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Computation of semantic number from morphological information ☆

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Abstract

The distinction between singular and plural enters into linguistic phenomena such as morphology, lexical semantics, and agreement and also must interface with perceptual and conceptual systems that assess numerosity in the world. Three experiments examine the computation of semantic number for singulars and plurals from the morphological properties of visually presented words. In a Stroop-like task, Hebrew speakers were asked to determine the number of words presented on a computer screen (one or two) while ignoring their contents. People took longer to respond if the number of words was incongruent with their morphological number (e.g., they were slower to determine that one word was on the screen if it was plural, and in some conditions, that two words were on the screen if they were singular, compared to neutral letter strings), suggesting that the extraction of number from words is automatic and yields a representation comparable to the one computed by the perceptual system. In many conditions, the effect of number congruency occurred only with plural nouns, not singulars, consistent with the suggestion from linguistics that words lacking a plural affix are not actually singular in their semantics but unmarked for number.

Keywords: Semantics; Morphology; Numerosity; Stroop; Hebrew

The concept of number has a double life in human cognition. One side may be called *conceptual number*: people can detect and reason about small numerosities with the help of perceptual mechanisms for individuating objects that develop in infancy and are shared with many other species (Butterworth, Cappelletti, & Kopelman, 2001; Carey, 2001; Dehaene, 1997; Geary, 1994). The other side may be called *semantic number*: people must engage in particular linguistic computations about number when using words and sentences according to the lexical conventions and grammatical rules of their language (Bloom, 1990; Chierchia, 1998; Jackendoff, 1991, 1996; Rijkhoff, 2002; Winter, 2002).

The distinction is manifested in many ways. Whereas infants, adults, and many animals readily distinguish particular numerosities up to four as well as aggregates of large numbers, particular languages may force the speakers of a language to dichotomize numerosity into

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singular and plural or to carve up the number line into singular/dual/plural or singular/dual/trial/plural. Moreover, the semantic number of a word is not fully determined by its reference, and hence cannot be computed from perceptual information alone. In particular, semantic number is restricted to semantic individuals: count nouns (e.g., *chairs*) can be semantically individuated and can take semantic number, whereas mass nouns (e.g., *furniture*) are semantically unindividuated and are devoid of semantic number. Such individuation may be specific to the lexical item (e.g., the difference in English between the count noun *noodle* and the mass noun *spaghetti*) and to the particular language (e.g., *spaghetti* is singular in English but plural in Italian). Similarly, a given scene, such as a chair and a table, may be denoted by a mass noun in one language (e.g., *furniture*, in English) and a count noun in another (e.g., *rahitim*, plural of *rahit*, in Hebrew). Semantic number can also be computed in the absence of lexical knowledge about a word's properties with the help of the grammar, specifically, the morphology. English speakers, for example, conclude that *blixes* denotes semantic plurality (several instances of the blix kind), whereas *blix* may be mapped onto a single individual. And once assigned, semantic number serves as a feature (like gender, person, or animacy) that may enter into grammar-internal computations such as agreement, concord, and the choice of determiners like *one*, *much*, and *many*.

Though conceptual and semantic number may be distinguished, they are clearly related. Semantic number refers to the numerosity of semantic individuals—bound, indivisible atoms of a single kind (Bloom, 2000; Jackendoff, 1991; Landman, 1996; Rijkhoff, 2002; Winter, 2002). The individuation of semantic atoms and their enumeration is computed by the semantic system, but this linguistic computation appears to be modulated by biases of human perception and cognition. For example, in languages with a count–mass distinction, easily distinguishable objects such as dogs are likely to be count nouns, homogeneous substances such as water are likely to be mass nouns, unbounded aggregates (which may be perceived either as a substance or as a collection of individuals) may be either (e.g., *pebbles/gravel, beans/rice*), and bounded aggregates (which may be perceived as a whole consisting of parts) are likely to be collective count nouns (e.g., forest).

In addition to the possible influence of the perceptual processes that distinguish individuals, substances, and collections, there may be influences of the cognitive processes that distinguish individuals and kinds. Across languages, plurals are typically marked for number overtly (e.g., by affixation), whereas singulars often lack any overt marking, as in the English contrast between *dog* (singular) and $dog + s$ (plural) (Greenberg, 1963). Linguists refer to this asymmetry in terms of singularity being *unmarked*, that is, the more expected, basic, and frequent value of a linguistic contrast (Greenberg, 1966; Tiersma, 1982). The phonological and morphological unmarkedness of singulars is in turn related to their semantic number: the singular form may be used not only to refer to a single individual but to a *kind*, treated as neutral with respect to number. For example, a *dog-lover* (incorporating morphologically unmarked *dog*) does not love a single individual canine, but dogs in general (Corbett, 2000; di Sciullo & Williams, 1987). Thus, the semantic number of singulars is ambiguous: by default (i.e., in the absence of lexical or conceptual information) the grammar may assign semantic number only to plurals; singulars may remain unspecified for semantic number.

Despite the large linguistic literature on semantic number, which frequently speculates on cognitive and perceptual biases involving conceptual number, there have been few experimental studies that actually examine the real-time processes that underlie the mapping between conceptual and semantic number. For example, we do not know whether people automatically compute the semantic number of singular or plural nouns as they encounter them, whether semantic number interfaces directly with the conceptual number computed by the perceptual system, or whether this interface shows the biases that linguists invoke to explain the distribution of marked, unmarked, singular, plural, count, mass, and collective forms across languages. The present paper reports the use of a novel technique to investigate this process, and findings on some of its salient characteristics.

Several studies have investigated the hypothesis that during on-line sentence production, people categorize morphologically singular forms as unspecified for number rather than conceptually singular. Subject–verb agreement is erroneously disrupted by the presence of an intervening noun (an attractor) whose number is incongruent with the subject. Interestingly, the pattern of interference is asymmetrical: Plural attractors interfere with singular subjects (e.g., *The key to the* ***cabinets*** *were lost*), but singular attractors do not reliably interfere with plural subjects (e.g., *The keys to the* ***cabinet*** *was lost* see Bock & Eberhard, 1993; Bock & Miller, 1991; Eberhard, 1997; Fayol, Largy, & Lemaire, 1994; Vigliocco, Butterworth, & Garrett, 1996).

Although the failure of singular nouns to interfere with syntactic agreement is consistent with the idea that they are unspecified for number, this finding may be specific to the computation of semantic number as it enters into phrasal syntax; it may not speak to whether particular nouns encountered individually are categorized as referring to a kind rather than a singular individual. Indeed, when nouns are perceived in isolation, there is no evidence that number distinctions are computed at all. Schiller and Caramazza (2002) used the word-picture interference paradigm in German: participants were asked to name a picture corresponding either to a single object (e.g., one nose) or to two instances of the object (e.g., two noses). These pictures were presented with a distractor: a printed word whose grammatical number either matched or mismatched the number of objects on the screen (e.g., a plural word with two objects or with one object). Participants were insensitive to the congruency between the morphological number of the distractor word and the number of objects displayed. The null effect was not due to a simple failure to process the distractor, as participants were clearly sensitive to the semantic relatedness between the target and the distractor. Thus, although morphological number interacts with the language-internal process of agreement, it may not interact with the perception of bare nouns.

