Presentation Modality in Age of Acquisition Rating Reflects Mode of Acquired Knowledge: Evidence from Category-Specific Effects

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Abstract

It has been argued that semantic information is distributed across various types of knowledge domains reflecting the manner in which information was acquired. We analyzed the influence of several common picture naming and word naming predictors across two categories: animals and tools/manipulable objects. However, in the regression analyses we used as additional predictors three different measures of age of acquisition which can be seen as associated with different types of knowledge acquisition (verbal and sensory-motor). The results show that motor information is important for tool and manipulable object processing, and that verbal but not sensory-motor information influences the picture naming of animals. Word naming processing was not influenced by any of the three AoA measures. The results are consistent with the view that the mode of knowledge acquisition is an important part of the semantic representation of an object and its development.

Keywords: object naming; word naming; category; age of acquisition; semantic knowledge representation.

Introduction

A central issue in cognitive neuroscience concerns the organization of semantic memory, and in particular, how different semantic categories are represented. Numerous neuropsychological studies have shown the so-called "semantic-category specific deficit", that is, a dissociation in cognitive performance for living and non-living things (see Gainotti, Silveri, Daniele, & Giustolisi, 1995; Caramazza & Shelton, 1998; Gainotti, 2004). Recently, the semantic category effect has been studied in non-impaired populations, too (e.g., Coppens & Frisinger, 2005; Filliter, McMullen, & Westwood, 2005; McMullen & Purdy, 2006). Typically, it is observed that both brain-damaged and brain-intact individuals are slower and less accurate at naming living objects than non-living. Two main accounts have been proposed on how semantic knowledge is organized in our brain: a domain-specific theory (Caramazza, & Shelton, 1998) and a sensory-functional theory (Warrington & Shallice, 1984; Saffran, 2000). The domain-specific view argues that there are separate, genetically based neural substrates for the processing of animate and inanimate things (Caramazza, & Shelton, 1998). In contrast, the sensory-functional account emphasizes the importance of sensory-motor characteristics in our semantic representations, in particular, the account postulates distributed differential weighting for functional and visual/sensory properties in the representation of living and non-living things (Saffran, 2000). It assumes that functional properties are more strongly weighted in the representation of non-living things and that visual properties such as shape, color, and texture, are more strongly weighted in the representation of living things (for neuropsychological and neuroimaging support, see Gainotti, 2004; Vitali et al., 2005). Furthermore, the account argues that this differentially distributed information reflects the means by which the information was acquired and typical experience with a particular object. The experiential differences are reflected in the distribution manner across sensory, motor, and verbal domains (Saffran, Coslett & Keener, 2003). Thus, knowledge of animate objects is obtained and experienced mainly visually and verbally (at least, for most animals and most urban populations), while knowledge of inanimate objects, specifically, of inanimate manipulable objects – mainly through motor-based information.

Recent research suggests that the manipulability of objects plays a central role in man-made object representation and is strongly connected to action knowledge of object utilization, for instance, neuroimaging studies show that passive observation, naming, categorization of tools and manipulable objects, and generation of tool names activates areas associated with motor functions (e.g., Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Gerlach, Law, & Paulson, 2002; Vitali et al., 2005).

Furthermore, an object and action processing study on aphasics and normals (Arévalo et al., 2007) suggested that manipulability as an object characteristic may contain more important (weighted) sensory-motor cortex-based distinctions than the well-known noun-verb distinction.

The present study investigates the role of the mode of acquired knowledge in category processing in two tasks (picture naming and word naming) and across two categories (animals and tools/manipulable objects). Assuming that visual word and pictorial stimuli are processed via different access routes (Koivisto & Revonsuo, 2003) and/or access different types of information, i.e., pictures access more conceptual, sensory-motor representations while words – more verbal ones (Saffran et al., 2003), we reasoned that different presentation modalities (visual, auditory, and pictorial) in subjective ratings of age of word/concept acquisition (AoA) would activate verbal and sensory-motor representations congruent with the modality and may thus reflect the mode of acquisition of a word or a concept in addition to providing information on AoA itself (for a similar account, see Yamazaki, Ellis, Morrison & Lambon Ralph, 1997).

