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Research report

Crossmodal integration between visual linguistic information and flavour perception ☆

Eugenia Razumiejczyk [a], Guillermo Macbeth [a], Fernando Marmolejo-Ramos [b,*], Kimihiro Noguchi [c]

[a] National Scientific and Technical Research Council, Department of Education Sciences, National University of Entre Ríos, Argentina
[b] Gösta Ekman Laboratory, Department of Psychology, Stockholm University, Sweden
[c] Department of Mathematics, Western Washington University, USA

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ABSTRACT

Many studies have found processing interference in working memory when complex information that enters the cognitive system from different modalities has to be integrated to understand the environment and promote adjustment. Here, we report on a Stroop study that provides evidence concerned with the crossmodal processing of flavour perception and visual language. We found a facilitation effect in the congruency condition. Acceleration was observed for incomplete words and anagrams compared to complete words. A crossmodal completion account is presented for such findings. It is concluded that the crossmodal integration between flavour and visual language perception requires the active participation of top-down and bottom-up processing.

Introduction

The human cognitive system has acquired abilities that promote survival in complex environments that include cultural aspects (Cosmides, 1989). Making decisions quickly while eating a packet of snacks when crossing the street is an example of this. The organism receives and processes inputs from different sensory channels, and handles the different processing speeds of the biological and cognitive apparatus. In our example, the cognitive system of the subject processes visual and gustatory information simultaneously, when making decisions about picking up the pace because the traffic lights are about to change, in spite of which the cognitive system is not overwhelmed by the great amount of information. These situations from daily life are evidence of the adaptation of the biological system to our cultural environment. Such multiplicity of information needs to be integrated in some way. Crossmodal integration has been defined as the cognitive process involved in carrying out such a task (Spence & Deroy, 2013). This complex resource has been observed in humans as well as animals. Another example of crossmodal integration is the salivatory reflex, which is activated by the expectation of eating as well as by smelling and observing food. The first study demonstrating this was carried out by Pavlov by conditioning dogs to salivate when listening to a bell that anticipated the act of eating (Rescorla, 1988). In that sense, the crossmodal concept refers to those situations in which the stimulation of a given perceptual modality influences the processing of a stimulus presented in a different modality (Spence & Deroy, 2013).

Working memory is critically involved in the process of crossmodal integration. This memory system maintains and manipulates information temporarily (Baddeley, 1992), and thus collaborates with the adaptation of the individual to the environment. One of its duties is to keep the information that enters at different times through different sensory modalities in such a way that it can be integrated. In this sense, multiple sources of information are combined to provide data adjusted to the external properties of objects (Driver & Spence, 2000). Nevertheless, modal integration has limitations. It has been found that an individual is not always able to process two sources of information simultaneously and efficiently (Baddeley, 1992; Roberts & Hall, 2008; Stroop, 1935; Weissman, Wagner, & Woldorff, 2004).

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* Corresponding author.
E-mail address: fernando.marmolejo.ramos@psychology.su.se (F. Marmolejo-Ramos).

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Crossmodal Stroop paradigm

Stroop (1935) carried out an experiment with words whose meanings referred to colours. These words were written in ink colours that were either identical or different from the meaning of the words. The task required the subject to name the colour with which the word was written in the shortest possible time. The results showed that congruent stimuli resulted in the largest amount of correct responses. Similarly, the congruent stimuli yielded shorter reaction times than incongruent stimuli (MacLeod, 1991). Congruence refers to the semantic coherence between the colour of the stimulus and the meaning of the word. The word red is congruent when presented as a visual stimulus written in red colour. The Stroop task triggers a competition between two sources of information (Kirn, Kirn, & Chun, 2005). Hence, an inhibition is required to achieve a correct response (Banich et al., 2000; MacLeod, 1991, 1992). The attention has to be directed to one source of information, i.e. the colour of the written word, and not to the other, i.e. the meaning of the written word (Cho, Lien, & Proctor, 2006; Kahneman & Chajczyk, 1983; Kim, Cho, Yamaguchi, & Proctor, 2008; Mitterer, La Heij, & Van der Heijden, 2003).

Stroop interference is observed in slower reaction times and fewer correct responses. Thus, there is a failure in the executive function of attention due to the distractors which are incongruent with the response that the participant should give. For example, in the incongruent stimuli condition (the word blue written in red ink) the participant says red with a longer reaction time than with congruent stimuli (the word blue written in blue ink). Additionally, this condition yields more mistakes than the congruent condition.