This investigation examines two questions about the cognitive processes at the interface between conceptual and semantic number. First, is the process that determines the semantic number of a noun autonomous—an automatic process that runs to completion despite its irrelevance to the task requirements (Logan & Cowan, 1984; Pavese & Umiltà, 1998; Tzelgov, 1997)? This will be addressed by seeing whether the semantic number of printed words affects the process of determining their conceptual number. Second, when people determine the semantic number of a noun from its morphology, do they assign it only for plurals, treating singulars as unmarked for number? The answer to the first question bears on the second one, because representations computed automatically may differ qualitatively from those constructed intentionally (Tzelgov, Meyer, & Henik, 1992). In particular, people may interpret a singular word like *dog* as indicating the kind "dog" under conditions that call for reflective judgment (the conditions that linguists investigate), but may interpret it as indicating a single dog when processing it automatically in real time (or vice versa). Accordingly, we assess the processing of the semantic number of nouns indirectly, under conditions that do not require explicit judgments of linguistic information. We employ a version of the Stroop procedure. Stroop-like procedures have been shown to be sensitive to grammatical information, such as gender (e.g., Costa, Kovacic, Fedorenko, & Caramazza, 2003; Miozzo, Costa, & Caramazza, 2002; Schriefers, 1993; Schriefers, Jescheniak, & Hantsch, 2005) and the phonological skeleton (Berent & Marom, 2005; Costa & Sebastian-Gallés, 1998). Our experiments use this method to examine the computation of semantic number.

Participants are presented with either one or two letter strings (which we call "strings") on a computer screen. They are asked to determine the number of strings (conceptual number) while ignoring their meaning (semantic number). The question of interest is whether the discrimination of conceptual number is affected by semantic number, which would suggest that

Table 1
The number congruency manipulation

	One string	Two strings
Singular	dog	dog dog
Plural	dogs	dogs dogs
Neutral	ddd	ddd ddd

the two are represented at a common level during the processes engaged by the task. Previous research examining the enumeration of digits, in which people must respond "2" when presented with, say, "7 7," has documented reliable effects of interference between discrimination of the number of digits presented and the numerosity they represent (e.g., Hock & Petrask, 1973; Pavese & Umiltà, 1998). Here, we examine whether there is similar interference from the semantic number of nouns, coming either from their lexical entry or their morphology. To this end, we compared three types of letter strings (see Table 1): singular words (e.g., *dog*), plural words (e.g., *dogs*), and a neutral condition consisting of repeated letters (e.g., *ddd*). As in English, Hebrew plurals are clearly marked by a suffix, whereas singulars are left unaffixed. If people compute semantic number from morphological marking automatically, then string enumeration should be impaired by incongruent number morphology. For instance, people may have difficulty responding "one" to a single instance of the plural noun *dogs*. The comparison of these congruency effects for singulars and plurals further allows us to examine how semantic number is computed. If semantic number is encoded for both singulars and plurals, then both should exhibit congruency effects: when the nouns are plural, it should be harder for participants to determine that one string is present and easier to determine that two strings are present compared to the neutral baseline; singulars should have the opposite effect. Experiment 1 examines the computation of semantic number from morphological information for existing words; Experiments 2 investigates whether numerosity can be extracted from the lexical properties of number words, whereas Experiment 3 investigates whether people can represent numerosity in the absence of lexical information, for nonwords.

Experiment 1

Experiment 1 examines the extraction of semantic number from morphological marking by comparing singular (e.g., *dog*) and plural (e.g., *dogs*) nouns. It also investigated whether the extraction of number depends on the regularity of the inflectional paradigm and the familiarity of the plural form (see Table 2). These manipulations depend on properties of Hebrew nominal inflection, which generates plurals by concatenating a

Table 2
The materials used in Experiment 1 (incorrect plural forms are asterisked)

	Regular base	Irregular base
Singular	kotz (thorn)	kol (voice)
Plural		
Regular suffix	kotzim	*kolim
Irregular suffix	*kotzot	kolot

suffix to the singular base. The choice of suffix depends on the gender of the base: regular masculine nouns are inflected with the suffix *-im*; irregular masculine nouns take the suffix *-ot*. In previous work we demonstrated several dissociations in the processing of regular and irregular masculine nouns (Berent, Pinker, & Shimron, 1999, 2002). If the extraction of numerosity depends on regularity (i.e., the relationship between the stem and the suffix), then congruency effects with regular and irregular plurals may differ in their magnitude. Conversely, it is possible that Hebrew speakers extract number on the basis of the plural suffix alone, irrespective of the stem. Because the irregular masculine suffix *-ot* happens to be the regular inflection for feminine nouns, the two suffixes, even processed in isolation, are equally reliable indicators of plurality. If numerosity can be extracted from the suffix alone, then regular and irregular plurals should yield comparable effects of numerosity.

If number in Hebrew can be extracted from the suffix alone, speakers should extract it not only for well-formed regular and irregular plurals but also for ungrammatical ones—irregular nouns with a regular suffix (in the case of the masculine nouns used here, *-im*) and regular nouns with an irregular suffix (in this case, *-ot*)—resulting in comparable effects of number congruency. If, in contrast, the extraction of numerosity depends on familiarity with the plural form, then any effect of number congruency should be stronger for correct (hence familiar) plurals than for incorrect (hence, unfamiliar) plurals (whether they are regularizations or irregularizations).

Method

Participants

Twenty Ben-Gurion University students participated in the experiment in partial fulfillment of a course requirement. They were all native Hebrew speakers with normal or corrected vision.

Materials

Sixty masculine nouns (30 regular, 30 irregular) served as stimuli (see Appendix A). Correct plurals were generated by concatenating the appropriate plural suffix to the singular base (*-im* for regulars, *-ot* for irregulars); incorrect plurals were generated by the reverse assignments. Regular and irregular nouns were arranged in matched pairs (see Appendix A). Members of a pair were matched on the number of letters (mean 3.8), and in 27 out of the 30 pairs, on the arrangement of consonants and vowels (e.g., irregular *kol* 'voice' and regular *kots* (*/koc/*) 'thorn,' which share a CVC structure). Thirty native Hebrew speakers rated the singular nouns for familiarity on a 1–5 scale (1 = rare, 5 = frequent). Irregular forms ($M = 3.7$) were rated as slightly more familiar than regular forms ($M = 3.0$, $F1(1,29) = 52.01$, $F2(1,29) = 31.32$; $\min F'(1,39) = 19.55$). In addition, 20 strings of three identical letters (e.g., *bbb*) were used as a neutral baseline, each presented three times in the experiment. Our choice of repeated letter strings as the neutral condition was designed to minimize its resemblance to potential Hebrew words. Because any string of alternating Hebrew letters (even vowel-less strings, e.g., *bdg*) is a potential word, a string of repeated letters is the least word-like letter combination. However, such strings do not represent a random sample (the Hebrew alphabet has only 22 letters), nor can they be meaningfully matched to the singular/plural pairs. Because the neutral condition violates the requirements for a repeated-measures analysis using items as a random variable, all subsequent comparisons of singulars and plurals to the neutral condition are conducted using participants as the sole random variable.

Singular words, plural words, and letter strings were presented in both the one-string and the two-string conditions. In the one-string condition, a single letter string was presented at the center of the screen; in the two-string condition, the string was displayed twice (simultaneously), separated by a space centered between the two strings. There were 300 one-string trials (120 with singular nouns, 120 with plural nouns, and 60 with repeated letter strings), and 300 two-string trials (with the same distribution of singular, plural, and repeated letter strings). In the set of plural trials, each base (30 regular and 30 irregular) was presented twice, once with the correct suffix and once with the incorrect suffix. To match singular and plural words for frequency of occurrence in the experiment, we repeated the 60 singular words twice. The stimuli were presented in a Courier New Hebrew font, size 18, using the E-prime software (Psychological Software tools).

To familiarize participants with the experimental procedure, we presented them with a practice session consisting of 16 one-string and 16 two-string trials. None of the practice words appeared in the experimental session.

