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Effects of morphosyntactic gender features in bilingual language processing[☆,☆☆]

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Abstract

A central issue in bilingual research concerns the extent to which linguistic representations in the two languages are processed independently of each other. This paper reports the results of an empirical study and a model stimulation, which provide evidence for the interactive view, which holds that processing is not independent. Specifically, a reading experiment examined whether morpho-syntactic features associated with lexical representations in a bilinguals' native language, in this case the masculine gender feature associated with the *er* ending of agentive nouns in German, are automatically activated by the processing of morphologically related representations in their second language, in this case English agentive nouns that end in *er*. Experimental findings suggest that the German–English bilinguals have a bias to interpret the referents of such nouns as male relative to English monolinguals. Subsequent computational simulation studies with an interactive activation network confirmed that this effect is due to the influence of the morphosyntactic *er* representation in the bilingual models that is absent in the monolingual models. The results provide evidence for an interactive view of bilingual memory and processing for language learners of age 8 and above.

Keywords: Bilingualism; Morphosyntactic gender; Second language; Bilingual language processing

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1. Introduction and Background

A central issue in bilingual research concerns the extent to which linguistic representations in the two languages are processed independently of each other. According to a modular or language-selective view, proficiency in a second language (L2) is characterized by an ability to process L2 lexical representations and their associated conceptual or semantic representations independently of—or without influence from—lexical representations in the native or (L1) language (e.g., Frenck-Mestre & Prince, 1997; Gerard & Scarborough, 1989; Kroll & Stewart, 1994; Scarborough, Gerard, & Cortese, 1984; Talamas, Kroll, & DuFour, 1999). According to the alternative, interactive or non-selective-language view, complete independence in processing L2 representations is unlikely, particularly in the case of L2 words that are similar in form (i.e., orthography and phonology) to L1 words (e.g., Cristoffanini, Kirsner, & Milech, 1987; de Bruijn, Dijkstra, Chwilla, & Schriefers, 2001; Lalor & Kirsner, 2001; MacWhinney, 1987; van Heuven, Dijkstra, & Grainger, 1998).

The interactive view is an extension of the more general constraint-satisfaction framework (e.g., McClelland, Rumelhart, & Hinton, 1986), which has guided considerable research in monolingual language processing (e.g., Bates & MacWhinney, 1982, 1989; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). According to this framework, processing involves integrating multiple sources of probabilistic constraints that are relevant to the task of mapping a message onto an utterance or vice versa. The relevant constraints are the relations between the various representations of an utterance's form (e.g., orthography, phonology, morphology, syntax) and representations of its meaning (semantics and pragmatics). Furthermore, knowledge of these relations is assumed to be acquired through experience with their imperfect correlations in the linguistic input (e.g., Bates & MacWhinney, 1989; Elman et al., 1996; Seidenberg & MacDonald, 1999).

The imperfect correlations arise from the many-to-many mappings that exist between individual representations of form and individual representations of meaning and the different frequencies of those mappings. From the perspective of comprehension, which is the focus of the study reported here, the many-to-many mappings between form and meaning results in ambiguity that must be resolved. One example is homographs or homophones, which are words whose orthographic or phonological forms are associated with multiple distinct meanings (e.g., BANK in English). This ambiguity has been the focus of numerous monolingual word-recognition studies, and, as explained further below, it is an analogue to an ambiguity that has been the focus of many bilingual word-recognition studies. A central question concerning the processing of homographs in monolingual research has been whether a context that biases one of a homograph's meaning can prevent access to (or activation of) the alternative meaning. In particular, the interactive (constraint-satisfaction) view predicts selective access to the contextually appropriate meaning because context is a "top-down" constraint that is assumed to be used to resolve ambiguity. However, early studies investigating this issue supported a modular view by providing evidence that both meanings of a homograph are activated immediately after encountering it, with only the contextually appropriate meaning remaining activated shortly thereafter (e.g., Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). However, this initial finding was qualified by results from subsequent studies that demonstrated an interaction between context and the relative frequencies of a homograph's meanings. Specifically, selective activation of only the contextually appropriate meaning of a homograph occurs when the alternative meanings are equal in frequency. When one meaning occurs more frequently or is more dominant than the other, then, selective activation occurs when the dominant meaning is contextually appropriate. In other words, non-selective activation of both meanings of a homograph occurs when a context biases the less frequent or subordinate meaning. In this case, the context increases the activation of the contextually appropriate meaning, but it is unable to prevent the activation of the inappropriate dominant meaning (e.g., Duffy, Morris, & Rayner, 1988; Kambe, Rayner, & Duffy, 2001; Tabossi, Colombo, & Job, 1987).

According to the constraint-satisfaction framework, the frequency-by-context interaction reflects differences in the relative strengths of various relations or constraints, which result from differences in their consistency (e.g., Bates & MacWhinney, 1989; MacDonald et al., 1994). In particular, in the case of homographs (or homophones) with dominant meanings as well as non-homographs (or non-homophones), the association between the word's form and a particular meaning is more consistent than the association between the word's meaning and other words or elements of the contexts in which it occurs. Thus, the highly consistent form–meaning relation is a strong constraint on the mapping process. However, in the case of homographs (or homophones) that are equally consistent with two or more meanings, the indeterminacy of the form–meaning relation makes this relation a weaker constraint. Consequently, the association between elements of the context and one of the homograph's meanings is a stronger constraint on the mapping process (e.g., Kawamoto, 1993).