The Stroop phenomenon has been studied in diverse crossmodal situations related to flavour perception. In the crossmodal Stroop task, the participant is presented two stimuli in different modalities with the instruction to process only one, such that the other functions as a distractor. Thus, computational resources of working memory compete in order to simultaneously process the two types of information present in two different modalities. Information presented in this way, i.e., in two different perception modalities, can be congruent, incongruent, or control. The independent variable is related to the type of congruence of the information between modalities. The standard experimental aim is to measure the interference through the variables that depend on reaction time and number of correct responses. In the Stroop paradigm, as opposed to the paradigm which studies the priming phenomenon, the stimuli are presented simultaneously. In the latter case, the stimuli can belong to the same or different sensory modality and are presented in succession. Priming this sequential presentation of stimuli is operated by means of the Stimulus Onset Asynchrony (SOA), which is the measure of the time that elapsed between the presentation of the prime stimulus and the target stimulus (Veldhuizen, Oosterhoff, & Kroeze, 2010). In the Stroop paradigm, the presentation of stimuli is simultaneous.

White and Prescott (2007) studied the link between gustatory and olfactory perception. They performed an experiment in which they asked the participants to identify a gustatory stimulus that was simultaneously presented with an olfactory stimulus. The presentation of stimulus pairs generated conditions of congruence, incongruence, and control. In the condition of congruence the olfactory and the gustatory stimuli belonged to the same object. Conversely, in the condition of incongruence, the stimuli did not belong to the same object. Lastly, in the control condition the olfactory stimulus was water. These data showed that the task of identifying gustatory stimuli was made easier in congruent conditions. Such results were interpreted as an adaptation of the individual to the environment due to the biological importance of discriminating potentially toxic components quickly and accurately before they are consumed. Nevertheless, it should be noted that there is a link in the perception of the olfactory stimulus administrated together with the retronasal olfaction produced by tasting the gustatory stimulus (Pfaar, Landis, Frasnelli, Hüttenbrink, & Hummel, 2006).

Crossmodal Stroop interference between flavour perception and linguistic representations has also been studied. In the auditory modality, Razumiejczyk, Jáuregui, and Macbeth (2012) presented words while administering gustatory stimuli. The presentation of pairs generated three conditions, as in White and Prescott's (2007) experiment: (1) congruent stimuli: the words coincided with the name of the gustatory stimulus; (2) incongruent stimuli: the words did not coincide with the gustatory stimulus but represented something edible; and (3) control stimuli: the words did not coincide with the gustatory stimulus and did not represent food. Their results showed that the interference was lower in the case of congruent stimuli, as was observed by White and Prescott (2007). The same method was used and similar results were obtained in a study comparing flavoural Stroop interference between linguistic and pictorial visual representations (Razumiejczyk, Macbeth, & Adrover, 2011). The results showed that the words were a greater distractor than the images in the crossmodal Stroop task, and required longer processing time to identify the gustatory stimulus (Razumiejczyk et al., 2011). These data suggest that the words presented in visual form produce a bigger attentional competition with the gustatory stimuli than pictorial distractors. It has been argued that the longer processing time required for the linguistic information might be explained by the high complexity of these mental representations (Gardner, Rothkopf, Lapan, & Lafferty, 1987). These data are relevant from an ecological approach given that words are part of the habitual human environment. Linguistic representations are not always presented in their full form in daily life. For example, during a car trip it might be necessary to read a visual traffic signal but it may only be possible to access a fragment of the word (hway exit for highway exit).

Crossmodal processing

In crossmodal processing top-down as well as bottom-up processes are involved (Spence, Levitan, Shankar, & Zampini, 2010). Examples of top-down processes are the expectations linked to the colour of gustatory stimuli when someone is about to taste food. Instead, there is involvement of bottom-up processes in the cases of cognitive influence particularly when guided by a physical stimulus. When reading incomplete linguistic representations of words or anagrams, top-down processes intervene. In this regard, Heimbauer, Beran, and Owren (2011) have shown that Panzee, an adult chimpanzee, has been able to recognise incomplete words presented in spoken language. According to Foley and Foley (2007), there are two main types of anagrams: easy and difficult. These authors also say that anagrams imply a computational cost of working memory when dealing with the problem-solving task. Thus, these linguistic representations are associated with the gustatory stimuli that are processed in a bottom-up direction in the crossmodal Stroop task. The process of crossmodal perceptual completion has been defined as the completion of the missing features of a stimulus in a modality that is physically present in another modality (Spence & Deroy, 2013).

Investigating how gustatory information coupled with incomplete linguistic input is integrated can help to understand the processing of degraded information. Previous studies have found that the visual modality is dominant when integrated with the gustatory modality (Razumiejczyk et al., 2011). Evidence suggests that visual perception operates as a strong distractor during the integration of vision with flavour. However, a recent study suggests that the human brain is able to integrate lexical internal information with external perceptual input (Bakker, Takashima, van Hell, Janzen, & McQueen, 2014). Similarly, Velasco, Salgado-Montejo, Marmolejo-Ramos, and Spence (2014) found that shapes, typefaces, names, and sounds are critically integrated by focusing on different correspondences when subjects evaluate food packaging (see also Velasco, Balboa, Marmolejo-Ramos, & Spence, 2014).