Procedure

Participants were tested individually. Each trial began with a fixation point (+) at the center of the screen presented for 300 ms, followed by a blank screen presented for 300 ms, followed by the target, also at the center of the screen. The target consisted of either one or two strings. Participants were asked to indicate the number of strings by pressing the z or / keys for one and two strings, respectively. The target remained on the screen until the participant responded. Incorrect responses triggered a message presented for 400 ms. After the response, a blank screen was presented for 300 ms, followed by the next trial. Participants were given a short break in the middle of the session.

Results

We excluded from the response-time analyses all responses falling 2.5 *SD* above the mean or shorter than 200 ms (1.7% of the observations). These outliers were equally distributed across conditions. Three sets of analyses were conducted. One probed for number congruency (Stroop) effects for singulars and plurals (collapsing across the regularity of the stem and its relation to the suffix), a second analysis compared these conditions to the neutral condition, and the final analysis probed for effects of regularity and familiarity with plural nouns. In this and all subsequent experiments we adopt .05 as the level of statistical significance.

(i) The effect of number congruency: Singulars vs. plurals. The effect of congruency between the morphological number of the strings (singular or plural nouns) and the number of strings (one or two) is presented in Fig. 1. With singular nouns, participants were quicker to judge that one string was present than that two strings were present (481 to 508 ms); with plural nouns, they were slightly faster to judge that two strings were present (502 to 510 ms). This shows that the enumeration of word strings is modulated by their semantic number. We first tested for the effect of number by comparing singulars and plurals presented either as one or two strings by means of a 2 (number) × 2 (strings) on response time and response accuracy (shown in Table 3) using participants (*F*1) and items (*F*2) as random variables, as well as the min F' (Clark, 1973). There was a significant interaction in both response time and accuracy (see Table 4a).

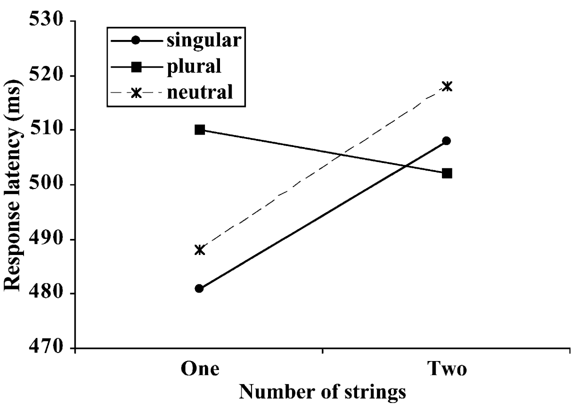

Fig. 1. Response time for singular words, plural words, and the neutral baseline, presented as either one or two strings in Experiment 1.

Table 3
Response accuracy (% correct) in Experiment 1

	One string	Two strings
Neutral	98.7	95.5
Singular	98.2	96.3
Plural	96.6	98.7

We next assessed the effect of plurality separately for one and two strings against the 95% confidence interval constructed for the difference between the means of singular and plural strings. The 95% confidence intervals in response time were 6.58 and 6.42 ms, calculated from the analyses of participants and items, respectively. For response accuracy, the respective confidence intervals were 1.11 and .96%, for participants and items, respectively. If the observed differences between singulars and plurals are reliable, then their magnitude should exceed the confidence interval constructed for the difference between their means (Loftus & Masson, 1994).[1] Compared against these confidence intervals, plurals elicited significantly slower ($\Delta = 29$ ms) and less accurate responses ($\Delta = 1.6\%$) relative to singular nouns in the one-string condition. Conversely, in the two-string condition, responses with plurals were significantly more accurate ($\Delta = 2.4\%$), albeit not significantly faster ($\Delta = 6$ ms) than with singulars.

[1] Note that these confidence intervals are constructed for the *difference* between means, rather than for *absolute* means. Loftus and Masson (1994) showed that these two types of confidence intervals are related by a factor of $\sqrt{2}$. They further demonstrated that the difference between any two sample means is significant by a two-tailed *t* test if any only if it exceeds the confidence interval constructed for the difference between those means (using the same α level). Accordingly, we test the reliability of the observed differences between means against the confidence intervals constructed for those differences. Confidence intervals are constructed by pooling the error terms from the respective simple main effects of plurality for one and two strings.

Table 4
Analysis of variance results for Experiment 1

Comparison	Source of variance		By participants		By items		Min F'	
			df	$F1$ value	*df*	$F2$ value	*df*	Min F' value
(i) The effect of number congruency: singulars vs. plurals	(a) 2 number (singular/plural) × 2 string (one/two)	RT	1, 19	47.36*	1, 29	71.64*	1, 48	28.51*
		%	1, 19	17.21*	1, 29	39.26*	1, 46	11.96*
(ii) Comparisons to the neutral condition	(b) 2 strings (one/two strings) × 3 type (singular/plural/neutral)	RT	2, 38	27.77*				
		%	2, 38	14.26*				
	(c) 2 type (singular/neutral) × 2 strings (one/two)	RT	1, 19	<1				
		%	1, 19	2.08				
	(d) 2 type (plural/non-plural) × 2 string (one/two)	RT	1, 19	64.07*				
		%	1, 19	23.85*				
(iii) The effect of regularity and familiarity with plural nouns	(e) Regularity	RT	1, 19	<1	1, 29	<1	1, 48	<1
		%	1, 19	<1	1, 29	<1	1, 46	<1
	(f) Familiarity	RT	1, 19	<1	1, 29	<1	1, 43	<1
		%	1, 19	<1	1, 29	<1	1, 42	<1
	(g) Regularity × familiarity	RT	1, 19	<1	1, 29	<1	1, 43	<1
		%	1, 19	2.66	1, 29	1.99	1, 42	1.14
	(h) String × regularity	RT	1, 19	3.04	1, 29	2.06	1, 41	1.23
		%	1, 19	<1	1, 29	<1	1, 48	<1
	(i) String × familiarity	RT	1, 19	<1	1, 29	<1	1, 45	<1
		%	1, 19	<1	1, 29	<1	1, 47	<1
	(j) String × regularity × familiarity	RT	1, 19	<1	1, 29	<1	1, 44	<1
		%	1, 19	3.55	1, 29	7.18*	1, 47	2.38
(iv) An analysis of strings that are matched for length	(k) 2 strings (one/two) × 2 number (singulars/plurals)	RT	1, 19	13.69*	1, 13	16.58*	1, 30	7.50*
		%	1, 19	<1	1, 13	<1	1, 16	<1

Note. Significant effects are marked by asterisk. RT, response time; %, accuracy.

(ii) A comparison to the neutral condition. To interpret the source of the differences between singulars and plurals, we next compare them to the neutral condition (a string of repeated letters). An inspection of the means (see Fig. 1) shows that singulars and plurals differ in their potential to interfere with an incongruent response: plurals slowed one-string response by 22 ms, whereas singulars did not interfere with two-string responses (a difference of −10 ms). This pattern is confirmed by the two-way ANOVAs (one/two strings × singular/plural/neutral string type) on response time and accuracy using participants as a random variable (as explained in Method, this analysis cannot be conducted using repeated measures on items). The analyses on response time and response accuracy both revealed a significant interaction between the number of strings and word type (see Table 4b).