Much of the evidence for the extension of the constraint-satisfaction framework or interactive view to processing in the bilingual lexicon comes from word-recognition and translation tasks investigating an analogue to the processing of homographs in the monolingual lexicon. In particular, the question of whether there is selective access to words in L1 or L2 in the bilingual lexicon has been extensively studied by measuring bilinguals' speed of recognizing or translating inter-lexical homographs—or false cognates (e.g., Altarriba & Gianico, 2003; Lalor & Kirsner, 2001). False cognates have similar forms (orthography and/or phonology) in both L1 and L2 but different meanings, such as the German–English false cognate, *Teller*, which corresponds to *plate* in English. The speed of recognizing or translating false cognates is often compared to the speed of recognizing or translating cognates as well as non-cognates. Cognates have similar form and meaning in both L1 and L2, such as the German–English cognate *Finger*, whereas non-cognates have different forms in L1 and L2 but similar meaning, such as *Pferd* in German and *horse* in English. The general finding is that, relative to non-cognates, cognates are recognized and translated faster (e.g., Costa, Caramazza, & Sebastian-Galles, 2000; Gollan, Forster, & Frost, 1997; Sánchez-Casas, Davis, & García-Albea, 1992; Van Hell & de Groot, 1998; Van Hell & Dijkstra, 2002), whereas false cognates are recognized and translated more slowly (e.g., de Groot, Delmaar, & Lupker, 2000; Dijkstra, Grainger, & Van Heuven, 1999; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Dijkstra, Timmermans, & Schriefers, 2000b). The faster recognition and translation of cognates is attributed to a common set of form representations (orthographic, phonological, and morphological) used to process them in both languages. Thus, the facilitation is analogous to the facilitatory effects of repetition priming in monolingual word recognition studies (e.g., Lalor & Kirsner, 2001). The interference in recognizing or translating false cognates is also attributed to a common set of orthographic and/or phonological representations used to process them in both languages, which, unlike cognates, activate two different semantic representations. Thus, the interference is due to the need to resolve the co-activation of more than one semantic representation and is analogous to the interference observed in monolingual word-recognition studies that require selection of a homograph's meaning (e.g., Rodd, Gaskell, & Marslen-Wilson, 2002).

Evidence of a frequency-by-context interaction that is predicted by the interactive view comes from studies that show greater interference in recognizing or translating L2 false cognates than L1 false cognates and that this interference decreases as L2 proficiency increases (e.g., Altarriba & Mathis, 1997; Jared & Kroll, 2001; Lalor & Kirsner, 2001; Talamas et al., 1999; van Heuven et al., 1998). Thus, context in the bilingual studies corresponds to the language in which a false cognate is presented for recognition or translation (e.g., Altarriba & Gianico, 2003). If the false cognate is presented as an L2 word, then the subordinate or less frequent meaning is the contextually appropriate meaning. Consequently, the L2 context will be unable to prevent the activation of the more dominant, but inappropriate L1 meaning associated with the false cognate, resulting in interference. The decrease in interference that occurs with increased L2 proficiency (and, hence L2 experience) results from the more equitable frequencies with which a false cognate is associated with the L2 meaning and L1 meaning.

Although the overall findings from individual word-recognition and translation tasks provide support for the interactive view of processing in the bilingual lexicon, the results of individual experiments appear to vary as a function of particular task demands, such as the nature of the response, the relative proportions of types of L1 and L2 words in the stimulus materials, and the particular instructions given to the bilingual participants. Consequently, the variability in the findings have raised questions about whether the interference or facilitatory effects reflect normal processing in the bilingual lexicon or strategic processing that is due to the idiosyncratic demands of the experimental tasks (e.g., de Groot, Borgwaldt, Bos, & van den Eijnden, 2002; Dijkstra et al., 1998, 1999; Dijkstra, De Bruijn, Schriefers, & Ten Brinke, 2000a; Dijkstra et al., 2000b; Green, 1998; von Studnitz & Green, 2002). Analogous questions have been raised about the interpretation of results in monolingual studies employing individual word recognition tests (e.g., Carr, 1998).

Consequently, researchers have sought converging evidence for the interactive view from sentence comprehension tasks that measure bilinguals' recognition of form-related L1 and L2 words presented in either L1 or L2 sentences. For example, a recent study by Spivey and Marian (1999) involving proficient Russian–English bilinguals provided evidence of interference from English–Russian false cognates in a task employing an eye-movement recording technique that has been shown to be a sensitive measure of the time course of recognizing words in spoken sentences (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Dahan, Magnuson, & Tanenhaus, 2001; Tanenhaus & Spivey-Knowlton, 1996; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In particular, Spivey and Marian recorded Russian–English bilinguals' eye movements as they followed spoken instructions for moving common objects on a display table. The participants were fluent Russian–English bilinguals and were tested in two separate language sessions: one conducted entirely in Russian and another conducted entirely in English. On critical trials, instructions such as, *Poloji bunka nije krestika.* or *Put the bunny below the cross.* were presented with a display table on which two of the four objects had names that were Russian–English false cognates, i.e., *bunka* (jar) and *bunny*. The bilinguals' fixations on critical objects were measured from the onset of the target's name in the spoken instructions (e.g., the phoneme /b/ in *bunka* for the Russian instruction and *bunny* for the English instruction). Interference was evidenced by a higher proportion of fixations on the false-cognate object than on an object with a phonetically unrelated name that occupied the same position as the false-cognate on control trials. Spivey and Marian's results showed reliable interference when the critical instructions were presented in Russian (the bilinguals' native language) and a trend toward interference when the critical instructions were presented in English. Thus, their study provides evidence that L2 words that are phonologically similar to L1 words are automatically activated during the process of recognizing L1 word.