The AoA effect on picture and word processing is widely documented (for a review, see Juhasz, 2005): words and pictures with early AoA are processed faster than words and pictures with later AoA. AoA is one of the most powerful predictors in picture naming, and to a lesser extent, in word naming (Juhasz, 2005).

Models of picture naming postulate at least three distinct processing stages – object recognition/identification, name activation, and response production (Johnson, Paivio & Clark, 1996). It is argued that picture naming processing necessarily requires meaning activation — picture naming data support this assumption showing that the processing is usually strongly affected by semantic variables while word naming is usually affected more by word-form properties such as word length and word frequency (Arévalo et al., 2007).

We have used the reaction time (RT) data from a picture naming norming study (Szekely et al., 2004) and from word naming of the dominant responses of pictures, identified subsets of animals and tools in the data base, and conducted multiple regression analyses on the RTs of the two tasks across the two categories. We reasoned that if different modalities of AoA ratings reflect somehow the mode of acquisition then this information would also be reflected in the analyses, in particular, the AoA measure that contains more (sensory)-motor information (in the pictorial modality) would contribute to the RT variance of tools' picture naming while the AoA measures that contain more verbal information (in the visual and auditory modalities), would not (according to the sensory-functional account, Saffran et al., 2003). Similarly, AoA with more verbal information (and, possibly, AoA with sensory-(motor) information) would contribute to animals' picture naming. As far as word naming is concerned, we hypothesized that since word naming is faster than picture naming and is typically affected by more word-form variables, then either AoA would not make a difference or only verbal measure(s) of AoA would contribute to the RT variance in both category sets.

Method

Participants 90 participants (48 females) took part in the AoA rating experiments. They were university students with an average age of 23.1 years (age range from 19 to 35, SD=3.8), native Bulgarian speakers with normal or corrected to normal vision. Participants received course credit or were paid for their participation.

Stimuli The pictorial stimuli for the AoA rating were 520 pictures from the data base of an on-line picture naming task in Bulgarian, which was part of a cross-linguistic study, 50 participants per language (Szekely et al., 2004). For more details on participants, procedures, and pictorial stimuli in the picture naming norming study, see Szekely et al. (2004) or visit an on-line data base at http://www.crl.ucsd.edu/~aszekely/ipnp/. It should be noted here that the data base contains also the word naming RT data of another 50 participants for each dominant response (unpublished).

All target names in the data base were subjected to five different tests aimed at obtaining separate subjective ratings for word frequency, object familiarity, image agreement, imageability (procedure adopted from Paivio, Yuille & Madigan, 1968), and concreteness, all rated on a 1 to 7 scale, from lowest to highest. Four different groups of 40 university students each participated in the frequency, object familiarity, concreteness, and imageability ratings. In addition, 20 students participated in the image agreement procedure (image agreement reflects the degree to which a mental image generated by participants in response to the name of the picture matches the picture). None of the participants in the rating tests participated in the on-line picture naming or word naming experiments. Target names were coded for word length measured in number of phonemes. Further, objective word frequency data were derived from a 72-million word data base (Simov et al., 2004), converted into frequency score per million and then 10-base logarithm of the score was taken with one added to the score per million to avoid the undefined Lg(0). Finally, subjective ratings of pictures' visual complexity (7-point scale, 7 – the most visually complex) were obtained with 30 Hungarian university students (Székely, unpublished).

Procedure Procedures in the three AoA rating experiments were identical apart from the instructions concerning AoA estimation of either the word (in auditory and visual modalities) or of the concept (in the pictorial modality). Dominant responses of the pictures served as visual or auditory stimuli for the AoA ratings. The rating was based on a 7-point scale where 7 referred to the earliest acquired items (under 2 years of age) and 1 – to the latest (above 13 years of age).

To avoid the potential fatigue effect, the 520 items were divided into 3 lists (one list contained 174 items and two other lists – 173 items each). Each list had a representation in each of the three modalities. A subject was run on all three lists, one in each presentation modality without repetition. The lists and modalities were counterbalanced across subjects.