To examine whether semantic numerosity is represented for both singulars and plurals, we next compared each of them to the neutral baseline. Because overall (main effect) differences between nouns (either singular or plural) and the neutral condition may be partly due to lexicality, we evaluated the effect of numerosity by testing for two orthogonal simple two-way interactions, one for singular nouns, one for plural nouns, of the number of strings and the nature of the letter string. If people compute both singular and plural semantic numerosity from singular and plural nouns, respectively, then the difference between one- and two-string responses should interact with the meaningfulness of the string in both cases. The ANOVA of singulars (singular/neutral × one/two strings) did not yield a reliable interaction (see Table 4c). Given that singulars do not differ from the neutral condition, we next collapsed across these two conditions and compared their mean to the plural condition. The one/two-string × plural/nonplural interaction was significant (see Table 4d), and it accounted for 74% of the sum of squares in the omnibus ANOVAs on response time and accuracy (two strings × three singular/plural/neutral). The 95% confidence intervals for the difference between the means of plurals and nonplurals were 6.13 ms and 1.08%, for response time and accuracy, respectively. These confidence intervals were next used to assess the reliability of the observed differences between plural and nonplural strings. With one string, plurals elicited significantly slower ($\Delta = 25$ ms) and less accurate ($\Delta = 1.89\%$) responses relative to nonplurals whereas with two strings, responses were significantly faster ($\Delta = 11$ ms) and more accurate ($\Delta = 2.78\%$) with plurals relative to nonplurals. These results suggest that semantic numerosity is computed only for plurals; singulars are unmarked for semantic number.

Table 5
Response time and accuracy for regular and irregular plural nouns in Experiment 1

	One string			Two strings		
	Correct suffix	Incorrect suffix	Mean	Correct suffix	Incorrect suffix	Mean
Regular	510	513	*511.5*	499	499	*499*
Irregular	509	508	*508.5*	503	508	*505.5*
Mean	*509.5*	*510.5*	*510*	*501*	*503.5*	*502.25*
Regular	97.5	95.8	*96.65*	98.5	98.7	*98.6*
Irregular	95.7	97.3	*96.5*	99.2	98.5	*98.85*
Mean	*96.6*	*96.55*	*96.57*	98.85	98.6	*98.72*

(iii) The effects of regularity and familiarity with plural nouns. In the final set of analyses, we examine whether the semantic numerosity of plurals is modulated by their regularity (i.e., regular vs. irregular plurals) and the familiarity with their plural form (i.e., correct plural forms—strings whose plural form is relatively familiar vs. strings whose plural form is incorrect, hence, relatively unfamiliar—either regularizations or irregularizations). This analysis is confined to plurals, discarding the singulars. Specifically, three-way ANOVAs were performed contrasting one and two strings, regular and irregular nouns, and familiar vs. unfamiliar plurals by participants and items (see Table 4e–j). Neither regularity nor familiarity affected the pattern of data. Likewise, the number of strings did not interact with either regularity or familiarity, nor was the three-way interaction significant. The means for these plural strings are provided in Table 5.

Discussion

The results of Experiment 1 demonstrate that the time people require to determine how many instances of a word are present is affected by whether the word is singular or plural: it takes longer to determine that one word is present when it is plural than when it is singular, and to determine that two words are present when they are singular than when they are plural, even when morphological number is irrelevant to the task. This suggests that people automatically extract the semantic number of nouns and represent it in the same format as the conceptual number that they are processing in the visual display. This effect, however, differed for singulars and plurals: plurals interfered with the determination that one string was present (compared both to the singular and the neutral conditions) whereas singulars did not interfere with the determination that two strings were present. The finding that semantic number is implicated only with plurals, not singulars, is consistent with the proposal by many linguists that the bare nouns used for the singular in languages like Hebrew are not encoded as singular per se but as being semantically unmarked for number.

The computation of semantic number in our experiment appears to have been triggered by grammatical, rather than lexical information, since the effect of semantic plurality was independent of whether the noun was regular or irregular and by whether it bore the correct or incorrect suffix. This effect may have occurred because in Hebrew, the suffix on an irregular plural noun is still a reliable plural marker, namely, the regular suffix for nouns of the other gender. This could encourage people, when they are attentive to number, to process the suffix in isolation from the stem. The fact that each stem was repeated many times in the experiment could have made it even easier for participants to have separated it from the suffix.

Before accepting this conclusion, however, we must ensure that the observed contrast between singulars and plurals was not caused by differences in their length. Hebrew plurals are longer than singulars, because they consist of the singular base plus a suffix. This means that the interference of plural nouns with the recognition that one string was present could have reflected a difficulty in categorizing long words, rather than plural words, as a single string. To test this alternative explanation, we divided the set of words into shorter stems (2–3 letter long, $M = 2.9$, $SD = .27$, $N = 14$) and longer stems (4–5 letter long, $M = 4.5$, $SD = .51$, $N = 16$, see Table 6). We next compared long singulars (mean length = 4.6 letters, $SD = 0.51$) to short plurals (mean length = 4.9 letters, $SD = 0.27$). If the effect of number congruency is an artifact of the greater length of plurals, then the effect of number congruency should be eliminated when the lengths of singular and plural words are matched. The mean response time and accuracy for those matched items are shown in bold typeface in Table 6. An analysis of this sample yielded a significant interaction of singular/plural × one/two strings for response time (see Table 4k). We next compared responses to singulars and plurals against the 95% confidence intervals constructed for their difference from the analyses by participants (10.24 ms) and items (7.26 ms). A comparison to these

Table 6
Response time and accuracy in Experiment 1, controlling for length

	One string			Two strings		
	Singular	Plural	Mean	Singular	Plural	Mean
Short	482	**505**	494	517	**504**	510
Long	**482**	513	498	**502**	500	502
Mean	*482*	509	495	*509*	502	506
Short	98.4	**97.7**	98.1	95.1	**98.3**	96.7
Long	**98.0**	95.6	96.8	**97.4**	99.1	98.2
Mean	*98.2*	96.7	97.42	*96.2*	98.7	97.5

Length-matched conditions are in boldface.

confidence intervals suggests that it took significantly longer to determine that a single string is present when the string was a plural noun ($M = 505$ ms) than when it was a singular noun ($M = 482$ ms, $\Delta = 23$ ms), whereas it took the same amount of time to determine that two strings were present regardless of whether they were singulars ($M = 502$ ms) or plurals ($M = 504$ ms; $\Delta = 2$ ms). Thus, the failure of singulars to interfere with determining that two strings are present cannot be explained by their length.

Experiment 2

Though singular nouns did not interfere with the detection of multiple strings in Experiment 1, one might worry whether this insensitivity merely reflects some feature of the experimental method that prevents people from registering the singular number of a singular noun because of the particular task demands. Alternatively, it is possible that singularity is encoded, but it fails to interfere with responses to two strings because people encode the conjunction of two singular nouns (e.g., *dog, dog*) as conceptual plurality (e.g., *dogs*), a representation that is congruent with the two-string response. To address this explanation, Experiment 2 examines nouns whose meanings blatantly signal singular and plural numerosity, namely the number words for 'one' and 'two' in Hebrew. Not only do these words inherently convey semantic number but they also correspond to the labels of the categories that participants are asked to discriminate in this paradigm. These number words were compared to a neutral baseline, consisting of a series of repeated letters, whose length range from two to five letters. If the failure of singulars to interfere with numerosity judgments in Experiment 1 was due to a general avoidance of lexical access in this task, or to a processing stream that extracted singular number but for some reason represented it in a way was congruent with conceptual number of the response, then even the word for 'one' should not interfere with the detection of multiple strings in this task. Specifically, if people represent two singulars (*one one*) as the aggregate (*two*), then they should respond more quickly to two strings of the word "one" relative to the neutral condition. If, on the other hand, word meanings are accessed and counterposed to perceptual representations in this task, but singularity is ordinarily not part of the meaning of singular nouns, then an exceptional word that does strongly convey semantic singularity should interfere with the detection of multiple strings.

Method

Participants

Twenty Ben-Gurion University students participated in the experiment in partial fulfillment of a course requirement. All were native Hebrew speakers with normal or corrected vision.

