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The Neural Correlates of Linguistic Distinctions: Unaccusative and Unergative Verbs

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Unaccusative verbs like *fall* are special in that their sole argument is syntactically generated at the object position of the verb, rather than at the subject position. Unaccusative verbs are derived by a lexical operation that reduces the agent from transitive verbs. Their insertion into a sentence often involves a syntactic movement from the object to the subject position. In order to explore the neurological reality of the distinction between different verb types and identify the cortical activations associated with the lexical and syntactic operations, we compared unaccusative verbs with verbs that do not undergo such operations– unergatives (verbs with one argument, an agent) and transitives (verbs with two arguments). The observed pattern of activation revealed that the brain distinguishes between unaccusative and unergative verbs, lending neurological support for the linguistic distinction. A conjunction analysis between the comparisons between unaccusatives and the other verb types revealed activations in the left inferior frontal gyrus (IFG) and the left posterior middle temporal gyrus (MTG). These, together with previous neuroimaging results, suggest that the IFG may be involved with the execution of the syntactic operation, whereas the MTG may be responsible for the lexical operation that derives unaccusative verbs.

INTRODUCTION

The sentences *The girl smiled* and *The girl fell* look, prima facie, very similar structurally. Both start with a noun phrase, *the girl*, and both include an intransitive verb, i.e., a verb with a single argument. However, there is a crucial difference between the verbs *smile* and *fall*: whereas the argument of *smile* is the subject, causer of the action, the argument of *fall* is, syntactically, a direct object. In other words, the subject of *fall*, unlike the subject of *smile*, is not actively responsible for the action described by the verb. According to linguistic theory, the derivation of verbs like *fall* and their insertion into a sentence are complex, involving both lexical and syntactic operations (e.g., Chierchia, 1989, 2004; Perlmutter, 1978; Reinhart, 2002). These verbs, termed *unaccusative verbs*, are at the focus of this fMRI study[1].

Unlike *unergative verbs*, such as *smile* or *sneeze*, which are retrieved from the lexicon and inserted into the sentence without any change, unaccusative verbs are derived by an operation that reduces an argument from a transitive verb (a verb that has two arguments). This operation completely eliminates the subject of the transitive verb or, in terms of thematic

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[1]Some verbs can alternate between unergative and unaccusative forms, but these were not used in this study.

roles, eliminates its *agent* or *cause* role (Reinhart, 2002; Reinhart & Siloni, 2005), leaving the direct object (the complement, or in thematic roles terms, the *theme* or the *patient*) of unaccusatives the sole argument. This operation is assumed to occur in the lexicon and it is called 'decausativization' (Reinhart & Siloni, 2005), or 'reduction' (Chierchia, 1989; Reinhart, 2000).

Because the argument of unaccusative verbs is a direct object, the basic syntactic structure of sentences with unaccusative verbs includes a noun phrase (NP) that *follows* the verb (henceforth, V-NP). Therefore, to create sentences of the order NP-V with an unaccusative verb (as in the sentence *The girl fell*), a syntactic movement (called *A-movement*) moves the NP from its original position after the verb to the subject position (Burzio, 1986; Levin & Rappaport-Hovav, 1995; Perlmutter, 1978; Perlmutter & Postal, 1984; See Figure 1). Such syntactic movement also leads to the assignment of thematic roles in an order that is linearly different from the canonical one, because the *theme* role is assigned to the subject position, which is usually associated with the *agent* role. Thus, unaccusatives and unergatives, when inserted in a sentence in NP-V order, differ in two aspects: unaccusatives are derived by a lexical operation (whereas unergatives are not) and involve a syntactic movement from object to subject position, which leads to a non-linear thematic role assignment (whereas unergatives do not).

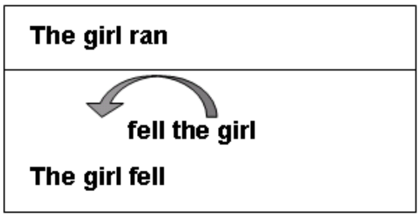

Figure 1. Illustration of a syntactic operation that moves the argument of unaccusative verbs from its original post-verbal position to the subject position to create NP-V order.

The lexical operation often has an effect in Hebrew on the morphology of the verbs. Hebrew morphology, as is characteristic of Semitic morphology, relies on roots and patterns. Within the verbal system, there are a number of patterns with relatively specific semantic characteristics. Some of the frequent unaccusative patterns (as well as the patterns of passive and reciprocal) are morphologically derived from the active pattern. For example, the unaccusative *hitrasek* (*crushed*, as in *The vase crushed*) is derived from the transitive *risek* (*smashed*, as in *Ron smashed the vase*). There are also unaccusative verbs that appear in the active pattern (e.g., *nafal* = *fell* or *namas* = *melted*). Thus, although the above lexical operations are usually associated with parallel morphological operations, the lexical operations can also occur without noticeable morphological change.