Visual stimuli (printed words) were presented in the center of the screen with 38-point CyrillicIISans font, and remained there until a key (from 1 to 7) was pressed. Auditory stimuli were recorded by a female native speaker in a neutral intonation. The words were digitized using the Macintosh SoundEdit system and placed in a sound file within the PsyScope experiment preparation shell (Cohen, MacWhinney, Flatt, & Provost, 1993). The sound stimuli were presented using the Macintosh inbuilt sound system without headphones. Pictorial stimuli (11 x 11 cm) were presented in the center of the screen and remained until the subject's response. The stimuli were presented in a different random order for each subject. Each trial started with an attentional cross ("+") presented for 500 ms. The AoA 7-point scale appeared after the cross (together with the stimulus) and remained in the upper left corner of the screen until the response. The intertrial interval was set to 1500 ms. Each session covered one of the three lists and was run on a different day for each subject; during each session participants had two breaks.

Participants were tested in a sound-proof booth. A Power Macintosh 6400/200 equipped with the PsyScope software (Cohen et al., 1993) controlled the stimuli presentation and registered the rating responses. Each experimental session lasted about 15-20 min.

Results and Discussion

The AoA rating data were averaged by items and combined with the picture naming data. Out of the 520 items, 79 items for each category along with their data were selected[1]. The two categories were living things (animals only) and tools or manipulable objects (e.g., *screwdriver, spoon, coin*). Table 1 presents descriptive statistics for the characteristics of each category over 79 items.

Table 1: Pictorial and target word characteristics for each semantic category.

	Tools/Manipulable Objects		Animals	
	Mean (SD)	Range	Mean (SD)	Range
PN_RT	1120(221)	768-1842	1219(252)	820-2035
WN_RT	588(50)	477-721	575(53)	490-816
VC	2.5(0.8)	1.2-4.8	4.4(0.7)	2.5-6.1
NA	79(19)	22-100	74(21)	10-100
ImAgr	5.5(0.6)	3.6-6.6	5.7(0.5)	4.1-6.4
NoPh	6.3(2.0)	3.0-14	5.6(1.7)	3-12
SubFrq	4.3(0.9)	2.6-6.4	3.4(0.9)	1.8-6.0
ObjFrq	0.6(0.5)	0.0-2.0	0.7(0.4)	0.0-1.5
Image	6.0(0.5)	3.3-6.6	5.9(0.5)	3.8-6.6
Fam	6.0(0.3)	4.6-6.5	5.7(0.4)	4.7-6.5
Concr	6.0(0.5)	4.3-6.8	5.9(0.5)	4.2-6.7
AoA_V	4.9(0.7)	2.4-6.5	5.1(0.7)	2.6-6.3
AoA_P	4.9(0.6)	3.8-6.3	5.2(0.6)	3.8-6.3
AoA_A	4.9(0.7)	2.7-6.4	5.1(0.7)	2.7-6.5

Note. PN_RT – picture naming RT; WN_RT – word naming RT; NA – name agreement[2], VC – visual complexity, ImAgr – image agreement, NoPh – number of phonemes, SubFrq – subjectively rated word frequency, ObjFrq – 10-base logarithm of objective word frequency, Image – word imageability, Fam – familiarity, Concr – concreteness, AoA_V, AoA_P, AoA_A – AoA ratings in visual, pictorial, and auditory modalities, respectively.

Naturally, visual complexity ratings were higher in the animal set (t=16.17; p<.001) than in the tools (cf. Table 1). Subjective frequency and length in phonemes were also significantly different between the two sets (t=6.43; p=0.00, and t=2.34; p<.05, respectively). The remaining characteristics did not differ across the two categories (all p_s>.08). A one-way ANOVA obtained a significant main effect on picture naming RT of tools and animals (F(1, 78)=7.63; p<.01) and a non-significant one on the word naming RT (F(1, 78)=2.76; p<.1). Most importantly, AoA in the three modalities within each category were not different from each other, in fact, they were practically equivalent (cf. Table 1).

One of the aims of the study was to compare the influence of the three AoA measures on picture and word naming processing. So, the predictors for the regression analyses were chosen to be identical in each analysis and relevant for each type of processing (e.g., image agreement

[1] The data base contains 103 pictures representing living things and 137 pictures of tools and manipulable objects. When human beings were excluded (e.g., pictures of a *baby* or a *woman*), 79 pictures of living things remained. The number of tools and manipulable objects was also reduced to 79 by selecting items with maximum manipulability taking into account the size of the object (e.g., a *vacuum cleaner* or an *accordion* are tools and are associated with particular movements but are not very manipulable).