Materials

The materials consisted of the Hebrew words for 'one' and 'two' in their masculine (*exad* and *shnaim*) and feminine (*axat* and *shtaim*) forms. The neutral condition consisted of repeated letters consisting of two to five letters (e.g., *ddd*). All items were presented in the one-string and two-string conditions. There were 80 trials with one string (20 singular, 20 plural, and 40 neutral), and 80 trials with two strings (same distribution). The neutral condition consisted of equal distributions of two, three, four, and five letter strings.

The practice session comprised 16 trials, divided equally among the one- and two-string conditions. Practice items were the same as the materials used in the experimental session. Otherwise the procedure was identical to that used in Experiment 1. The only exception is that participants were now asked to respond using the keys . and / (for one and two strings, respectively), allowing them to respond to both conditions using the index and middle fingers in the dominant hand.

Results

We excluded from the response time analyses all responses falling 2.5 *SD* above the mean or shorter than 200 ms (1.4% of the total correct responses). Outliers were distributed equally across conditions.

(i) The effect of number congruency for number words. Response times are shown in Fig. 2, accuracy levels in Table 7. With number words, as with the plural nouns in Experiment 1, determining the conceptual number of words in a visual display was modulated by the words' semantic number. Specifically, it was more diffi-

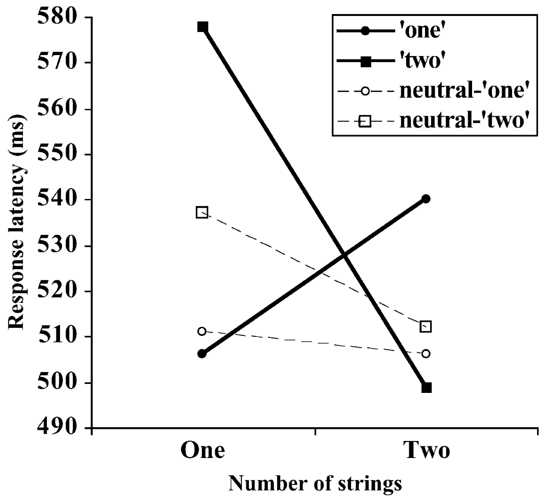

Fig. 2. Response time as a function of the number of strings and semantic numerosity for the words 'one' and 'two' and their respective neutral conditions in Experiment 2.

cult to determine that one word was present when it consisted of the word 'two' than when it consisted of 'one' (578 to 506 ms), whereas it took longer to determine that two words were present when they consisted of the word 'one' than when they consisted of the word 'two' (540 to 499 ms). This pattern is confirmed by the three-way ANOVAs on response times and accuracy (one/two strings × singular/plural number × masculine/feminine gender), which yielded a significant interaction between number of strings and singular/plural semantic number (see Table 8a). The three-way interaction was not significant (see Table 8b). We next compared responses to singular and plural strings against the 95% confidence intervals constructed for the difference between their means (33 ms, 3.5%, for response time and accuracy, respectively). In the one-string condition, responses to the word 'one' were significantly faster ($\Delta = 72$ ms) and more accurate ($\Delta = 4.5\%$) than responses to the word 'two.' In contrast, in the two-string condition, responses were significantly faster ($\Delta = 41$ ms, but not reliably more accurate $\Delta = 2.3\%$) for the word 'two' than to the word 'one.'

(ii) A comparison of number words to the neutral condition. To ensure that the effects of word meaning are not artifacts of length differences, we compared the responses to the words with the responses to the items in the baseline condition, namely strings of repeated letters. An inspection of the neutral condition (see Table 7) shows that the discrimination of one from two letter

Table 7
Response time and accuracy (% correct) in Experiment 2

	'One'	'Two'	Two letter neutral	Three letter neutral	Four letter neutral	Five letter neutral
One string	506	578	540	511	537	557
Two strings	540	499	540	506	512	493
One string	99.75	95.25	98	99.5	96.5	95.0
Two strings	96.5	98.75	90.0	98.5	98.0	98.5

Table 8
Analysis of variance results for Experiment 2

Comparison	Source of variance		By participants *df*	*F*1 value
(i) The effect of number congruency for number words	(a) 2 strings (one/two) × 2 number (singular/plural)	RT	1, 19	49.25*
		%		13.18*
	(b) 2 strings (one/two) × 2 number (singular/plural) × 2 gender (masculine/feminine)	RT	1, 19	2.05
		%		$F < 1$
(ii) A comparison of number words to the neutral condition	(c) 2 strings (one/two) × 2 length (short/long) × 2 number (number-word/neutral-string)	RT	1, 19	13.69*
		%		2.90
	(d) 2 strings (one/two) × 2 number ('one'/neutral-string)	RT	1, 19	10.53*
		%		2.49
	(e) 2 strings (one/two) × 2 number ('two'/neutral-string)	RT	1, 19	6.24*
		%		1.11

Note. Significant effects are marked by asterisk. RT, response time; %, accuracy.

strings was affected by the strings' length.[2] In view of the effect of length, we compared responses to the words for 'one' and 'two' against baseline strings that match the target on length (in Hebrew). For the word for 'one,' we chose a three-letter string as the baseline, whereas for the word for 'two,' we chose a four letter string as the baseline.[3]

Fig. 2 shows the pattern of discriminating short from long words interacted with whether the string was a number word or a neutral string, and whether the number was 'one' or 'two.' The three-way interaction of one/two strings × short/long × number-word/neutral-string was significant for response times and approached significance for accuracy (see Table 8c). Responses with the words 'one' and 'two' were next compared to their respective neutral conditions (short, for 'one'; long, for 'two') by means of two orthogonal two-way ANOVAs (one/two strings vs number-word/neutral-string). The simple interaction between the number of strings and whether those strings were words was significant for both 'one' (see Table 8d) and 'two' (see Table 8e) for response times. These interactions were not significant for accuracy. The difference in responses latency to number words and neutral strings was next compared against the 95% confidence intervals, computed for the difference between these means. The confidence intervals for 'one' and neutral strings was 19 ms; for 'two' and neutral strings, it was 29 ms. A comparison of the observed means against these confidence intervals showed that the word 'one' significantly interfered with two-string responses relative to the neutral condition ($\Delta = 34$ ms), though it did not facilitate responses to single strings ($\Delta = 6$ ms). In contrast, with the word 'two,' one-string responses were significantly slower than the neutral condition ($\Delta = 42$ ms), whereas two-string responses were not reliably faster than the neutral baseline ($\Delta = 12$ ms). These findings suggest that people automatically extracted the semantic numerosity of the words 'one' and 'two' when it is strongly signaled by lexical information.

Discussion

Experiment 2 confirms that the extraction of semantic number from words often proceeds automatically and yields a representation that is comparable to the one formed by the extraction of conceptual number from visual strings. Moreover, the results show that the asymmetry between singular and plural morphological forms in Experiment 1 (in which singulars appeared to be perceived as unmarked for semantic number rather than conveying singularity per se) cannot be attributed to some feature of the experimental task that artificially prevents people from attending to the content of the words or attenuates its sensitivity to conceptual singularity, because in this experiment, using the same paradigm, a singular word did interfere with the discrimination of the number of strings present. Presumably when semantic singularity is a salient part of a word's core meaning, number information, in a form comparable to that extracted from perception, is automatically available. Because the response categories in this experiment were labeled "one" and "two," we cannot determine whether the lexical effects occurred at the stage at which semantic numerosity is first extracted or at a stage of response competition. Either way, these findings demonstrate that the semantic number of "one" is automatically extracted from the word itself and interferes with the classification of conceptual numerosity from the visual input.