Evidence for the distinction between unaccusative and unergative verbs and for the different origins of their arguments comes from their different syntactic behavior. This is seen, for example, in some languages (e.g., Dutch or Italian), in which unergatives and unaccusatives select different auxiliaries (Chierchia, 2004; Perlmutter, 1978; van Hout, 2004). Additionally, it has been shown that unaccusatives can serve as prenominal modifiers and can appear in resultative construction (e.g., "the fallen vase" or "the river froze solid"), but unergative verbs cannot (e.g., *"the laughed girl" or *"the dog barked hoarse") (Levin & Rappaport-Hovav, 1995; Perlmutter, 1978; van Hout, 2004). In Hebrew, unaccusatives differ from unergatives in two ways. First, both V-NP and NP-V orders are acceptable for unaccusative verbs, but only NP-V is acceptable for unergatives[2] (Siloni, 2002, 2008). Additionally, it is possible in Hebrew to insert a possessive dative between the NP and the unaccusative verbs, in both orders (e.g., "nafal *li* ha-sefer" which means "fell *to-me* the-book") (Borer & Grodzinsky, 1986; Siloni, 2002, 2008), whereas such insertion is ungrammatical for unergative verbs. This type of insertion is used as a diagnostic for arguments in object position (internal arguments); and it is permissible with unaccusative verbs because their subject originates in the object position.

The differences between unergatives and unaccusatives are also evident in developmental studies and on-line processing studies. It has been found that English-speaking children mistakenly produce V-NP order when using unaccusatives, but not when using unergatives (Pierce, 1989, 1992). In Hebrew and European Portuguese, both V-NP and NP-V are acceptable with unaccusative verbs, but only NP-V with unergative verbs. Children can distinguish between the two verb types as early as at the age of two when, in both Hebrew and European Portuguese, they produce both orders for unaccusatives, but only the NP-V order for unergatives (Costa & Friedmann, in press; Friedmann, 2007). Children who acquire Italian are also reported to be able to distinguish very early between unaccusative and unergative verbs (Lorusso, Caprin, & Guasti, 2005). The psycholinguistic distinction between NP-V sentences with unaccusative and unergative verbs is also found in online studies of sentence comprehension in adults. Using a cross modal lexical decision task, Friedmann, Taranto, Shapiro, and Swinney (2008) show reactivation of the moved NP in its original post-verbal

[2] This generalization holds for sentences that do not start with a non-subject element (such as "yesterday"). Sentences that start with such element trigger a different type of movement and creates V-NP order regardless of the verb type. Therefore such sentences do not qualify as a diagnostic of unaccusativity/unergativity.

position in NP-V sentences containing unaccusatives, but not in NP-V sentences containing unergatives.

Some support for the distinction between unaccusative and unergative verbs comes from aphasia. Individuals with agrammatic aphasia present a somewhat mixed pattern of performance. Their comprehension of unaccusative verbs is relatively normal, and usually no difference is found in the comprehension of unaccusatives and unergatives (Lee & Thompson, 2004; Piñango, 2000; Thompson, 2003). On the other hand, individuals with agrammatic aphasia produce very few unaccusatives (Kegl, 1995) and show greater difficulty in producing unaccusatives compared to unergatives (Biran & Friedmann, 2008; Lee & Thompson, 2004; Thompson, 2003) and transitives (Bastiaanse & Zonneveld, 2005; Biran & Friedmann, 2008). Furthermore, Biran and Friedmann (2008) report that patients with aPASia (impaired access to Predicate Argument Structure information) following fronto-temporal and temporo-parietal lesions tend to add a redundant argument to unaccusatives (e.g., *He fell the boy*) and to use an animate argument (which is less frequent for unaccusatives). This pattern of production errors may suggest an impairment in the execution of lexical operations (for example, a failure to reduce the agent).

The present study examines the patterns of cortical activation that are associated with the comprehension of unaccusatives. Although the comprehension of unaccusatives involves many interesting aspects (such as the exact nature of their derivation or unergative/unaccusative alternation), this study specifically aims to examine whether, as predicted by linguistic theory, the cortical representation of unaccusative verbs differs from that of unergative and transitive verbs or, more generally, verbs that do not undergo either lexical operation or syntactic movement.