[2] Name agreement refers to the degree to which participants agree on the name of the picture measured by the percentage of people who produced a given name.

is relevant in picture naming but not that much in word naming). In addition, to avoid the co-linearity problem, the logarithm of objective frequency was chosen to be a frequency predictor since the correlation between familiarity and subjective frequency was very high in both sets (*r*=.85 and *r*=.78 in animal and tool sets, respectively). Thus, the following semantic and lexical predictors were entered into the regression equations: length in phonemes, objective word frequency, imageability, concreteness, and object familiarity. Each AoA measure entered the regression separately (along with the other five predictors) because of co-linearity between the measures in three modalities (*r* varied from .75 to .96).

Table 2 presents the results of simultaneous multiple regressions (all six predictors entered the equation together) for picture naming RT separately for each category and each AoA modality measure. All predictors together in the animal set accounted for 44.5% (F(6,72)=9.63; p=0.00) of RT variance with AoA measured in the visual modality, for 44.5% (F(6,72)=9.64; p=0.00) with AoA measured in the pictorial modality, and for 47.8% (F(6,72)=10.79; p=0.00) with AoA measured in the auditory modality. The results showed a stable independent contribution to RT variance of animals' naming made by objective frequency and imageability. Of the three AoA measures only auditory AoA made its contribution to the RT variance (cf. Table 2). Thus, it seems that for the given item set and population, animals are more associated with verbal knowledge which is confirmed by a stable frequency contribution[3].

Regression analyses on the RT of tool naming revealed again significant equations though with overall lower R^2 compared with the animal set: the predictors accounted for 17.7% (F(6,72)=2.58; p<.05) with AoA in the visual modality, for 30.2% (F(6,72)=5.20; p<.001) with AoA measured in the pictorial modality, and for 17.6% (F(6,72)=2.57; p<.05) with AoA in the auditory modality. Across the three regressions, a significant independent contribution to the RT variance of tool naming was made by imageability. Most importantly, out of the three AoA measures only the pictorial AoA measure significantly contributed to the RT variance (cf. Table 2). Note that R^2 with the pictorial AoA is almost twice higher than the R^2 with the other AoA measures. It seems that tool naming is strongly influenced by motor knowledge which can be activated by pictures[4] (see Grafton et al., 1997; Gerlach et al., 2002; Vitali et al., 2005).

Table 2: Simultaneous multiple regression analysis on picture naming RT separately for each semantic category and each AoA measure.

		Modality					
		Visual		Auditory		Pictorial	
		β	*t*	β	*t*	β	*t*
ANIMALS	NoPh	-.04	-.38	-.04	-.38	.04	-.37
	ObjFrq	**-.22**	**-2.3**	**-.23**	**-2.5**	**-.22**	**-2.3**
	Image	**-.43**	**-2.6**	**-.35**	**-2.2**	**-.55**	**-3.9**
	Concr	-.05	-.54	-.04	-.51	-.07	-.78
	Fam	.21	1.1	.30	1.8	.19	1.1
	AoA	-.33	-1.6	**-.52**	**-2.7**	-.23	-1.6
TOOLS	NoPh	.13	1.0	.13	1.0	.05	.43
	ObjFrq	-.05	-.46	-.05	-.43	-.05	-.49
	Image	**-.45**	**-2.6**	**-.45**	**-2.6**	**-.36**	**-2.3**
	Concr	-.04	-.37	-.04	-.37	-.07	-.61
	Fam	.07	.39	.07	.41	.26	1.6
	AoA	.05	.35	.04	.28	**-.43**	**-3.6**

Note. For each predictor, the beta weight (β) and *t* statistic value (*t*) are reported; bold values are significant at p<.05 or lower. NoPh – number of phonemes, ObjFrq – 10-base logarithm of objective word frequency, Image – word imageability, Fam – familiarity, Concr – concreteness.