The specific aim of this study is to evaluate top-down and bottom-up processes in the crossmodal integration of gustatory and visual linguistic information presented in three forms: complete words, incomplete words, and anagrams. Two comparisons will be performed, one for flavour||word pairing condition and the other for word type group. Bottom-up dominance is expected for the flavour||word comparison. Matching between the gustative stimulus and the corresponding word in the congruency condition might generate a data-driven process. This convergence might explain the occurrence of shorter reaction times (RTs) and higher accuracy rates. This phenomenon might not occur under incongruency and control conditions. Top-down dominance is expected for the word type group comparison. If crossmodal Stroop effect was only bottom-up, then the RT differences between the three conditions should not be significant. On the contrary, a significant difference is predicted if the crossmodal Stroop task has top-down dominance processes. It is predicted that incomplete words and anagrams will be processed faster than complete words. This prediction is justified by the acceleration of RTs produced by crossmodal completion (Spence & Deroy, 2013). Non-significant differences are predicted for the accuracy rates between complete words on the one hand, and incomplete words and anagrams on the other hand.

Methods

Participants

One hundred and five undergraduate students (70 females and 35 males) from the National University of Entre Ríos volunteered to participate in the experiment ($M_{age} = 24.10$, $SD = 4.89$). Based on previous studies (Razumiejczyk, Macbeth, & Leivobich de Figueroa, 2013), participants were selected if (i) they were between 20 and 40 years old (West, 2004), (ii) were non-smokers, and (iii) had not ingested any drink, except water, or food three hours prior to participating in the experiment. The study was approved by the ethics committee of the university.

Materials

The gustative stimuli, *durazno* (peach), *ciruela* (plum), *frutilla* (strawberry) and *naranja* (orange), were all natural fruits administered in the form of liquefied slurry at room temperature. The visual stimuli consisted of the words corresponding to each of the four flavours (congruent condition), four words corresponding to other fruits (incongruent condition), and four words corresponding to non-edible objects (control condition) (all sets of words had similar length: $M_{word\ length\ flavours} = 7.25$, $M_{word\ length\ fruits} = 6$, and $M_{word\ length\ objects} = 7$, $range_{word\ length} = 5$~9). In addition to the complete words described above (complete word group), incomplete words (incomplete word group) and anagrams (anagrams group) of the same flavours were used in the experiment. Incomplete words were generated by randomly omitting one letter per syllable and whenever a word had only one syllable no letter was omitted (e.g. the word 'anteojos' [spectacles] has four syllables, an/te/o/jos, so the letter "o" was not deleted from the third syllable). Anagrams were created by randomly rearranging the order of the syllables instead of single letters. This type of 'syllable anagram' was used based on previous studies reporting that participants find it quite difficult to identify the target word from anagrams in which only letters are rearranged (Foley & Foley, 2007) (see Table 1).

Procedure

Participants were randomly allocated to the following groups: $n_{complete\ words\ group} = 43$, $n_{incomplete\ words\ group} = 34$, and $n_{anagrams\ group} = 28$. Using a crossmodal Stroop paradigm, the gustatory stimuli and the words were administered simultaneously to participants. The experimenter gave the participant a disposable teaspoon containing approximately 5 ml of the gustatory stimuli and instructed the participant when to bring the teaspoon to his/her mouth without smelling it. Before each trail, the participants were instructed to rinse their mouths with water. The experimenter also controlled when the word would appear on a 21.5 LCD screen connected to a laptop computer. The participants' task was to verbalise, as quickly as possible, the name of the stimuli being tasted while looking at the screen. Task instructions gave no specifications about swallowing. However, all the participants swallowed before verbalising the answer.

The participants' response times and accuracy rates were registered by the experimenter in each trial. The response times were registered by the experimenter via pressing a key on the computer keyboard and the software PsychoPy (Peirce, 2007) was used to register the key press. A pair of spectacles was designed to prevent participants from seeing the gustative stimuli while enabling them to see the word presented on the screen (Morrot, Brochet, & Dubourdieu, 2001) (see Fig. 1). All words were presented in uppercase black colour over a white background.

Gustative stimuli were always presented simultaneously with the complete word for the flavour being administered (i.e. 'complete words' group; e.g., FRUTILLA $_{flavour}$|| FRUTILLA $_{word}$), the incomplete word for that flavour (i.e. 'incomplete words' group; e.g., FRUTILLA $_{flavour}$|| F_U_ILL_ $_{word}$), or the anagram word for that flavour (i.e. 'anagrams' group; e.g., FRUTILLA $_{flavour}$|| LLATIFRU $_{word}$). Within each of the three 'word type' groups, the 'Flavour||Word' pairings were fixed (see rows in Table 1) and were randomly presented to the participants. For example, a participant in the 'complete words' group could have undergone the following trial: FRUTILLA $_{flavour}$|| FRUTILLA $_{word}$→ DURAZNO $_{flavour}$|| ANANÁ $_{word}$→ FRUTILLA $_{flavour}$|| MONEDA $_{word}$→ DURAZNO $_{flavour}$|| ANTEOJOS $_{word}$ and so on, until 12 trials have been completed (see Table 1). The experiment was conducted on the same time of the day for each participant and lasted roughly 7 minutes.