METHODS

Participants: Eighteen healthy volunteers (7 females) aged 22-44 (mean age: 28;4) participated in the experiment. They had normal hearing, no language impairment, and no psychiatric or neurological history. All participants were native speakers of Hebrew, which was their sole mother tongue. They were all right handed (as assessed by the Edinburgh handedness inventory, Oldfield, 1971). Written informed consent was obtained from all subjects. The Tel-Aviv Sourasky Medical Center and Tel Aviv University ethics committees approved the experimental protocol.

Materials and Procedure: The experiment included 42 verbs of three categories: unaccusative verbs, unergative verbs, and transitive verbs (see *Appendix A* for a full list). The verbs for the unaccusative and unergative conditions were chosen based on two distinguishing criteria of word order and possessive datives: intransitive verbs that could be used in V-NP sentences and could appear with possessive datives were classified as unaccusatives and intransitive verbs that could not appear in these environments were classified as unergatives (Siloni, 2008). Each verb appeared in two different sentences forming a total of 84 sentences for the entire experiment. Sentences of all three conditions included a subject (*theme* in the case of unaccusatives, and *agent* in the case of unergatives and transitives), the verb, and two additional constituents: in the sentences with unaccusative and unergative verbs– a PP (prepositional phrase) adjunct and modifier[3] or an additional adjunct, and in sentences with transitive verbs– a PP complement and an adjunct or a modifier, so that in the case of the unaccusative and unergative verbs, the PPs were adjuncts and in sentences with transitive verbs, the first PP was a complement of the verb. Examples for sentences from each condition are presented in Table 1. The number of verbs of the *kal* template was controlled across conditions, because, unlike other verb templates, this template was assumed not to be derived by a morphological operation. Half of the sentences in each condition had an animate subject and half had an inanimate subject. In all of the sentences, the verb was inflected for third person singular and past tense. Half of the sentences of each condition included a feminine subject (and hence the verb was inflected for the feminine), and half a masculine subject. The structure of the complements and adjuncts was controlled across conditions. The verbs were controlled for frequency as determined by the Hebrew Word Frequency Database (Frost & Plaut, 2005). ANOVA showed no significant differences among the various conditions ($F(2, 41) = 1.05$, $p = .35$ for the combined frequency of masculine and feminine forms; mean frequency = 8.7, 10, and 20.2, for unaccusatives, unergatives, and transitives respectively). The number of syllables in each sentence was controlled and ranged between 11 and 14 syllables (mean = 12.5; mean duration [ms] = 1862.6, 1899.9, 1895.6, for unaccusatives, unergatives, and transitives, respectively). There were no duration differences among the three conditions ($F(2, 83) = .39$, $p = .67$).

[3] ‘‘Adjunct’’ stands for any phrase that is not required by the verb, and can be attached to every verb, usually in the form of time and place descriptions, e.g., ‘‘at the wedding’’ in the sentence ‘‘John broke the glass at the wedding’’. ‘‘Modifier’’ stands for any phrase added to a complement, such as ‘‘yellow’’ in the sentence ‘‘John touched the yellow shirt’’.

Table 1. Example sentences of each condition.

Condition	Examples
Unaccusatives	ha-yeled nafal [me-ha-mita ha-xadasha]
	The-boy fell [from-the-bed the-new]
	The boy fell [from the new bed] $_{adjunct}$
Unergatives	ha-yalda hit'atsha [al ha-shatiax ha-adom]
	The-girl sneezed [on the-carpet the-red]
	The girl sneezed [on the red carpet] $_{adjunct}$
Transitives	ha-yeled nish'an [al ha-ec ha-gavoha]
	The-boy leaned [on the-tree the-tall]
	The boy leaned [on the tall tree] $_{complement}$

Sentences were divided into 21 blocks and each block consisted of four sentences with verbs of the same condition. Each condition was repeated 7 times. Each verb appeared in a block only once. In each block, half of the sentences included a subject and a verb in a masculine form and half of the sentences were in a feminine form. The blocks and the sentences in each block were presented in a pseudo-random order (which was determined using a Matlab script), with no more than two consecutive blocks of the same condition. The presentation of each block lasted 14 seconds. Sentences were separated by silence periods of 1500 ms. A tone was heard at the end of each block to signal 6 or 8 seconds of silence. During silence, subjects were instructed to concentrate on the noises of the MRI scanner. Stimuli were delivered to the subjects via MRI compatible headphones using Presentation software (http://nbs.neuro-bs.com).