Experiment 3

The findings of Experiment 1 suggest that by default, people extract semantic number for plurals but not singulars. The fact that the extraction of semantic number was insensitive to lexical information (i.e., the regularity of the base and the familiarity with the plural form) further suggests that ordinarily, semantic number is automatically computed from morphological information alone.

Experiment 3 explores this possibility further by investigating the perception of numerosity when no lexical information is available, namely, from nonwords. Once again, it is necessary to show that any distinction between singulars and plurals is not due to their length, so this experiment compares singular and plural nonwords that are strictly matched on length (see Table 9): One member had three letters (e.g., *mik*) whereas

[2] We examined the effect of length in the neutral condition by means of a two strings (one vs. two) × length (1/2/3/4/ letters) ANOVA. The effect of length was significant in response time (1/2/3/4 letters × 1/2 strings; $F1(1,19) = 5.47$, $MSE = 1529$, $p < .003$) and accuracy ($F1(1,19) = 5.22$, $MSE = .005$, $p < .003$). As the strings' length increased beyond three letters, it was harder to respond to one string and easier to respond to two-strings. This trend did not hold for strings consisting of two letters, which were particularly difficult to classify in the one-string condition, perhaps because the twoness of the letters in the string was easier to pick up than other numerosities of letters (perhaps in turn because of the ease of representing two as opposed to higher numbers of object files, Carey, 2001), resulting in interference not from the number of strings but from the number of letters.

[3] The Hebrew word for 'two' consists of five letters, but two of these letters are *yod*, which is extremely narrow and short. Because our neutral baseline consisted of wide letters, the total physical length of the word 'two' was closer to a four-letter string than to a three-letter string. The Hebrew word for 'one' (אחד) which consists of three wide letters, was compared to three-letter strings.

Table 9
The nonword stimuli used in Experiment 3

	Singular	Plural	Neutral
Short	mik מיק	***mikim*** מיקים	mmm ממם
Long	***mikus*** מיקוס	mikusim מיקוסים	***mmmmm*** ממממם

Length-matched conditions are in bodldface.

the other member had five letters (e.g., *mikus*). Each member was presented in both its singular (e.g., *mik*, *mikus*) and plural (e.g., *mikim*, *mikusim*) forms. The neutral condition consisted of strings of either three or five letters. If semantic number is confined to plurals, then plurals, but not singulars, should impair the detection of an incongruent numerosity. That is, plurals should impair the determination that one string is present, but singulars should not impair the determination that two strings are present, irrespective of length. To test this prediction, we compare long singulars (e.g., *mikus*) to their matched short plurals (e.g., *mikim*) and to a neutral condition (e.g., *mmmmm*), each consisting of five letters.

Method

Participants

Twenty Ben-Gurion University students participated in the experiment in partial fulfillment of a course requirement. All were native Hebrew speakers with normal or corrected vision.

Materials

The materials consisted of 120 nonwords and 60 strings of repeated letters, representing the neutral condition. The nonwords (see Appendix B) comprised 30 matched quadruples including a three-letter singular (e.g., *mik*), a five-letter singular (e.g., *mikus*) and their corresponding plural forms (e.g., *mikim*, *mikusim*). The short singular invariably consisted of a CVC nonword, whereas the long plural consisted of a CVCVC nonword. Likewise, the neutral condition included strings of either three letters (matching the short singulars) or five letters (matching the short plural and long singular).[4] The resulting 120 items were presented both as one string and as two strings (a total of 240 trials per condition). The procedure is as described in Experiment 2.

Results and discussion

Correct responses falling 2.5 *SD* above the mean or shorter than 200 ms (2.5% of the data) were excluded from the response-time analyses.

The data will be presented in two ways. The first simply presents the short and long items separately, as if they were two replications of Experiment 1; this will show that the basic effect holds both with short and with long strings. The second presents data from the subsets of items in the two conditions that allow singulars and plurals to be equated for length, that is, the singular of long words and the plural of short ones.

(i) The effect of number congruency for short vs. long words. Mean response times for short (e.g., *mik*, *mikim*, *mmm*) and long (e.g., *mikus*, *mikusim*, *mmmmm*) nonwords are presented in Figs. 3A and B; the accuracy means are presented in Table 10. In each case, participants appear to be sensitive to the congruency between the plurality of the nonword and the number of letter strings: responses are more difficult when morphological number is inconsistent with the number of strings. As in Experiment 1, the interference from incongruent number appears to come only from the plurals; since singulars (both short and long) pattern with the neutral condition.

These conclusions are supported by ANOVAs (short/long × one/two strings × singular/plural) on response time and accuracy. Both analyses yield a significant interaction of the number of strings with plurality (see Table 11a). The three-way interaction did not approach significance (see Table 11b).[5]

(ii) The effect of number congruency for length-matched items. To demonstrate more conclusively that the effects of number congruency are not artifacts of length, we now examine the effects of number for singulars, plurals and neutral strings that are matched for length, that is, we compared long singulars (e.g., *mikus*) with short plurals (e.g., *mikim*) and the long neutral letter-strings—all of which are five letters long (see Fig. 4).

[4] Due to an error, the number of items in the two length groups was unbalanced (there were 50 long neural strings and 10 short neutral strings). However, the outcomes of the neutral condition remained essentially unchanged when the number of observations per condition was equated (by randomly removing the additional observations fro the long condition).

[5] Although the effect of number congruency was not reliably modulated by string length, an inspection of Fig. 3 suggests an intriguing difference: with short string plurals appear to facilitate response to two strings, whereas with long strings, plurals appear to inhibit response to one string. This difference can be explained by the overall bias towards "one-string" responses with short string, and towards "two-string" responses with long strings (a bias documented with the neutral condition of Experiment 2, see Footnote 2). Accordingly, single long strings and dual short strings manifest a conflict between the length-bias and the correct response. The resulting instability might render these conditions particularly sensitive to the effect of plurality.

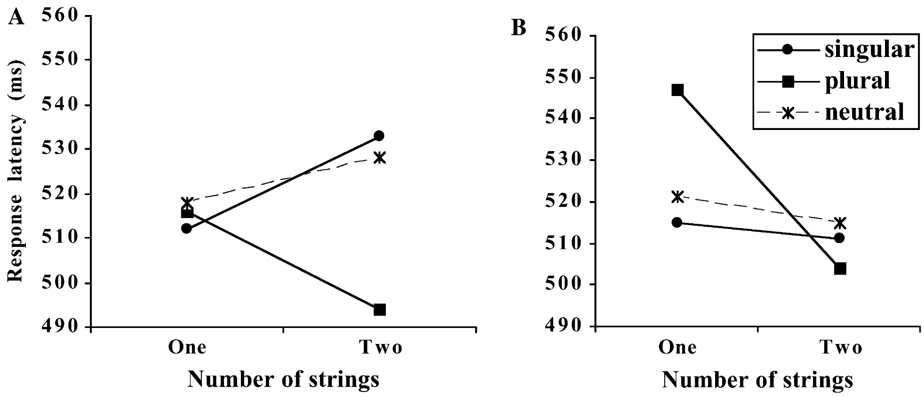

Fig. 3. Response time as a function of morphological number (singular vs. plural) and the number of strings (one vs. two) in Experiment 3 for short letter strings (e.g., *mik*, *mikim*, *mmm*, A); long strings (e.g., *mikus*, *mikusim*, *mmmmm*, B).

Table 10
Accuracy (% correct) in Experiment 3

	One string			Two strings		
	Singular	Plural	Neutral	Singular	Plural	Neutral
Short	98.67	**97.33**	99.0	96.50	**98.50**	97.75
Long	**98.33**	94.83	**98.40**	**98.17**	99.0	**97.0**

Length-matched conditions are in boldface.