Table 1
Stimuli and design used in the experiment.

Flavour||word pairing condition	Gustative stimuli	Complete words group	Incomplete words group	Anagrams group
Congruent	Frutilla	FRUTILLA	F_U_ILL_	LLATIFRU
	Durazno	DURAZNO	D_R_ZN_	RAZDUNO
	Ciruela	CIRUELA	C_RU_L_	LACIRUE
	Naranja	NARANJA	N_RA_J_	JANARAN
Incongruent	Frutilla	BANANA	B_N_ _A	NABANA
	Durazno	ANANÁ	AN_ _Á	NAÁNA
	Ciruela	SANDÍA	SA_D_A	DÍASAN
	Naranja	MANZANA	MA_Z_ _A	NAMANZA
Control	Frutilla	MONEDA	M_N_D_	DAMONE
	Durazno	ANTEOJOS	A_T_OJ_S	JOSOTEAN
	Ciruela	BICICLETA	B_C_ _LET_	TACLECIBI
	Naranja	RELOJ	R_ _OJ	LOJRE

Note: Flavour||word pairing conditions (i.e. congruent, incongruent, and control) were within-subjects factors and word types (i.e. complete, incomplete and anagram words) were between-subjects factors. *Congruent condition words*: durazno = peach, ciruela = plum, frutilla = strawberry, and naranja = orange. *Incongruent condition words*: banana = banana, ananá = pineapple, sandía = watermelon, and manzana = apple. *Control condition words*: moneda = coin, anteojos = spectacles or glasses, bicicleta = bicycle, and reloj = clock or watch.

Fig. 1. Spectacles used in the experiment.

Design and analyses

This experiment was a 3 (word group: complete, incomplete, anagram) × 3 (word type: congruent, incongruent, control) mixed factorial design with the first variable administered between-subjects and the second variable administered within-subjects. The dependent variables were the response times and the accuracy rates. In this study, the response times were defined as the time-lag between the presentation of the 'Flavour || Word' pairing and the verbal response of the participant. Accuracy rates consisted of the proportion of times that the participant correctly identified the stimulus being tasted.

The Anderson–Darling normality test and the bootstrap modified robust Brown–Forsythe Levene-type homogeneity of variance test (based on the absolute deviations from the median with modified structural zero removal method and correction factor) (Conover, Johnson, & Johnson, 1981; Noguchi & Gel, 2010) suggested that the dependent variables were not normal in various cases and between-subjects factors had heterogeneous variances in the dependent variables across levels of the within-subjects factors (see Table 2).[1] These results thus preclude the use of parametric tests and, instead, call for the use of robust nonparametric tests.

The ANOVA-type statistics (ATS), a robust nonparametric rank-based version of the ANOVA *F*-test (Noguchi, Gel, Brunner, & Konietschke, 2012; see supporting information section in Marmolejo-Ramos, Elosúa, Yamada, Hamm, & Noguchi, 2013 for extra details) was used to determine global main effects and interactions (specifically the F1-LD-F1 model was used). A nonparametric multiple contrast testing procedure (MCTP), a robust rank-based test for multiple comparisons for relative effects, which controls the family-wise Type I error rate well (Konietschke, Bathke, Hothorn, & Brunner, 2010; Konietschke, Hothorn, & Brunner, 2012), was used to analyse Tukey type all-pairwise comparisons of interest (the multivariate *t*-distribution was used to calculate the *p*-value).[2] The measure of stochastic superiority effect size (A) was estimated for the pairwise comparisons (A_i denotes the A effect size for independent samples and A_d denotes the A effect size for dependent samples), and the A average absolute pairwise deviation effect size (A_{AAPD}) was estimated for the overall results of the MCTP (Vargha & Delaney, 2000). The A effect size can be interpreted using the following benchmarks: .56 ≈ small, .64 ≈ medium, and .71 ≈ large. Also the A_{AAPD} can be interpreted using the following benchmarks: .06 ≈ small, .14 ≈ medium, and .21 ≈ large.[3]

The shifting boxplot (SBplot) was used to report the central tendency and dispersion of the data obtained. The SBplot displays observations lying ±2 SD beyond the mean (represented by dashes), observations between −2 and +2 SD (longest and thinnest box), observations that fall between the mean of the first half of the data and the mean of the second half of the data (intermediate box), and the mean of the data (middle thickest and longest horizontal line) and its 95% bootstrap bias-corrected and accelerated confidence intervals (95% CI_{BCa}) (outermost shortest and thickest box). Also, the median and its 95% CI_{BCa} are represented by a solid small square and whiskers around it (see Marmolejo-Ramos & Tian, 2010 for details).

Results

The median, a robust measure of central tendency resistant to outliers (Rosenberg & Gasko, 1983), was used to estimate average response times for each participant in each condition. Accuracy rates for each participant were estimated as described above. The distributions of the results are shown in Fig. 2.