Throughout the experiment, participants performed a comprehension task to ensure that they attended to the sentences and processed them fully. In this task, the subjects were asked to listen to the sentence and decide whether the event described in the sentence was more likely to happen at home or not. Responses were given during the intra-block silences (responses were not allowed before the end of a sentence or after the beginning of the following sentence). Subjects were requested to press a "yes" or a "no" button with their left hand fingers (to avoid interference in frontal language areas) after the end of the sentence. For example, for the sentence "*Dan slept in the yellow tent*", participants had to press the "no" button; for the sentence "*Jane fell from the small chair*", they had to press the "yes" button. There were equal numbers of predicted "yes" and "no" responses in the entire experiment, and the number of predicted "no" responses in each block differed (ranging 1-3). All responses and reaction times were recorded.

Each participant completed a short practice session outside and inside the MRI scanner. The four practice blocks included sentences that were similar to those used in the experiment, but with verbs that were not included in the experiment. The experiment lasted 13 minutes and the entire imaging session (including practices, anatomical and other functional scans) lasted approximately an hour and a half.

Data Acquisition: MRI scans were conducted in a whole-body 3 Tesla, General Electric scanner, located at the Whol Institute for Advanced Imaging in the Tel-Aviv Sourasky Medical Center. Anatomical images for each subject were acquired using a 3D spoiled gradient echo (SPGR) sequence with high resolution, to allow volume statistical analyses in single subjects. The whole brain was covered by 150-166 slices, 1 mm thick (no gap). Functional MRI protocols included T2*-weighted images in runs of 392r volumes acquired in two separate functional sessions. We selected 33 sagital slices (based on a mid-sagital slice), 3.5 mm thick (no gap), covering the whole of the cerebrum and most of the cerebellum. We used FOV of 20 cm and matrix size of 64x64, TR = 2000ms, TE = 30, and flip angle = 90.

Data Analysis: Image analysis was performed using SPM2 (Wellcome Department of Cognitive Neurology, http://www.fil.ion.ucl.ac.uk/spm/). Functional images from each subject were motion-corrected, normalized to the SPM EPI template, resampled with a voxel size of 3 x 3 x 3 mm (Ashburner & Friston, 1999), and spatially smoothed using a Gaussian filter (6-mm kernel). The analysis assumed the general linear model (GLM, Friston et al., 1995) as implemented in SPM2. The BOLD response was modeled with the canonical hemodynamic response function (HRF). In the group level analyses, contrasts were examined using *t*-test with uncorrected p value ($p < .005$) and a minimum cluster size of 25 voxels and conjunction analyses were examined using uncorrected p value ($p < .01$) and a minimum cluster size of 15 voxels. The peak coordinates were transformed to Talairach space using mni2talsoftware (Brett, 1999) and areas of activations, as well as Brodmann areas (BA), were localized using Talairach daemon software (Lancaster, Summerin, Rainey, Freitas, & Fox, 1997). In addition, areas that were revealed in the conjunction analysis were defined as regions of interest (ROIs) using MarsBar (http://marsbar.sourceforge.net) in order to extract the average beta values of each cluster. For the beta values extraction, we used ANOVA design with all of the conditions.

RESULTS

The comparisons of the activations in response to unaccusative verbs and the other verb types indicated that, first, the brain distinguishes between unaccusative and unergative verbs, even when they appear in identical structures. The results further suggest cortical locations for the operations associated with unaccusative verbs.

First, we compared unaccusative verbs with each of the two other verb types separately. The comparison between unaccusatives and unergatives (unaccusatives > unergatives) revealed activations in the left inferior frontal gyrus (IFG; BA 45/46/47), left posterior middle temporal gyrus (MTG; BA 21), left medial superior frontal gyrus (SFG), and right cerebellum. Two of these areas, the left IFG (BA 45/46 and BA 47) and the left MTG, were also identified when comparing unaccusatives with transitives (unaccusatives > transitives), in addition to activations in the left inferior parietal lobule (iPL), left middle frontal gyrus (MFG) and the right MTG. These results are presented in Table 2.

Table 2. Coordinates, cluster sizes, and maximal *t* values of brain regions identified in the separate comparisons ($p < .005$, cluster size > 25) and the conjunction analysis ($p < .01$, cluster size > 15).