The current study also tested the predictions of the interactive view using a written sentence comprehension task to examine the extent to which German nouns that are morphologically similar to English nouns reliably influence German–English bilinguals' interpretation of the English nouns. Specifically, we examined whether the masculine gender feature associated with the *er* ending of nouns in German is automatically activated when German–English bilinguals read English nouns that end in *er* but are not associated with any grammatical feature for gender. As explained further below, the activation of the masculine gender feature was assessed by comparing the eye-movements of German–English bilinguals and English monolinguals as both groups read sentences containing *er* nouns that denote human entities (e.g., *robber*, *hairdresser*, *speaker*) and were antecedents of gender-marked reflexive pronouns (i.e., *himself* or *herself*).

1.1. Gender and sex in German and English

The morphological markings of gender on words reflect a grammatical or syntactic property, which, in the case of masculine or feminine gender, may not be correlated with a semantic property of male or female sex. Aside from the pronominal system in English, only a few English nouns are morphologically marked for gender (e.g., *actor*, *actress*, *waiter*, *waitress*, *host*, *hostess*). The markings on these nouns, as well as on 3rd person singular pronouns, are determined by the biological sex of the referent.

In German, all nouns as well as pronouns possess one of three classes of grammatical gender: masculine, feminine, or neuter. Nouns that denote inanimate entities may be either masculine e.g., *Stock* (stick), feminine e.g., *Gabel* (fork), or neuter e.g., *Obst* (fruit), and therefore, their gender has no biological basis. Instead, the gender of inanimate nouns is based on a complex set of semantic, morphological, and phonological "rules" or regularities (e.g., Zubin & Köpcke, 1986).

However, most nouns that, by definition, denote an entity of a particular biological sex have gender that matches the sex, e.g., *Schwester* (feminine, *sister*), *Bruder* (masculine, *brother*), *Hengst* (masculine, *stallion*). Exceptions include *Weib* (neuter, *woman* or *wife*) as well as diminutive nouns such as, *Mädchen* (neuter, *little girl*), or *Büblein* (neuter, *little boy*).

In both German and English *er* is a productive morpheme that can combine with a verb stem to form a noun that denotes an agent of the verb or an instrument, with the latter frequently forming compound nouns. For example, in English, the verbs in the infinitives *to speak* and *to print* combine with *er* to form the agentive noun *speaker* and the instrument noun *printer* or *laser printer*. Likewise, in German, the verbs in the infinitives *sprechen* (*to speak*) and *drucken* (*to print*) combine with *er* to form the agentive noun *Sprecher* (speaker) and the instrument noun

Drucker (*printer*) or *Laserdrucker* (*laser printer*). However, whereas English *er* nouns have no grammatical gender associated with them, most German *er* nouns are grammatically masculine. Furthermore, this morphological regularity interacts with a semantic regularity in which the gender of a noun that denotes a human entity matches the entity's sex. Thus, in English, the agentive noun *speaker* denotes either a male or female, whereas the corresponding German agentive noun *Sprecher* denotes a male speaker. To refer to a female speaker, the feminine inflection *in* is added to the agentive noun, i.e., *Sprecherin*.

In German, most nouns that end in *er* are grammatically masculine regardless of whether the *er* is a derivational morpheme (e.g., *Slipper* (masculine, *slipper*), *Partner* (masculine, male *partner*)). However, there are exceptions that include *er* nouns that, by definition, denote a female (e.g., *Mutter* (feminine, *mother*), *Schwester* (feminine, *sister*)). Nevertheless, evidence that native German speakers have a strong association between masculine gender and the *er* ending comes from studies demonstrating that they ubiquitously use the grammatically masculine definite article *der* with nonsense nouns ending in *er* as well as *er* nouns ending that are borrowed from other languages (Mills, 1986; Salmons, 1994).

1.2. Gender agreement

Studies involving native speakers of languages that regularly mark grammatical gender on nouns have shown interference when the morphosyntactic gender of a noun mismatches the morphosyntactic gender of an agreeing word such as a preceding determiner (e.g., Cole & Segui, 1994; Guillelmon & Grosjean, 2001; Gunter & Friederici, 2000) or pronoun (e.g., Cacciaria, Carreiras, & Cionini, 1997; Rigalleau & Caplan, 2000).

