .544** | .298** |
| Concreteness | .763** | .100* |
| Age of acquisition | -.558** | -.218** |
| Sensory experience ratings | .461** | .332** |

* the correlation is significant at the .05 level
** the correlation is significant at the .01 level

Table 3. Hierarchical regression coefficients models for lexical decision RTs in study 3.

| Step | | β | $R^2$ | $\Delta R^2$ | *Sig. F Change* |
|---|---|---|---|---|---|
| Model 1 | | | | | |
| Step 1 | Imageability, auditory perceptual strength, FreqBooks, Nsyllables, Old20, Subjective frequency | | .409 | .409 | .000 |
| Step 2 | Visual perceptual strength | -.154 | .416 | .007** | .000 |
| Model 2 | | | | | |
| Step 1 | Imageability, visual perceptual strength, FreqBooks, Nsyllables, Old20, Subjective frequency | | .413 | .413 | .000 |
| Step 2 | Auditory perceptual strength | -.055 | .416 | .003** | .000 |
| Model 3 | | | | | |
| Step 1 | Concreteness, auditory perceptual strength, FreqBooks, Nsyllables, Old20, Subjective frequency | | .411 | .411 | .000 |
| Step 2 | Visual perceptual strength | -.225 | .427 | .017** | .000 |
| Model 4 | | | | | |
| Step 1 | Concreteness, visual perceptual strength, FreqBooks, Nsyllables, Old20, Subjective frequency | | .421 | .421 | .000 |
| Step 2 | Auditory perceptual strength | -.078 | .427 | .006* | .022 |
| Model 5 | | | | | |
| Step 1 | SER, auditory perceptual strength, FreqBooks, Nsyllables, Old20, Subjective frequency | | .425 | .425 | .000 |
| Step 2 | Visual perceptual strength | -.081 | .429 | .005* | .039 |
| Model 6 | | | | | |
| Step 1 | SER, visual perceptual strength, FreqBooks, Nsyllables, Old20, Subjective frequency | | .427 | .427 | .000 |
| Step 2 | Auditory perceptual strength | -.056 | .429 | .003 | .110 |

Note: Models include lexical variables and a semantic predictor (i.e., imageability, concreteness and SER) in the first step. Visual and auditory perceptual strength were entered in the first and second steps in different models. $\Delta R^2$ is the incremental increase in the model $R^2$ that results from the addition of a predictor or set of predictors in a new step of the model.

$*p < .05$ $**p < .01$