Region	**x**	**y**	**z**	**Cluster size (voxels)**	**t max**
Unaccusatives > Unergatives					
Left IFG (BA 45/46/47)	-51	30	12	131	5.47
Left MTG (BA 21)	-9	24	57	26	4.15
Left SFG	-60	-42	-12	28	3.91
Right cerebellum	36	-78	-45	48	5.22
Unaccusatives > Transitives					
Left IFG (BA 45/46)	-48	33	21	114	4.73
Left IFG (BA 47)	-39	30	-6	30	4.13
Left MTG (BA 21)	-63	-45	-15	26	4.54
Right MTG	45	-45	-6	45	5.52
Left iPL (BA 39)	-54	-57	39	65	4.38
Left MFG	-48	21	36	27	3.58
Conjunction Analysis					
Left IFG (BA 45/46)	-51	30	15	107	4.4
Left MTG (BA 21)	-63	-45	-12	15	3.16

The differential activations of the above comparisons arise from the differences between unergative and transitive verbs[4]. In order to identify the activations that relate to the lexical operation and the syntactic movement of unaccusatives, and distinguish them from activations linked to a specific difference between unaccusatives and each of the other types of verbs, we performed a conjunction analysis ([unaccusative > unergative] ∩ [unaccusative > transitive]). This analysis showed activations in the left IFG (BA 45/46) and the left posterior MTG (Table 2 and Figure 2).

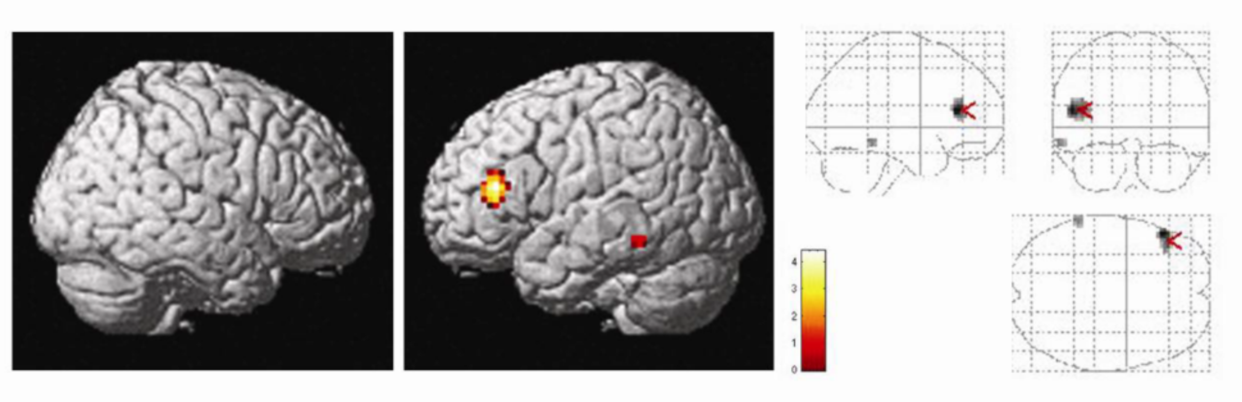

Figure 2. Regions activated in the conjunction analysis of the comparison of unaccusatives to unergatives and the comparison of unaccusatives to transitives ($p < .01$, cluster size > 15).

In order to quantify the difference between unaccusative verbs and the other verbs, we computed the average beta weights for each of the clusters that were identified in the conjunction analysis (Figure 3), so there were 2 X 3 beta weights for each subject (clusters X conditions). Using t-tests, we compared the average weights of the different conditions. Significant differences were found between unaccusative verbs and unergative verbs ($t(17) = 3.43$, $p = .0003$; $t(17) = 2.13$, $p = .0013$ in the left IFG and the left MTG respectively), as well as between unaccusative and transitive verbs ($t(17) = 3.7$, $p = .0003$; $t(17) = 0.34$, $p = .0029$ in the left IFG and the left MTG respectively). The differences between unergative and transitive verbs were not significant ($p = .98$; $p = .59$ in the left IFG and the left MTG respectively).

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[4] Unaccusatives, unlike unergatives, often describe unfortunate events (such as breaking, wrinkling etc.). Thus, areas that participate in the processing of such events may be activated solely in the comparison between unaccusative and unergative verbs. To control for these differences, we added transitive verbs that were chosen specifically to describe unfortunate events. Therefore, a conjunction between the two comparisons (unaccusatives > unergatives and unaccusatives > transitives) should eliminate the effects of unfortunate events as well as the effects of the number of arguments.