Studies involving native English speakers have shown that mismatches between a pronoun's gender and an antecedent noun's stereotypical sex results in comprehension difficulty (e.g., Carreiras, Garnham, Oakhill, & Cain, 1996; Garnham, Oakhill, & Reynolds, 2002; Kerr & Underwood, 1984; Osterhout, Bersick, & McLaughlin, 1997; Sturt, 2003). In studies that have recorded readers' eye-movements, the difficulty is reflected in both longer and more frequent fixations on a mismatching pronoun than on a matching pronoun (Kerr & Underwood, 1984; Sturt, 2003). The longer reading time of the gender-mismatching pronouns is assumed to reflect a delay in updating the semantic property of sex associated with the human entity denoted by the antecedent noun. Specifically, upon recognizing a noun, such as *butcher*, a token of the concept associated with the lexical representation of *butcher* would be established in the discourse model. At a minimum, this concept is assumed to consist of basic semantic features that represent the core meaning or sense of the noun. In the case of *butcher*, the features would include animate, human, as well as other features specifying the basic type or category of humans denoted by the word (e.g., individuals who cut meat). The set of semantic features associated with a noun that denotes a human category will include features for sex. The semantic feature representing the core sense or meaning of nouns that obligatorily denote a female or male category, such as *nun* and *priest*, would include a feature that is specified as female or male, respectively. Similarly, the semantic feature associated with a gender-marked pronoun in English would be specified as male or female, according to whether the pronoun's gender was masculine or feminine, respectively. However, because sex is a salient property of humans in general, it is likely to be a feature that is included in the conceptual representation associated with any noun that denotes a category of humans. Unlike "definitionally" female or male nouns (e.g., *mother*, *sister*, *man*) as well as gender-marked pronouns, the semantic feature associated with nouns, such as *butcher*, would not be obligatorily specified as male or as female sex, but, rather the strength of the specification of one or the other values would depend on the relative frequency of male and female exemplars of the conceptual category in the world. So, for example, to the extent that one has experienced more male exemplars of butchers than female exemplars, there will be a stronger specification of male sex associated with the concept of *butcher*.

Thus, the initial encounter of the word *butcher* in a discourse would result in the establishment (e.g., activation) of a token concept of butcher in the discourse model that would possess a stronger representation of male sex than female sex. If *butcher* is the antecedent of a subsequent masculine pronoun, such as *himself*, then no updating of the sex associated with the concept of *butcher* is required. However, if *butcher* is the antecedent of a subsequent feminine pronoun, such as *herself*, then updating is required because of the inconsistency between the female sex specified by the pronoun's feminine gender and the male sex that is strongly associated with the concept of butcher. The updating of the specification of sex associated with an antecedent noun's conceptual representation is assumed to be a primary source of the longer reading times observed for pronouns whose gender mismatches the stereotypical sex of the antecedent nouns (e.g., Carreiras et al., 1996; Kerr & Underwood, 1984).

2. Experiment 1

The limited cases of grammatical gender marking on nouns in English means that the gender marking on pronouns, such as *she*, *he*, *herself*, *himself*, etc., is primarily determined with respect to the conceptual sex of the antecedent noun's referent. One consequence of the predominate relation between gender marking and conceptual sex in English is that native English speakers often have difficulty learning languages, such as German, in which gender-agreement relations are frequently based on morphosyntactic gender (e.g., Guillelmon & Grosjean, 2001). In contrast, speakers whose native language regularly marks grammatical gender, and where agreement relations are thus predominately determined with respect to this morphosyntactic feature, appear to have less difficulty mastering the predominant semantic-based agreement relations in English (Mills, 1986). However, Experiment 1 demonstrated a case in which morphosyntactic markings of gender in ones' native language may influence the processing of non-gender marked words in English.

Specifically, the experiment reported here used the association of masculine gender with the *er* ending of nouns in German to test the predictions of the interactive view of bilingual memory. According to this view, when German–English bilinguals read an English noun ending in the agentive *er* morpheme, which has no grammatical gender associated with it in English, this morpheme should nonetheless automatically activate the masculine gender associated with it in German. Because the *er* noun denotes a human, the activated masculine gender feature should activate the corresponding conceptual feature for male sex, thus biasing a male interpretation of the noun. This bias, in turn, should cause interference if the *er* noun is an antecedent of a feminine pronoun, such as *herself*.

To test this prediction, we compared the eye movement patterns of German–English bilinguals and English monolinguals when they read English sentences such as the following:

(1) The robber disguised himself/herself by wearing a mask.
(2) The hairdresser used the shampoo on himself/herself and on the customers.
(3) The speaker introduced himself/herself to the audience.

As shown by the examples, the critical sentences began with an *er* noun that referred to a human entity that is stereotypically male (*robber*), female (*hairdresser*), or neutral (*speaker*). The *er* nouns were antecedents of either the feminine reflexive, *herself*, or the masculine reflexive, *himself*. If the masculine gender associated with the noun's *er* ending in German is automatically activated, then it should strengthen the representation of male sex that is initially associated with the concept denoted by the *er* noun. As a consequence, the sex property will require a different amount of updating for the German–English bilinguals than for English monolinguals, and this difference should be reflected in a difference in the two groups' relative reading times for the pronouns.