Response times

The ATS showed a main effect of word type group [F_{ATS} (1.86, 81.17) = 32.4, $p < .001$, $A_{AAPD} = 0.263$][4] in that incomplete words had faster RTs than anagrams and anagrams, in turn, had faster RTs than complete words across flavour||word pairing conditions [$M_{incomplete} = 6.58$, $SE = 0.342$; <$M_{anagrams} = 10.40$, $SE = 0.822$; <$M_{complete} = 14.13$, $SE = 0.889$]. Pairwise comparisons using ATS with Bonferroni adjustments showed that the RTs of word type groups differed significantly [$F_{ATS\ complete\ vs\ incomplete}$ (1,70.49) = 79.14, $p < 0.001$, $A_i = 0.863$; $F_{ATS\ complete\ vs\ anagrams}$ (1,63.33) = 9.98, $p = 0.007$, $A_i = 0.680$; $F_{ATS\ incomplete\ vs\ anagrams}$ (1,50.44) = 23.14, $p < 0.001$, $A_i = 0.747$].

A main effect of flavour||word pairing condition also emerged [F_{ATS} (1.74, ∞) = 29.90, $p < .001$, $A_{AAPD} = 0.184$], suggesting that congruent words were processed faster than incongruent and control words across word type groups [$M_{congruent} = 8.80$, $SE = 0.047$; <$M_{incongruent} = 11.43$, $SE = 0.068$; <$M_{control} = 11.85$, $SE = 0.058$]. Pairwise comparisons using ATS with Bonferroni adjustments showed the RTs of flavour||word pairing conditions across word type groups differed significantly [$F_{ATS\ congruent\ vs\ incongruent}$ (1, ∞) = 33.53, $p < 0.001$,

[1] There are numerous homogeneity of variance/normality tests available. One may naively think that reporting the average of the *p*-values of such tests would provide reliable results. However, as Vovk (2012) discussed, such a procedure may lead to inflated Type I errors, and he suggested twice the average of the *p*-values as a reasonable method. This method controls Type I error for any dependent structure, but he also warned that it could lead to very conservative results. Thus, the topic of averaged combined *p*-values for homogeneity and normality tests should be investigated further.

[2] The ATS test is implemented in the 'nparLD' R package using the 'f1.ld.f1' function and the MCTP test is implemented in the 'nparcomp' R package using the 'mctp' and 'mctp.rm' functions. The estimators of effect size were coded in R.

[3] The benchmarks to interpret the effect sizes A_d and A_{AAPD} are not explicitly stated in Vargha and Delaney (2000). However, as A_{AAPD} is a generalisation of A_i or A_d, it is reasonable to use the benchmarks provided in Table 1 in Vargha and Delaney (2000). Specifically, the benchmarks can be obtained after subtracting 0.50 from the values in Table 1 so that A_{AAPD} and A_i are mathematically equivalent for the independent two-sample case.

[4] The effect sizes presented in this paragraph need to be interpreted with caution because the data are correlated within each group given the repeated measures design.

Table 2
Results of the normality and homogeneity tests for the response time and accuracy rate data.

Flavour||word pairing condition	Normality test			Homogeneity test
	$Complete_{word}$	$Incomplete_{word}$	$Anagram_{word}$	
$Congruent_{RT}$	$AD = .36, p = .42$	$AD = .17, p = .91$	$AD = .30, p = .54$	$L = 18.67, p < .001$
$Incongruent_{RT}$	$AD = .34, p = .46$	$AD = .65, p = .08$	$AD = 1.11, p = .005$	$L = 8.39, p < .001$
$Control_{RT}$	$AD = .44, p = .27$	$AD = 1.30, p = .001$	$AD = .74, p = .04$	$L = 2.67, p = .052$
$Congruent_{AR}$	$AD = 2.97, p < .001$	$AD = 2.57, p < .001$	$AD = 1.92, p < .001$	$L = 0.04, p = .95$
$Incongruent_{AR}$	$AD = 1.83, p < .001$	$AD = 1.50, p < .001$	$AD = 1.57, p < .001$	$L = 0.23, p = .8$
$Control_{AR}$	$AD = 2.31, p < .001$	$AD = 1.84, p < .001$	$AD = 2.65, p < .001$	$L = 2.01, p = .13$

Note: RT = response times, AR = accuracy rates. Significant results are shaded.

$A_d = 0.738$; $F_{ATS\ congruent\ vs\ control}\ (1, \infty) = 53.68$, $p < 0.001$, $A_d = 0.776$; $F_{ATS\ incongruent\ vs\ control}\ (1, \infty) = 5.356$, $p = 0.037$, $A_d = 0.538$].