The regression results for word naming RT are presented in Table 3. Overall, in word naming of animals, the predictors accounted for 38.7% (F(6,72)=7.58; p=0.00) with pictorial AoA, for 39.4% (F(6,72)=7.82; p=0.00) – with visual AoA, and for 40.0% (F(6,72)=8.00; p=0.00) – with auditory AoA. Word naming of animals was significantly affected by length in phonemes across the three regression analyses. When the pictorial measure of AoA participated in the regression, imageability emerged as a significant predictor. The regression equations of word naming of tools were also highly significant and showed the same pattern of results independently of AoA type (cf. Table 3). Predictors together accounted for 60.3% (F(6,72)=18.22; p=0.00) with auditory AoA, for 60.3% (F(6,72)=18.23; p=0.00) – with pictorial AoA, and for 60.9% (F(6,72)=18.72; p=0.00) – with visual AoA. Length in phonemes and objective frequency predicted the word naming RT. No other significant contribution was found.

3 To test for the possible confounding of manipulability in the animal set, animals were coded as manipulable and not (for example, 1 for 'fly' vs. 0 for 'giraffe'). This manipulability factor was entered into the regression and showed no significant contribution to the animal naming RT variance.

4 Separate analyses were conducted with name agreement, image agreement, and visual complexity included as predictors into the regression on picture naming RT in both categories. The results showed the same AoA pattern for both categories with the usual strong name and image agreement contributions to the RT variance across categories.

Table 3: Simultaneous multiple regression analysis on word naming RT separately for each semantic category and each AoA measure.

		Modality					
		Visual		Auditory		Pictorial	
A		β	*t*	β	*t*	β	*t*
N	NoPh	**.50**	**5.0**	**.50**	**5.0**	**.51**	**5.1**
I	ObjFrq	-.02	-0.21	-.03	-.26	-.02	-.19
M	Image	-.25	-1.5	-.23	-1.3	**-.34**	**-2.3**
A	Concr	.03	.27	.03	.29	.03	.27
L	Fam	.13	.68	.16	.85	.01	.06
S	AoA	-.20	-.95	-.26	-1.3	.02	.12
	NoPh	**.61**	**7.2**	**.62**	**7.3**	**.64**	**7.6**
T	ObjFrq	**-.24**	**2.9**	**-.25**	**-3.0**	**-.24**	**-2.9**
O	Image	-.05	-.41	-.06	-.54	-.07	-.63
O	Concr	-.10	-1.2	-.10	-1.2	-.10	-1.2
L	Fam	-.02	-.21	-.04	-.31	-.03	-.23
S	AoA	-.15	-1.7	-.11	-1.2	-.11	-1.2

Note. For each predictor, the beta weight (β) and *t* statistic value (*t*) are reported; bold values are significant at $p<.05$ or lower. NoPh – number of phonemes, ObjFrq – 10-base logarithm of objective word frequency, Image – word imageability, Fam – familiarity, Concr – concreteness.

Thus, word naming was affected only by word-form variables (with one exception) and was not affected by any AoA measure, unlike picture naming speed. This result is in line with the semantic hypothesis of AoA (Brysbaert et al., 2000) which attributes a strong semantic component to the AoA measure.

Conclusion

The primary purpose of the study was to test the account of the sensory-functional theory (Saffran et al., 2003) which posits that the semantic knowledge of objects is distributed across domains (sensory, motor, verbal) and that the knowledge of a concept or an object is a function of the experience with that object and of the manner in which the information was acquired, which is reflected in the knowledge distribution profiles (Saffran et al., 2003). We explored the types of experience that may be reflected in the two categories (animals and tools/manipulable objects) by studying the impact of three types of AoA measures on RT processing of picture naming and word naming.

The results clearly showed that the modality of presentation in AoA ratings makes a difference in knowledge access and that this knowledge can be caught in category-specific effects. In addition, the results suggested that AoA ratings contain semantic information which is in support of previous accounts that regard AoA as a factor that carries semantics (e.g., Brysbaert, Van Wijnendaele, & De Deyne, 2000). The results of this study indicate the importance of sensory-experienced and verbally learned information (see also Noppeney & Price, 2003) in the organization of semantic knowledge and is in accordance with the distributed sensory-functional account of semantic organization.

Acknowledgments

We would like to thank Velina Balkanska for help in data collection and two anonymous reviewers for useful comments and suggestions. This study was partially supported by a McDonnell foundation grant on "Cross-linguistics studies of aphasia."

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