More specifically, the strength of the male sex that is associated with the concept denoted by the *er* noun should be reflected in the size of the mismatch effect, calculated by subtracting each language groups' average total fixation duration on *himself* from the average total fixation duration on *herself*. Thus, we predicted that both the German–English bilinguals and English monolinguals would exhibit a positive mismatch effect for sentences containing a stereotypical male antecedent noun (e.g., (1) above), with the German–English bilinguals potentially exhibiting a larger mismatch effect if it is possible to further increase the already strong association of male sex with the antecedent nouns' concepts in this condition. The increased male bias that results from the masculine *er* ending in German should be reflected in German–English bilinguals exhibiting a positive mismatch effect for sentences containing a stereotypical neutral antecedent noun (e.g., (3) above). In contrast, English monolinguals should exhibit no mismatch effect for these sentences. Finally, the German–English bilinguals should exhibit a smaller negative mismatch effect than the English monolinguals when the sentences contain a stereotypical female antecedent noun (e.g., (2) above) because the male bias from the masculine *er* ending should counter the female sex that is stereotypically associated with the nouns' concepts.

2.1. Method

2.1.1. Participants

Twenty native English monolinguals and 20 fluent German–English bilinguals participated in the experiment. All had normal or corrected-to-normal vision and received payment in exchange for their participation. The 20 English monolinguals (6 males and 14 females) were between the ages of 18 and 21 years and were tested at the University of Notre Dame. None had any formal experience with German. The 20 German–English bilinguals (8 males and 12 females) were between the ages of 17 and 25 years and were tested at the University of Vienna in Vienna, Austria. They had an average of 9 years of formal English instruction (range: 5–14 years). The average age at which English instruction began was 8 years (range: 5–10).

2.1.2. Materials

The materials consisted of 30 pairs of English sentences.[1] Each sentence began with a definite noun phrase containing an *er* noun that referred to a human entity and was the antecedent of a reflexive pronoun. The sentences within a pair were identical except for the reflexive's gender. The 30 pairs represented six conditions created from crossing the two levels of the reflexive's gender (himself or herself) with three levels of the stereotypical sex of the antecedent *er* noun (male, female, or neutral). The initial assignment of the nouns to a stereotypical sex condition was based on the experimenters' intuitions and subsequently verified with the results of a rating task described below.

The materials also consisted of 46 filler sentences and 30 yes/no comprehension questions. All of the filler sentences began with a definite noun phrase containing an -er noun that referred to a human entity. None of the *er* nouns occurred in the critical sentences and they were never antecedents of pronouns. The 30 yes/no comprehension questions were designed to encourage the participants to read for meaning. Twenty questions referred to the meaning of a preceding filler sentence, and 10 referred to the meaning of a preceding critical sentence. For example, the critical sentence, *The hunter hurt herself after falling out of a tree.* was followed by the question, *Did the hunter get hurt while climbing a tree?*

Two 106-item lists were constructed. Each list contained 30 critical sentences, one from each pair, all 46 filler sentences, and all 30 comprehension questions. Within each list, five critical sentences represented each of the six conditions, and across both lists, each critical sentence occurred once. The lists began with four filler questions, two of which were followed by a comprehension question. The order of the remaining critical and filler sentences was random except for the constraint that two critical sentences could not occur consecutively.

After the reading task, the participants completed a rating form. The form listed the 30 critical *er* nouns in random order with a 9-point scale next to each one. The end points of the scale were labeled as 1 = *always male* and 9 = *always female*. The instructions printed at the top of the rating form were as follows:

> Please rate the following words for how often, in your experience, they have been used to refer to a male or a female. If, in your experience, the word is always used to refer to a male, then circle the number 1 on the rating scale next to it. If the word is always used to refer to a female, then circle 9. Feel free to use the full range of numbers on the scale.

The bilinguals completed an electronic version of the rating form and indicated their rating by selecting a box beneath a number on the scale. In addition, each noun on the bilinguals' forms was preceded by a selection box that was to be selected if the noun was unfamiliar to the participant.

2.1.3. Procedure

Each participant was randomly assigned to one of the two lists, with an equal number of bilingual and monolingual participants assigned to each list. The participants were seated in front of a computer monitor at a comfortable viewing distance. They were given instructions for the experiment in English. Specifically, they were told that a list of sentences would be presented one at a time in the center of the monitor. They were instructed to read each sentence and then press the "b" key on the computer's keyboard to advance to the next sentence. They were told that some of the sentences would be followed by a yes/no comprehension question, which they were to answer by pressing either the z key, which was labeled *yes*, or the/key, which was labeled *no*.

The sentences appeared individually on a single line in the center of a 15 in. computer monitor. They were displayed in 14 point black font against a white background at 640×480 screen resolution. The critical *er* nouns and the reflexive pronouns each subtended approximately $1.05^\circ \times 2.87^\circ$ of visual angle. The participants' key-press responses were recorded for each trial.