There was also a significant interaction between word type group and the flavour||word pairing condition [$F_{ATS}\ (2.94, \infty) = 3.48$, $p = .016$]. However, this interaction has no practical significance and is due to the within-subjects factors varying across levels of the between-subjects factors and vice versa. For example, while the RTs for the control flavour||word pairing condition were slower than the incongruent flavour||word pairing condition in the anagrams and incomplete word groups, this pattern was reversed in the complete word group (see Fig. 2).

Accuracy rates

The ATS showed a main effect of word type group [$F_{ATS}\ (1.97, 99.99) = 7.59$, $p < .001$, $A_{AAPD} = 0.096$] in that complete words were recognised more accurately than incomplete and word anagrams across flavour||word pairing conditions [$M_{complete} = .60$, $SE = 0.026$; $>M_{incomplete} = .53$, $SE = 0.026$; $>M_{anagrams} = .46$, $SE = 0.019$]. Pairwise comparisons using ATS with Bonferroni adjustments showed the accuracy rate of complete and anagram word type groups differed significantly [$F_{ATS\ complete\ vs\ incomplete}\ (1,73.21) = 2.830$, $p = 0.29$, $A_i = 0.566$; $F_{ATS\ complete\ vs\ anagrams}\ (1,68.74) = 16.50$, $p < 0.001$, $A_i = 0.647$; $F_{ATS\ incomplete\ vs\ anagrams}\ (1,73.21) = 4.151$, $p = 0.14$, $A_i = 0.576$].

A main effect of flavour||word pairing condition also emerged [$F_{ATS}\ (1.90, \infty) = 115.54$, $p < .001$, $A_{AAPD} = 0.243$], suggesting that congruent words were processed more accurately than incongruent and control words across word type groups [$M_{congruent} = .76$, $SE = 0.0019$; $>M_{incongruent} = .44$, $SE = 0.0024$; $>M_{control} = .43$, $SE = 0.0022$]. The MCTP test showed the mean accuracy rate of flavour||word pairing conditions across word type groups differed significantly; except in the case of incongruent vs control conditions [$F_{ATS\ congruent\ vs\ incongruent}(1, \infty) = 140.4$, $p < 0.001$, $A_d = 0.838$; $F_{ATS\ congruent\ vs\ control}(1, \infty) = 191.69$, $p < 0.001$, $A_d = 0.867$; $F_{ATS\ incongruent\ vs\ control}(1, \infty) = 0.161$, $p = 1.000$, $A_d = 0.524$].

The interaction between word type group and flavour||word pairing condition did not reach significance [$F_{ATS}\ (3.70, \infty) = 2.24$, $p = .06$].

The results of other multiple pairwise contrasts of interest are shown in Table 3.

General discussion

We present an experiment aimed to evaluate the crossmodal Stroop interference between the flavoural and visual modalities. The latter consisted of linguistic representations that were presented in a complete manner, incomplete, or modified as anagrams. Three experimental conditions were employed, i.e. congruency, incongruency, and control. The main findings showed shorter RTs for incomplete words than for anagrams, and shorter RTs for anagrams than for complete words. No significant differences were observed in accuracy rates between some word type groups, i.e. between complete words and incomplete words, incomplete words and anagrams. However, a significant difference was observed between complete words and anagrams.

In the congruency condition the RTs were shorter and the accuracy rates were higher when compared to incongruent and control conditions in the three word type groups. This acceleration effect can be understood as an exogenous benefit rather than endogenous expectancy (Spence, Nicholls, & Driver, 2001), i.e. the crossmodal processing stems from the same edible object. This stimulus-driven processing guided by target expectancy was also described as a modality-shifting effect by Spence et al. (2001).

The same pattern of results was found by White and Prescott (2007) for olfactory-gustative stimuli, by Razumiejczyk et al. (2012) for gustative-auditive stimuli, and by Razumiejczyk et al. (2011) for gustative-pictorial stimuli. Several authors have argued that such Stroop effect triggers selective attention processes (Cho et al., 2006; Kahneman & Chajczyk, 1983; Kim et al., 2008; Mitterer et al., 2003). Such processes may occur because gustative stimuli compete against

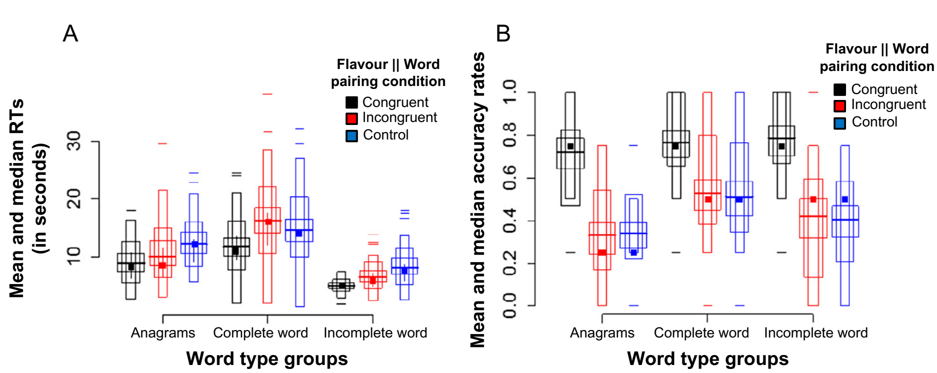

Fig. 2. Shifting boxplot representing the response time (A) and accuracy rate (B) data distributions of the 3-between (word type groups) by 3-within (flavour || word pairing conditions) mixed factorial design.