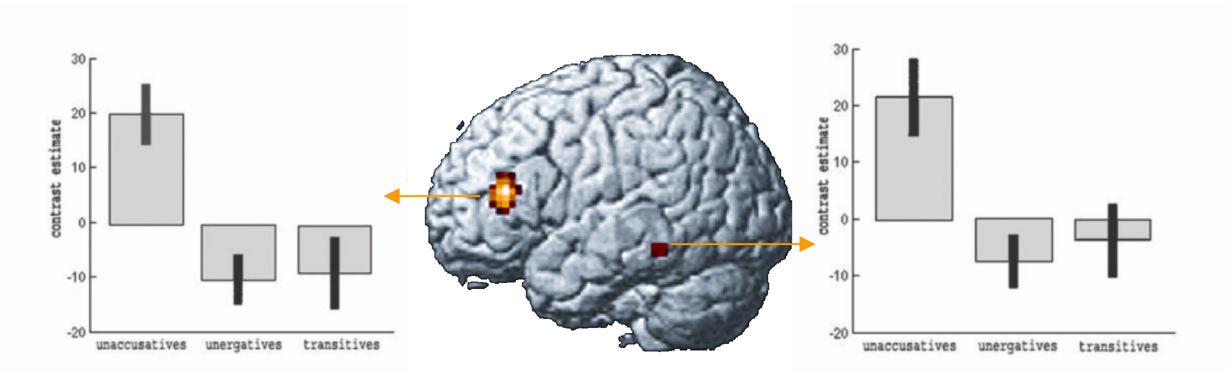

Figure 3. Beta weights with error bars extracted from clusters identified in the conjunction analysis in the left IFG (left chart) and in left MTG (right chart).

In a final analysis, we masked the comparison between unaccusative and transitive verbs (unaccusatives > transitives) with an inclusive mask of the comparison between unergative and transitive verbs (unergatives > transitives). This was done because both unaccusatives and unergatives are intransitive verbs and may differ from transitive verbs in similar ways. This comparison revealed activation only in the right posterior MTG.

DISCUSSION

This is the first neuroimaging study to specifically test the cortical activations associated with the processing of unaccusative verbs. According to linguistic theory, sentences with unaccusative verbs involve lexical and syntactic operations that do not occur in sentences with other verb types, such as unergatives or transitives (Chierchia, 2004; Perlmutter, 1978; Reinhart, 2002). First and foremost, the results of this study support this linguistic analysis by demonstrating differential activations of unaccusative and unergative verbs even when they are incorporated in identical sentence structures. These results join a growing body of findings from various methodologies and populations, suggesting evidence for the neuropsychological and psycholinguistic reality of this distinction generally, and for the analysis of unaccusative verbs specifically. The available findings come from developmental studies (Costa & Friedmann, in press; Friedmann, 2007; Lorusso et al., 2005; Pierce, 1989, 1992), on-line studies that tested reaction times (Friedmann, Taranto, Shapiro, & Swinney, 2008), and production studies with individuals with aphasia (Bastiaanse & Zonneveld, 2005; Biran & Friedmann, 2008; Kegl, 1995; Lee & Thompson, 2004; Thompson, 2003).

The comparison of unaccusative verbs to the two other verb types, as well as the conjunction analysis of both of these comparisons, have revealed two clusters of activations, one in the left IFG (BA 45/46) and one in the left posterior MTG (BA 21). These areas are assumed to take part in the execution of the lexical and syntactic operations. Although the present study cannot conclusively determine which operation is associated with each of the identified areas, inferences can be made on the basis of previous findings regarding the functions of the areas that we identified.

The left IFG, and especially Broca's area (BA 44/45), has been consistently linked to syntactic processing, across a wide range of approaches and methods (Ben-Shachar, Hendler, Kahn, Ben-Bashat, & Grodzinsky, 2003; Ben-Shachar, Palti, & Grodzinsky, 2004; Caplan, Alpert, & Waters, 1999; Constable et al., 2004; Dapretto & Bookheimer, 1999; Friedmann, 2006; Friedmann and Shapiro, 2003; Grodzinsky, 2000, 2006; Moro et al., 2001; Shetreet, Friedmann, & Hadar, 2009; Stromswold, Caplan, Alpert, & Rauch, 1996; Zurif, 1995). Specifically, this area has been associated with the processing of syntactic movement. Individuals with agrammatic aphasia, who have a lesion in the left IFG, often fail to understand sentences with moved constituents, following either an A-movement in structures such as passive sentences (Grodzinsky, Piñango, Zurif, & Drai, 1999; Luzzatti et al., 2001) or a Wh-movement in structures such as object relatives or Wh-questions (Caramazza & Zurif, 1976; Friedmann & Shapiro, 2003; Grodzinsky, 2000). In addition, healthy subjects show consistent activations in Broca's area in response to sentences that include movement (Dapretto & Bookheimer, 1999; Ben-Shachar et al., 2003, 2004; Constable et al., 2004; Grodzinsky & Friederici, 2006; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Stromswold et al., 1996). This may imply that the activation in the IFG with regard to unaccusative verbs is related to the syntactic movement of the object to the subject position[5].