2.1.4. Apparatus

The participants' eye movements were recorded using a free-head eyetracking system (Applied Science Laboratories, Model 501). The system consists of a lightweight eye camera attached to an adjustable headband that is worn by the participant. The eye camera is positioned above the participant's left eye and captures an infrared image of the eye at a 60 Hz sampling rate. The distance between the centers of the corneal and pupil infrared reflections are used to calculate the relative eye-in-head position. The position of the participant's head with respect to the computer monitor was simultaneously measured using a magnetic head-tracking device (Acension Laboratories). The measurements from the headtracker and eyetracker were recorded in real time as a serial data stream to a PC. An analysis program converted the data stream into the XY coordinates of the participants' fixations, sampled every 16.67 ms. A videotaped record of the participants' fixations was also made. This record consisted of the image of the sentences displayed on the computer monitor in front of the participant (the scene image) and a superimposed set of cross-hairs indicating the participant's line of gaze. The video record was recorded onto Hi8 video tape and frame-by-frame playback was used to verify the accuracy of the fixation data computed from the data stream recorded onto the PC. At the beginning of an experimental session a 2-min calibration routine was conducted to map nine eye position coordinates onto nine corresponding scene image coordinates. The accuracy of the resulting eye fixation record is approximately 0.50° over a range of $\pm 20^\circ$.

2.2. Results

2.2.1. Rating data

There was a high degree of consistency between the English monolinguals' and German–English bilinguals' ratings of the *er* nouns' stereotypical sex. The largest difference between the two groups' ratings occurred with the nouns, *gardener* and *horseback rider*. The German–English bilinguals' average ratings of these nouns were 3.30 and 3.65, respectively, indicating a male association, whereas the English monolinguals' average ratings were 4.85 and 5.95, respectively, indicating a neutral association. Both groups' ratings conflicted with the initial assignment of the two nouns to the stereotypical female condition. Because of the discrepancies between the groups' ratings of these nouns, and the nouns' initial assignment to the female condition, they were eliminated from the analyses of the reading task data, reducing the number of items representing the female condition to eight. The final set of 28 items are given in Appendix A along with each language group's average stereotypical sex rating of the *er* nouns.

Table 1
The English and German–English participants' average sex ratings (standard deviations) of the *er* nouns (1 = always male; 9 = always female) in each stereotypical sex condition and the corresponding weights of the "dist" connections between the lexical-concept nodes and the male and female sex nodes in the English and German–English models

Stereotypical sex	Average rating	Model	
		$dist_{MN}$	$dist_{FN}$
English			
Female	7.47 (0.69)	0.110	0.290
Neutral	4.70 (0.69)	0.218	0.182
Male	2.58 (0.84)	0.316	0.084
German–English			
Female	7.27 (1.10)	0.110	0.290
Neutral	4.52 (0.32)	0.220	0.180
Male	2.38 (0.61)	0.318	0.082

Table 1 shows the groups' average ratings of the remaining nouns in each stereotypical sex condition. The German–English bilinguals' average rating of all 28 nouns was 4.54, which was slightly toward the male end of the rating scale relative to the English monolinguals' average rating of 4.73 for all 28 nouns (paired $t(27) = 1.62$, $p = .12$ two-tailed). None of the separate t-tests of the differences between the two groups' average ratings of the sets of nouns within each stereotypical sex condition was significant (ts < 1.00 in the male and female conditions, and paired $t(9) = 1.04$ in the neutral condition).

The absence of a significant difference in the ratings of the nouns by the two language groups was expected because both groups' experience with the distribution of female and male exemplars of the categories denoted by the nouns should be similar given that both groups live in Western cultures. Specifically, compared to the English monolinguals living in the United States, there is no reason to expect that the German–English bilinguals living in Austria would have less experience with female butchers, less experience with female swimmers, or less experience with female babysitters.

Although nonsignificant, the slight male bias in the German–English bilinguals' ratings may be due to the same bias that is hypothesized to occur in the online reading task. In particular, the masculine gender associated with the -er ending of the critical nouns may have biased the bilinguals to initially interpret them as referring to a male, and, this in turn, led them to give a slightly more male rating for the sterotypical sex. Critically, however, it is impossible for the slight male bias in the bilinguals' ratings to be due to their having an "a priori" stronger association of male sex with the concepts denoted by the critical English nouns that results from the nouns being associated with masculine gender in German. The reason is that the German translations of all critical English nouns have both a masculine form and a feminine form. That is, the English noun "swimmer" can be translated as either the masculine form "Schwimmer", which is used to refer to a male swimmer, or the feminine form "Schwimmerin", which is used to refer to a female swimmer. The relative frequency with which the masculine versus feminine forms are used in German should reflect the relative frequency of male versus female swimmers. In other words, the stereotypical sex of the referents of the category denoted by the

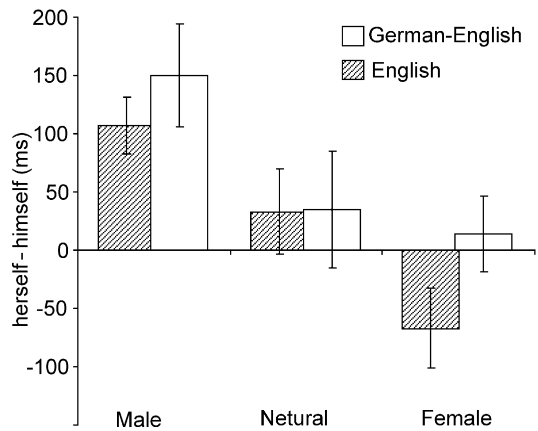

Fig. 1. English monolinguals' and German–English bilinguals' average differences between their total fixation duration on *herself* vs. *himself* in the three stereotypical sex conditions. Error bars are standard errors of the means.

critical nouns should influence the use of masculine versus feminine forms in German, but not vice versa.