Table 3
Multiple pairwise comparisons between within-subjects factors (i.e. flavour||word pairing conditions) in each of the between-subjects factors (i.e. word type groups) (A) and multiple pairwise comparisons between between-subjects factors (i.e. word type groups) in each of the within-subjects factors (i.e. flavour||word pairing conditions) (B). The MCTP value was obtained via the *max-T* procedure (e.g., $MCTP_{RT\ complete\ word}$ = max(|−5.28|,|−4.54|,|2.02|) = 5.28).

A

DV	Word type groups: Complete$_{word}$	Incomplete$_{word}$	Anagram$_{word}$
RT	$T_{congruent\ vs\ incongruent}$ (42) = −5.28, p < .001, A_d = .76	$T_{congruent\ vs\ incongruent}$ (33) = −2.96, p = .01, A_d = .76	$T_{congruent\ vs\ incongruent}$ (27) = .98, p = .58, A_d = .66
	$T_{congruent\ vs\ control}$ (42) = −4.54, p < .001, A_d = .80	$T_{congruent\ vs\ control}$ (33) = −5.09, p < .001, A_d = .75	$T_{congruent\ vs\ control}$ (27) = −3.70, p = 002, A_d = .76
	$T_{incongruent\ vs\ control}$ (42) = 2.02, p = .11, A_d = .62	$T_{incongruent\ vs\ control}$ (33) = −1.58, p = .11, A_d = .62	$T_{incongruent\ vs\ control}$ (27) = −3.43, p = .005, A_d = .73
	MCTP = 5.28, p < .001, A_{AAPDd} = .23	*MCTP* = 5.09, p < .001, A_{AAPDd} = .20	*MCTP* = 3.70, p = .002, A_{AAPDd} = .22
AR	$T_{congruent\ vs\ incongruent}$ (42) = 5.93, p < .001, A_d = .76	$T_{congruent\ vs\ incongruent}$ (33) = 10.04, p < .001, A_d = .91	$T_{congruent\ vs\ incongruent}$ (27) = 9.15, p < .001, A_d = .85
	$T_{congruent\ vs\ control}$ (42) = 7.18, p < .001, A_d = .81	$T_{congruent\ vs\ control}$ (33) = 9.81, p < .001, A_d = .89	$T_{congruent\ vs\ control}$ (27) = 12.46, p < 001, A_d = .91
	$T_{incongruent\ vs\ control}$ (42) = .13, p = .99, A_d = .53	$T_{incongruent\ vs\ control}$ (33) = .58, p = .83, A_d = .52	$T_{incongruent\ vs\ control}$ (27) = −.01, p = .99, A_d = .50
	MCTP = 7.18, p < .001, A_{AAPDd} = .20	*MCTP* = 10.04, p < .001, A_{AAPDd} = .28	*MCTP* = 12.46, p < .001, A_{AAPDd} = .26

B

DV	Flavour||word pairing conditions: Congruent	Incongruent	Control
RT	$T_{complete\ vs\ incomplete}$ (31) = 9.48, p < .001, A_i = .89	$T_{complete\ vs\ incomplete}$ (51) = 9.75, p < .001, A_i = .90	$T_{complete\ vs\ incomplete}$ (62) = 5.74, p < .001, A_i = .80
	$T_{complete\ vs\ anagram}$ (31) = 2.27, p = .07, A_i = .66	$T_{complete\ vs\ anagram}$ (51) = 4.17, p < .001, A_i = .76	$T_{complete\ vs\ anagram}$ (62) = 1.53, p = .28, A_i = .61
	$T_{incomplete\ vs\ anagram}$ (31) = −4.38, p < .001, A_i = .77	$T_{incomplete\ vs\ anagram}$ (51) = −3.21, p = .006, A_i = .70	$T_{incomplete\ vs\ anagram}$ (62) = −3.79, p < .001, A_i = .75
	MCTP = 9.48, p < .001, A_{AAPDi} = .28	*MCTP* = 9.75, p < .001, A_{AAPDi} = .29	*MCTP* = 5.74, p < .001, A_{AAPDi} = .23
AR	$T_{complete\ vs\ incomplete}$ (58) = −0.37, p = .92, A_i = .52	$T_{complete\ vs\ incomplete}$ (60) = 1.78, p = .18, A_i = .61	$T_{complete\ vs\ incomplete}$ (59) = 1.99, p = .12, A_i = .62
	$T_{complete\ vs\ anagram}$ (58) = 1.04, p = .55, A_i = .56	$T_{complete\ vs\ anagram}$ (60) = 3.70, p = .001, A_i = .71	$T_{complete\ vs\ anagram}$ (59) = 3.56, p = .002, A_i = .71
	$T_{incomplete\ vs\ anagram}$ (58) = 1.35, p = .37, A_i = .59	$T_{incomplete\ vs\ anagram}$ (60) = 1.54, p = .27, A_i = .59	$T_{incomplete\ vs\ anagram}$ (59) = 1.34, p = .37, A_i = .58
	MCTP = 1.35, p = .37, A_{AAPDi} = .06	*MCTP* = 3.70, p = .001, A_{AAPDi} = .14	*MCTP* = 3.56, p = .002, A_{AAPDi} = .14