The effect of number congruency: Singular vs. plural nonwords

We first assessed the effect of number congruency for word-like strings (omitting the neutral strings) in a 2 (one vs. two strings) × 2 (singulars vs. plurals) ANOVA using both participants and items as random variables. The interaction between singular/plural and one/two strings was significant in the analysis of response times over participants and marginally so over items (the same interaction did not approach significance in the accuracy data, see Table 11c). The 95% confidence intervals for the difference between the means of singulars and plurals were 14.69 and 13.87 ms, by participants and items, respectively. A comparison of the observed means against these confidence intervals showed that one-string responses did not differ for singulars ($M = 515$ ms) and plurals ($M = 516$, $\Delta = 1$ ms). In contrast, two-string responses were significantly faster for plural ($M =$ 494 ms) than for singular nonwords ($M = 511$ ms, $\Delta = 17$ ms).

A comparison to the neutral condition

We next compared the singular and plural nonwords to the neutral condition by means of a 2 (one vs. two strings) × 3 (singulars, plurals, and neutrals) ANOVA

Table 11
Analysis of variance results for Experiment 3

Comparison	Source of variance		By participants		By items		Min F'	
			df	*F*1 value	*df*	*F*2 value	*df*	Min F' value
(i) The effect of number congruency for short vs. long words	(a) 2 number (singular/plural) × 2 string (one/two)	RT	1, 19	19.16*	1, 29	36.25*	1, 48	12.53*
		%	1, 19	11.54*	1, 29	30.32*	1, 45	8.36*
	(b) 2 number (singular/plural) × 2 string (one/two) × 2 length (short/long)	RT	1, 19	<1	1, 29	<1	1, 23	<1
		%	1, 19	<1	1, 29	<1	1, 47	<1
(ii) The effect of number congruency for length-matched items	(c) 2 strings (one vs. two strings) × 2 number (singular vs. plural)	RT	1, 19	5.18*	1, 29	2.97	1, 39	1.89
		%	1, 19	1.60	1, 29	1.55	1, 46	<1
	(d) 2 strings (one vs. two strings) × 3 number (singulars/plurals/ neutrals)	RT	2, 38	2.77				
		%	2, 38	2.83				
	(e) 2 number(singulars/neutral) × 2 strings (one/two)	RT	1, 19	$F < 1$				
		%	1, 19	1.30				
	(f) 2 number (plurals/non-plurals) × 2 strings (one/two)	RT	1, 19	4.55*				
		%	1, 19	4.35				

Note. Significant effects are marked by asterisk. RT, response time; %, accuracy.

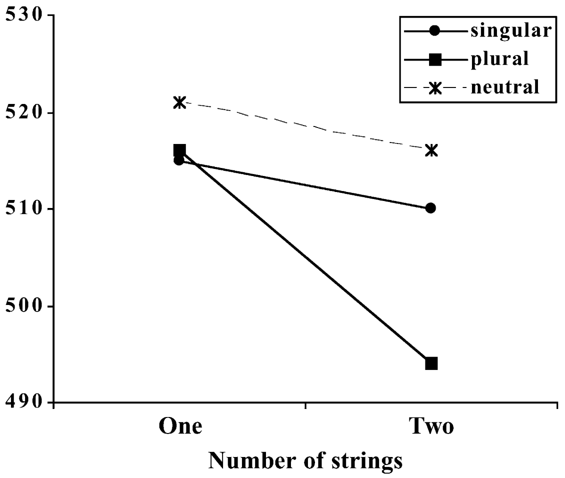

Fig. 4. Response time as a function of morphological number (singular vs. plural) and the number of strings (one vs. two) in Experiment 3 for length-matched strings of five letters (e.g., *mikus*, *mikim*, *mmmmm*).

by participants (as explained in Experiment 1, this analysis cannot be conducted using repeated measures on items). The interaction approached significance in both response time and accuracy (see Table 11d). We next compared singulars and plurals to the neutral condition using two orthogonal simple interactions. The first interaction compared singulars to the neutral condition by means of a 2 (singulars/neutral) × 2 (one/two strings) ANOVA. There was no hint of an interaction on either response time or accuracy (see Table 11e). Accordingly, we next collapsed the singulars and neutrals, and compared their mean to the plural condition in a second 2 (plurals/nonplurals) × 2 (one/two strings) ANOVA. Unlike singulars, for plural nonwords, the interaction was significant for response time and marginally so for response accuracy (see Table 11f). This simple interaction accounted for 75% of the sum of squares in the omnibus analysis on response time (singular/plural/neutral × one/two strings). The 95% confidence intervals for the difference between the means of plurals and non-plural strings were 15.23 ms and 1.20%, for response time and accuracy, respectively. A comparison of the observed means against these confidence intervals showed that responses to two strings were significantly faster with plural nonwords ($M = 494$ ms) relative to length-matched non-plural strings ($M = 513$ ms, $\Delta = 19$ ms). In contrast, with one strings, responses to plurals ($M = 516$ ms) and nonplurals ($M = 518$ ms; $\Delta = 2$ ms) did not differ reliably. Likewise, the plurality of a nonword did not reliably affect response accuracy with either one (1.03%) or two ($\Delta = .09\%$) strings.

In sum, results suggest that the discrimination of one from two letter strings is affected by morphological number of nonwords: responses for plurals differ from neutral letter strings, which, in turn do not reliably differ from a string of repeated letters. Although the discrimination of one from two strings is sensitive to word length, word length cannot account for the effect of number congruency. Not only did the congruency effect obtain for both short strings and long strings, but crucially, it obtained even when singulars, plurals, and letter strings were matched for length. In all cases, the effect of number is significant only with plurals, not singulars: plurals tend to impair responses to a single string and to facilitate responses to two strings, whereas the effect of singulars is similar to the neutral condition. These results suggest that morphological (and, consequently, semantic) number can be assigned by the grammatical processor even in the absence of lexical information, since nonwords lack such information entirely. Moreover, in the default case, semantic number is confined to plurals, with nouns lacking a number affix being interpreted as unmarked for number rather than singular in number.

General discussion

The findings of Experiments 1–3 demonstrate that readers extract the semantic number of bare nouns automatically and represent it in a way that is comparable to the conceptual number that they extract from visual perception. Because these effects of number congruency were observed when lexical semantic features are absent (for nonwords, used in Experiment 3), these results demonstrate that semantic number can be extracted via grammatical knowledge from morphological marking alone. The grammatical computation of semantic number can result in Stroop-like interference or facilitation in the judgment of the number of words in the display, despite the irrelevance of the grammatical number of the word to the task demands.

Our experiments consistently found the effect of number congruency with plurals, but failed to observe significant effects for singulars (other than the word for 'one'). Although we cannot rule out the possibility that an effect of grammatical singularity might be observed with sensitive methods, such an effect, if it exists, is far weaker than that of plurality. These conclusions are consistent with linguistic analyses suggesting that the representation of semantic number in a person's grammatical knowledge is restricted to plurals—when singulars are unspecified for morphological number, they may be unspecified or semantic number as well. The ability to encode a single value (e.g., plurality), without being committed to the opposing value (e.g., singularity) has long been proposed by linguists to explain patterns of overt- and zero-inflection, neutralization, borrowing, irregularity, and other phenomena.

This has been observed in the interpretation of number, such as the fact that a *birdwatcher* does not watch just one bird but birds in general (di Sciullo & Williams, 1987; Pinker, 1999). The unspecification of unmarked linguistic values is a widespread feature of language, and is seen in phonology as well as morphology (Chomsky & Halle, 1968; Greenberg, 1966; Smolensky, 2005; Steriade, 1995). Our findings show that unspecification may be a feature of the automatic cognitive processes that map number information onto words and affixes.