2.2.2. Reading data

A total of 21 trials (4%) were eliminated from the German–English participants' data because the participants indicated on their rating forms that they did not know a critical *er* noun (11) or because of a degraded eye-tracking record (10). Six trials (1%) were eliminated from the English participants' data because of a degraded eye-tracking record.

For the remaining trials, fixations that occurred on or between the character spaces immediately preceding and following the reflexives were scored as fixations on the reflexive. For each participant and for each critical sentence, the total duration of all fixations on a reflexive pronoun were calculated and then averaged across each pronoun gender (see Table 3). Fig. 1 shows the German–English bilinguals' and English monolinguals' average mismatch effects in each stereotypical sex condition, which were calculated by subtracting each language group's average total fixation duration on *himself* from their average total fixation duration on *herself*. Thus, positive mismatch effects correspond to longer fixations on *herself*, and negative mismatch effects correspond to longer fixations on *himself*.

Separate 2 $\times$ 2 ANOVAs were conducted on the average total fixation durations in each stereotypical sex condition because the critical sentences were not equated with respect to length and lexical content across the three sex conditions. The ANOVAs were conducted with subjects as a random factor and then with items as a random factor (designated as $F1$ and $F2$, respectively). The two factors were language (bilingual or monolingual), which was a between-subjects factor and a within-items factor, and pronoun (*herself* or *himself*), which was a within-subjects factor and a within-items factor.

The analyses of the average fixation durations in the male condition yielded a reliable main effect of language ($F1(1, 38) = 10.61$, $p < .01$; $F2(1, 9) = 16.57$, $p < .01$) with English monolinguals' exhibiting overall shorter fixation durations on the pronouns than the

German–English bilinguals (430 ms versus 593 ms, respectively). The main effect of pronoun was also reliable ($F1(1, 38) = 25.72$, $p < .001$; $F2(1, 9) = 11.55$, $p < .01$), reflecting an overall mismatch effect of 128 ms, resulting from longer average fixation durations on *herself* (576 ms) than on *himself* (448 ms). As shown in Fig. 1, the German–English bilinguals' mismatch effect of 150 ms was numerically larger than the English monolinguals' mismatch effect of 107 ms; however, the difference between the two groups' mismatch effects was not significant as reflected by the lack of a reliable interaction between language and pronoun (Fs < 1).

The analyses of the average total fixation durations in the neutral condition yielded a reliable main effect of language ($F1(1, 38) = 7.01$, $p < .05$; $F2(1, 9) = 11.57$, $p < .01$), which, again, reflected overall shorter fixation durations on the pronouns by the English monolinguals than by the German–English bilinguals (419 ms versus 527 ms, respectively). Contrary to the predicted larger positive mismatch effect for the German–English bilinguals, both language groups exhibited small and approximately equal positive mismatch effects (35 ms for the German–English bilinguals and 33 ms for the English monolinguals). Thus, the main effect of pronoun was not significant ($F1(1, 38) = 1.22$; $F2(1, 9) = 1.75$) nor was the interaction between language and pronoun (Fs < 1).

The analyses of the fixation durations in the female condition yielded a marginally significant main effect of language in the analysis by subjects ($F1(1, 38) = 3.06$, $p = .09$; $F2(1, 7) = 6.43$, $p < .05$), which, as in the analyses of the other two conditions, reflected the English monolinguals' overall shorter fixation durations on the pronouns than the German–English bilinguals (423 ms versus 497 ms, respectively). The main effect of pronoun was not reliable ($F1(1, 38) = 1.20$; $F2(1, 7) = 1.35$). However, the interaction between language and pronoun was marginally significant in the analysis by subjects ($F1(1, 38) = 2.87$, $p = .09$; $F2(1, 7) < 1$).[2] The English monolinguals' average total fixation duration was longer on *himself* (456 ms) than on *herself* (390 ms) whereas the German–English bilinguals' average total fixation duration was slightly shorter on *himself* (490 ms) than on *herself* (504 ms). The English monolinguals' mismatch effect of −67 ms was significant by subjects (paired $t(19) = 1.94$, $p < .05$, one-tailed; $t(7) < 1.00$ by items).[3]

2.3. Discussion

The graph in Fig. 1 was expected to show a relatively linear decrease in the average mismatch effects across the male, neutral, and female conditions, respectively, for both the English monolinguals and German–English bilinguals. The additional male bias from the masculine gender associated with *er* in German was expected to cause the German–English bilinguals' mismatch effect to be more positive than the English bilinguals' mismatch effect in each sex condition. However, the German–English bilinguals' average mismatch effects in the male and neutral conditions were not significantly more positive than the English monolinguals' average mismatch effects in these conditions. Consequently, the decrease in the German–English bilinguals' mismatch effects across the three sex conditions was less linear than the decrease in the English monolinguals' average mismatch effects. This difference in linearity is more evident in Fig. 2, which plots the German–English bilinguals' and English monolinguals' average mismatch effects for each of the 28 critical pairs of sentences as a function the respective