Note: DV = dependent variable, RT = reaction times, and AR = accuracy rates. *T* denotes the statistic associated to the MCTP test and the value between parentheses denotes the degrees of freedom with a Satterthwaite approximation of the multivariate *t*-distribution. A_i denotes the *A* effect size for independent samples and A_d denotes the *A* effect size for dependent samples. *MCTP* denotes the quantile of the overall statistic of the multiple pairwise comparisons performed in the variable of interest. A_{AAPD} denotes the measure of stochastic superiority effect size (*A*) using average absolute pairwise deviation (*AAPD;* A_{AAPDd} for the dependent samples case and A_{AAPDi} for the independent samples case. Benchmarks for their interpretation appear in the 'Design and analyses' section). Significant pairwise comparisons are shaded.

stimuli from other modalities for attentional resources. The inhibition of such distractors was not successfully achieved under incongruent and control conditions. However, between the former and the latter no differences were found for accuracy rates in our experiment. One significant difference was observed between incongruent and control conditions in the anagrams group. A further semantic gradient experiment (Risko, Schmidt, & Besner, 2006) might be recommended to compare the incongruent and control conditions. Incongruent words referred to edible objects, whereas control stimuli referred to inedible objects. Hence, a bigger interference was expected for the incongruent condition than for the control condition because the edibility is semantically closer to the gustative modality. A simple strategy to generate a more controlled semantic distance between words would be to define two levels of incongruency besides the congruent and control conditions.

Regarding the word type groups, the observed RTs were in line with the expectations. Faster responses were observed for incomplete words than for anagrams and complete words. The effect sizes for this phenomenon were large. These results can be interpreted in the context of the crossmodal perceptual completion proposed by Spence and Deroy (2013). This completion implies that the gustative input processing completes the visual linguistic representation in an involuntary manner. Spence and Deroy (2013) suggested that some gustative sensations are produced by certain smells. Similarly, the gustative stimuli presented in our experiment probably triggered the spontaneous completion of incomplete words. This effect can be interpreted as top-down processing activated by bottom-up inputs. This interpretation can be considered ecologic insofar as the mental computations promote the adjustment of the individual to the environment (Cosmides, 1989). In line with this idea, a recent study employing a statistical learning approach to visual working memory argues that the latter makes efficient use of its limited resources beyond the eventual biases that were experimentally detected from a statistical learning perspective (Orhan, Sims, Jacobs, & Knill, 2014).

The RTs were shorter for anagrams than for complete words. However, the accuracy rates were higher for complete words than for anagrams. This particular result might be understood as a difficulty effect. Anagrams might be intrinsically harder to process than complete words. We used simple anagrams for our study, i.e. they were constructed through syllable swaps. The letter swap strategy might generate harder anagrams. However, we avoided swapping letters because in such case the gustative experimental task might be confounded with a problem-solving task, as was suggested by Foley and Foley (2007). Further experiments that control the anagrams' difficulty may be recommended. The construction of an empirical difficulty gradient for a set of anagrams might provide the adequate materials to avoid confounding effects in future studies and discriminate between crossmodal integration tasks and problem-solving tasks.

One possible limitation of our study concerns the stimuli that were used. Specifically, we selected a relatively small set of gustative stimuli. Although the stimuli employed in the current study have been previously validated for the specific participants' population we tested, the inclusion of a greater number of stimuli may be recommended. Nevertheless, the materials used in this experiment are ecologically valid. We used liquefied slurry of natural fruits at room temperature, whereas previous studies used artificial stimuli like essences or electric stimulation of the tongue (Halpern, 2005; Keast, Canty, & Breslin, 2004; Kelling & Halpern, 1987; Kobayakawa, Ogawa, Kaneda, Ayabe-Kanamura, & Saito, 1999). Another limitation of our study concerns the different levels of abstraction in language comprehension (Zwaan, 2014). The degree in which the language use is embedded in the environment seems to be a critical issue for crossmodal phenomena. Hence, the generalisation of our findings is restricted to the kind of words and task instructions that we employed.

In sum, the evidence obtained in our experiment suggests that crossmodal integration of gustative and linguistic visual information combines bottom-up with top-down processes. The dominance of the latter could explain the word type group comparisons. On the contrary, the dominance of the former could explain the flavour||word pairing condition.

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