One open question concerns the generality of computation of semantic number across languages and syntactic contexts. Borer (2005) suggests that the grammatical computation of semantic number is subject to cross-linguistic variation. English and Hebrew, for example, appear to differ in their representation of singularity. In English, bare singulars are unspecified for number, whereas Hebrew singulars come both ways—either specified or unspecified for number. For instance, the Hebrew word for 'apple' (*tapuax*) can function in a manner that is equivalent either to the English *apple* or to *an apple*. This proposal explains why an English noun (e.g., *apple*) must be portioned out by a morpheme before it can be counted (*half an apple*, not **half apple*), whereas a Hebrew noun can directly combine with a fraction (e.g., *xaci tapux*, half an apple). If this account is correct, there must be cues that indicate which interpretation is appropriate in a given context. We found no evidence for the marking of number on bare Hebrew singulars presented in isolation, suggesting that the unmarked interpretation may be the default, and that the marked interpretation may require specific support from the syntactic context. The generality of the grammatical computation of semantic number across other contexts and other languages awaits further research.

A second question raised by our results concerns the interaction between the grammar and the lexicon in the computation of semantic number. Our finding that people are sensitive to the semantic numerosity of nonwords suggests that semantic number may be computed by the grammar based on morphological information alone, even when lexical semantic information is absent. However, linguistic analysis suggests that lexical semantic information may modulate the computation of semantic information. Specifically, Tiersma (1982) notes that in many languages, the default markedness of plurals is subject to exceptions based on the way their referents are encountered and hence conceptualized. Plurals referring to pairs, groups, and collectives (e.g., *data*, *teeth*, *mice*, *children*) tend to be treated as morphologically unmarked. In particular, they are often more frequent than their singulars, prone to irregularization, prone to double marking in dialects and in the speech of foreign speakers (e.g., *mices*), and susceptible to being the form of the word that is borrowed into other languages. These observations suggest that semantic number may sometimes be extracted from both the morphological marking and semantic information stored in the lexical entry of a stem, as might have happened in Experiment 2 in the case of the word for 'one.' That is, the default of unmarked singulars can be modified by lexical semantic features which make the plural the unmarked case. The interaction between grammatical and lexical information in the representation of semantic number requires further investigation.

In sum, the results of these studies show that semantic number is automatically computed by the grammar on-line from morphological inflections. Studies of real-time processing of numerosity and studies of the distribution of number-marking within and across languages can inform one another, and both are necessary for a complete understanding of the psychological phenomena related to number.

Appendix A. The singular forms of the regular and irregular nouns used in Experiment 1

Irregular			Regular		
Hebrew	Transcription	Gloss	Hebrew	Transcription	Gloss
דור	dor	generation	חור	xor	hole
סוד	sod	secret	חוט	xut	Thread
קול	kol	voice	קוץ	koc	Thorne
חוב	xov	debt	נוף	nof	View
נר	ner	candle	גן	gan	Garden
קיר	kir	wall	מיץ	mic	Juice
זוג	zug	pair	סוג	sug	Kind
לוח	luax	board	לול	lul	coop
עור	ʔor	skin	גוש	guʃ	Bulk
כוח	koax	force	בול	bul	Stamp
ארון	ʔaron	closet	מום	mum	Blemish

(*continued on next page*)

Appendix A (*continued*)

Irregular			Regular		
Hebrew	Transcription	Gloss	Hebrew	Transcription	Gloss
ריח	ɾeax	smell	חוש	xuʃ	Sense
גבול	gvul	boarder	גדוד	gdud	Brigade
רחוב	ɾexov	street	נאום	neʔum	Speech
חלום	χalom	dream	כדור	kadur	Ball
חלון	χalon	window	תנור	tanur	Oven
אסון	ʔason	disaster	אגוז	ʔegoz	Walnut
כינור	kinor	violin	כינוס	kinus	Convention
צינור	cinor	Hose	צימוק	cimuk	Raisin
וילון	vilon	curtain	רימון	ɾimon	Granade
חשבון	χeʃbon	calculation	חלבון	xelbon	Protein
יתרון	yitron	advantage	זרעון	zerʔon	Seed
דמיון	dimyon	similarity	דרכון	darkon	Passport
רעיון	ɾaʔayon	idea	פעמון	paʔamon	Bell
שטר	ʃtar	bill	פגם	pgam	Defect
מזל	mazal	luck	מבט	mabat	Look
גורל	goral	fortune	קולב	kolav	Hanger
אוצר	ʔocar	treasure	אלון	ʔalon	Oak
שולחן	ʃulxan	Table	אגרוף	ʔegrof	Punch
קורבן	korban	Victim	פתגם	pitgam	proverb

Appendix B. The short and long nonwords used in Experiment 3

Long-singular		Long-plural		Short-singular		Short-plural	
מיקוס	mikus	מיקוסים	mikusim	מיק	mik	מיקים	mikim
לישוף	liʃuf	לישופים	liʃufim	ליש	liʃ	לישים	liʃim
ליסוק	lisuk	ליסוקים	lisukim	ליס	lis	ליסים	lisim
גידון	gidun	גידונים	gidunim	גוד	gud	גודים	gudim
דימול	dimul	דימולים	dimulim	דול	dul	דולים	dulim
ביגוש	biguʃ	ביגושים	biguʃim	בוג	bug	בוגים	bugim
ניפוג	nipug	ניפוגים	nipugim	ניג	nig	ניגים	nigim
ריזוב	rizuv	ריזובים	rizuvim	ריז	riz	ריזים	rizim
שיפוג	ʃipug	שיפוגים	ʃipugim	שיף	ʃif	שיפים	ʃifim
סימוג	simug	סימוגים	simugim	סים	sim	סימים	simim
מידוג	midug	מידוגים	midugim	מיד	mid	מידים	midim
פידוב	piduv	פידובים	piduvim	פיד	pid	פידים	pidim
ביגול	bigul	ביגולים	bigulim	ביג	big	ביגים	bigim
חיגום	xigum	חיגומים	xigumim	חים	xim	חימים	ximim
גיפוש	gipuʃ	גיפושים	gipuʃim	גיש	giʃ	גישים	giʃim
חימוג	ximug	חימוגים	ximugim	חיג	xig	חיגים	xigim
שימוג	ʃimug	שימוגים	ʃimugim	שוג	ʃug	שוגים	ʃugim
רימוק	rimuk	רימוקים	rimiakim	רים	rim	רימים	rimim
שיבון	ʃibun	שיבונים	ʃibunim	שיב	ʃiv	שיבים	ʃibim
שירוג	ʃirug	שירוגים	ʃirugim	שיג	ʃig	שיגים	sigim
מילוב	miluv	מילובים	miluvim	מוב	muv	מובים	mubim
טינוץ	tinuc	טינוצים	tinucim	טין	tin	טינים	tinim
ניסול	nisul	ניסולים	nisulim	ניל	nil	נילים	nilim
בילוק	biluk	בילוקים	bilukim	ביק	bik	ביקים	bikim
פיקול	pikul	פיקולים	pikulim	פוק	puk	פוקים	pukim
חיפון	xipun	חיפונים	xipunim	חיף	xif	חיפים	xifim
שימוף	ʃimuf	שימופים	ʃimufim	שוף	ʃuf	שופים	ʃufim
פיצום	picum	פיצומים	picumim	פיץ	pic	פיצים	picim
לימוק	limuk	לימוקים	limukim	ליק	lik	ליקים	likim
חילוס	xilus	חילוסים	xilusim	חיס	xis	חיסים	xisim

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