However, the part of the IFG activated in the current study, i.e., Brodmann area 45/46, is slightly anterior to Broca's area. This anterior region of the IFG was also found to be activated during syntactic processing (Caplan, Alpert, & Waters, 1998; Kang, Constable, Gore, & Avrutin, 1999). By contrast, other studies attributed the activation in BA 45/46 to lexical and semantic processing (Homae, Hashimoto, Nakajima, Miyashita, & Sakai, 2002; Suzuki & Sakai, 2003). Sakai and colleagues (Homae et al., 2002; Suzuki & Sakai, 2003) argue that the

[5] According to the VP internal subject hypothesis (e.g., Kitagawa, 1986; Koopman & Sportiche, 1991; Kuroda, 1988), all subjects originate within the VP and move to spec-IP, regardless of the verb type. That is, a movement of the subject from within the VP to spec-IP occurs for both unaccusatives and unergatives. The subtraction analysis we conducted here, which compared unaccusatives and unergatives, was targeted to eliminate the processing effects that are shared by both verb types, and leave only the differential effects for these verb types. The fact that this comparison revealed activation in the IFG, attributed to movement processing, suggests that there is movement that occurs with unaccusatives but not with unergatives. Thus, these findings support the assumption that the A-movement of unaccusative verbs in sentences of NP-V order actually involves two movements: one from object to subject position (which does not occur for unergatives), and one from spec-VP to spec-IP, which occurs with all verb types (see Costa & Friedmann, in press, Friedmann, 2007, and Silva, 2004, for this syntactic analysis which was suggested on independent grounds).

activation in this area is related to integration of semantic information of different words during sentence comprehension. This is in line with other claims that the anterior part of the IFG is associated with the processing of thematic information of the verb's arguments (Caplan, Stanczak, & Waters, 2008; Newman, Just, Keller, Roth, & Carpenter, 2003). In NP-V sentences with unaccusatives, the object/*theme* is placed in the subject position and therefore the assignment of thematic role is different from the canonical one, in which the subject position is associated with the *agent* role. Such deviation from the canonical order of thematic assignment may load onto areas that participate in the processing of thematic information. Thus, it may be that the activation in the IFG in the current study also involves linking the thematic role which is assigned to the post-verbal position with the NP that moved to the subject position.

The other area identified in the conjunction analysis is *the left posterior MTG*. The posterior left temporal regions, including the MTG, have been associated with lexical and semantic processes (Demonet et al., 1992; Friederici, Optiz, & von Cramon, 2000; Gold et al., 2006; Humphries, Binder, Medler, & Liebenthal, 2006; Kotz, Cappa, von Cramon, & Friederici, 2002; Palti, Ben-Shachar, Hendler, & Hadar, 2007; Price, Moore, Humphreys, & Wise, 1997; Rissman, Eliassen, & Blumstein, 2003). Furthermore, the posterior MTG has been reported to be activated in verb processing (Kable, Spellmeyer-Lease, & Chatterjee, 2002; Perani et al., 1999; Tyler, Randall, & Stamatakis, 2008). These findings may suggest that the MTG is involved in the lexical aspects of processing unaccusative verbs. The lexical operation of unaccusative verbs in Hebrew is often linked to a morphological change, and this may imply that the MTG also executes a morphological operation. However, the fact that some of the unaccusative verbs used in our experiment did not involve any morphological change supports the idea that this area is specifically involved in the processing of the lexical operation.

More direct support for the role of the left posterior MTG in performing the lexical operation comes from a study that tested another type of lexical operation. Some verbs allow the omission of their objects (e.g. *John ate at midnight* compared with *John ate an apple at midnight*). This omission is achieved using a lexical operation that saturates the thematic role of the object within the lexicon (Bresnan, 1982; Dowty, 1978, 1989). The middle fusiform gyrus (BA 20/37) was identified as the best candidate for executing this operation (Shetreet, Friedmann, & Hadar, in press). This area is located just medially to the posterior MTG. This may suggest that the posterior middle temporal regions subserve lexical operations with sub-regions that are specialized for different operations: the medial region (fusiform gyrus) may subserve lexical saturation whereas the lateral region (posterior MTG) may support lexical reduction.

The possible identification of an area in which a lexical operation takes place when one hears an unaccusative verb sheds light on an interesting question in the psycholinguistics of lexical operations. Whereas various accounts agree that a lexical operation takes place in unaccusative verbs, it is not clear whether such an operation takes place each time an unaccusative verb is encountered, or whether it is an operation that, at some point in lexical acquisition, takes place, and from then on the verb is already stored in its derived, unaccusative, form. The finding that an area related to lexical operations is activated when an unaccusative verb is heard supports the first kind of approach, according to which this derivation takes place upon each encounter with the verb.

Other activations were identified only in the comparison of unaccusatives with unergatives (left SFG and right cerebellum) or only in the comparison of unaccusatives and transitives (left MFG, left iPL, and right MTG). All of these activated areas were previously linked to language processing (Ackermann, Wildgruber, Daum, & Grodd, 1998; Binder et al., 1997; Bottini et al., 1994; Desmond & Fiez, 1998; Fabbro, Moretti, & Bava, 2000; Marien, Engelborghs, Fabbro, & De Deyn, 2001; Palti, 2007; Picard & Strick, 2001; Postle, McMahon, Ashton, Meredith, & de Zubicaray, 2008; Price, 2000; Shetreet et al., 2009; Silveri, Leggio & Molinari, 1994). In our study, these activations are assumed to be associated with processes other than the lexical and syntactic operations that construct sentences with unaccusatives.

Interestingly, the right posterior MTG, which was found in the comparison of unaccusatives and transitives, and not in the comparison of unaccusatives and unergatives, was also found in the comparison between unergatives and transitives. This activation may arise from the differences between the prepositional phrases that followed the verbs, which originated from the basic difference between transitive and intransitive verbs. In the present study, transitive verbs, which have complements, were followed by subcategorized prepositions, whereas unaccusative and unergative verbs were followed by meaningful prepositions. Meaningful prepositions, like place prepositions (e.g., *on* in *The book is on the table*) convey semantic information about space organization. By contrast, subcategorized prepositions (e.g., *on* in *The farmer relied on the rain*) are obligated by the verb and are not semantically motivated (Neeleman, 1997). Support for the difference between meaningful and meaningless prepositions was found in reaction time experiments (Friederici, 1985) and in studies with patients with agrammatic aphasia (Druks, 1991; Friederici, 1982; Mätzig, 2009;

Zurif, Caramazza, & Myerson, 1972) and patients with Wernicke's aphasia (Friederici, 1982). The right posterior MTG was linked to space processing (Kalénine et al., 2009) and this may underlie its activation in response to (meaningful) place preposition in the present study.

In conclusion, our findings indicate that brain activation is sensitive to the difference between unaccusative and unergative (and transitive) verbs, hence supporting the linguistic analyses of the difference between unaccusative and unergative verbs. They join past psycholinguistic findings to demonstrate the neuro-psychological reality of the linguistic distinction. These differences arise from syntactic and lexical operations that are executed for the derivation of unaccusative verbs, which may be performed in the left IFG (BA 45/46) and in the left posterior MTG respectively.

APPENDIX A

Unaccusatives: hitkavec (*shrank*), hitkalkel (*broke down*), naval (*withered*), hitkamet (*became wrinkled*), namas (*melted*), hitrasek (*crashed*), hitparek (*fell apart*), hitmotet (*collapsed*), hitlaxlex (*became dirty*), hityabesh (*dried*), nafal (*fell*), hitkarer (*cooled down*), nirtav (*got wet*), hitkalef (*got peeled*).

Unergatives: nacac (*sparkled*), tiftef (*dripped*), hivhev (*flickered*), hidhed (*echoed*), cifcef (*beeped*), xarak (*squeaked*), caf (*floated*), nirdam (*fell asleep*), nax (*rested*), hit'atesh (*sneezed*), hishta'el (*coughed*), yashan (*slept*), micmec (*blinked*), pihek (*yawned*).

Transitives [subcategorized preposition]: naga [be] (*touched*), hegen [al] (*protected*), hezik [le] (*harmed*), histagel [le] (*adapted to*), hishtalet [al] (*took over*), nish'an [al] (*leaned on*), paga [be] (*hurt*), nig'al [me] (*was disgusted by*), tipel [be] (*treated*), hictaref [le] (*joined*), hit'alem [me] (*ignored*), nitkal [be] (*bumped into*), nirta [me] (*flinched*), hitgaber [al] (*overcame*).

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