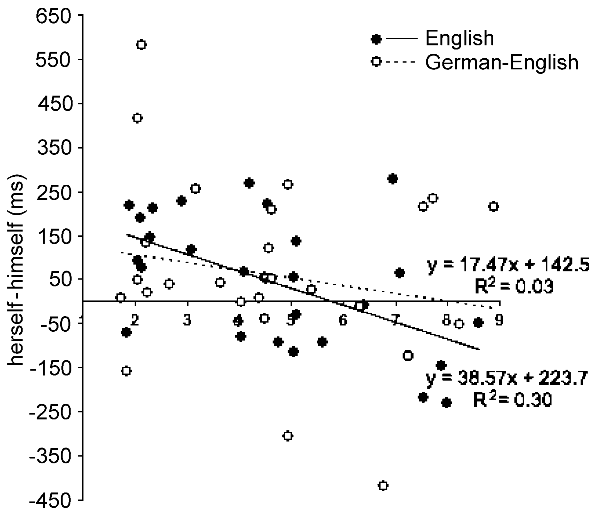

Fig. 2. Average mismatch effect for each of the 28 *er* nouns plotted as a function of the nouns' average stereotypical sex rating (1 = always male; 9 = always female).

language group's average stereotypical sex rating of the *er* nouns in the sentences. The analysis of variance for the English monolinguals' linear regression line was significant ($F(1, 26) = 11.27$, $p < .01$); however, the analysis of variance of the German–English bilinguals' linear regression line was not significant ($F(1, 26) < 1$). It is unclear whether the failure of the German–English bilinguals to exhibit a greater positive mismatch effect in the male and neutral conditions, which results in the apparent nonlinear relation in the pattern of their data, is due to the masculine gender associated with *er* in German or other aspects of processing that may contribute to the overall fixation durations on the pronouns. Thus, to examine these questions, connectionist network models were constructed to simulate the pattern of mismatch effects observed in the empirical study.

3. Model simulations

In this section, we present a computational model for the *er* effect that was observed in the experiment. Specifically, we consider a neural network model of the process of updating the sex associated with a token of the human concept denoted by a noun that is the antecedent of a gender-marked reflexive pronoun. In addition, we present an extension of the model that simulates the influence on the updating process of gender features associated with the antecedent noun's morphology in a bilingual's native language. The primary objective of the bilingual version of the model is to simulate the male bias from the masculine gender associated with the *er* agentive morpheme of nouns in German.

The proposed models (for monolinguals and bilinguals) are processing models, and, as such, are concerned with the temporal unfolding of the process of associating a particular sex with a human concept denoted by a noun, which is initially based on the stereotypical sex of the exemplars in the corresponding category in the world. The models capture the overall processing sequence using the English and German–English participants' average total fixation durations on three lexical items in the critical sentences: antecedent (subject) noun, verb, and reflexive pronoun. Simulations are reported for the six conditions tested in the experiment, which correspond to cases in which a stereotypical male, female, or neutral noun is the antecedent of a masculine or feminine reflexive pronoun. We begin with an overall description of the architecture and processing in the models and then present the results of specific simulations.

3.1. Model architecture

We distinguish three levels in the architecture of our models: (1) a lexical (word) level, the representations at which are assumed to become activated (recognized) as a result of processing at sublexical levels (e.g., letter and/or phoneme level as well as feature level) which are not implemented in the model; (2) a morphosyntactic level consisting of the syntactic features associated with morphology of the items at the lexical level, which, in the current model, is restricted to gender features; and (3) a conceptual level consisting of concepts and their semantic properties.

At the lexical level, words are recognized as lexical entities (Rumelhart & McClelland, 1986; van Heuven et al., 1998). Once the recognition of an entity is complete, the next entity is processed. In reading tasks, this typically involves advancing the eye to fixate the next word. Since modeling the advancement of the eye is not our focus, we simply assume that there is a processing mechanism that advances the fixation after a certain time interval dependent on the lexical item. Typically, this interval corresponds to when the activation of the lexical and conceptual representations have surpassed a certain threshold, thus indicating that the lexical item has been recognized. Furthermore, we assume that semantic processing can also influence the fixation of a lexical item. For example, it can lead to extended fixation times if there is a mismatch between the meaning of the item (such as *himself*) and some internal representation (such as the subjects of the sentence being represented as female, see below for details). Of course, these are simplified assumptions of eye movements during reading, which do not take into account a number of other factors that can influence fixation times (e.g., for a review see, Rayner, 1998; Reichle, Pollatsek, Fisher, & Rayner, 1998), yet they are sufficient for the purposes of our model.

At the morpho-syntactic level, lexical items (i.e., words) are connected to nodes representing the grammatical features associated with them. For example, the reflexive pronouns *himself* and *herself* activate syntactic gender features of masculine and feminine gender, respectively. Similarly, this level includes representations of the morphological marking of grammatical gender features, such as the agentive *er* morpheme of nouns in German. These morphological representations of gender are activated by the lexical representations that possess them.

At the conceptual level, the concept nodes represent the semantic properties associated with each lexical item.[4] Each concept node receives activation from its associated lexical representation and activates semantic property nodes connected to it. Specifically, we assume that the semantic properties of male and/or female sex are associated with all nouns that denote human entities. This assumption is represented in the model by connections between the concept nodes and both the male and female sex nodes (i.e., property nodes). Since we are only interested in the process of activating sex properties associated with the lexical concepts,

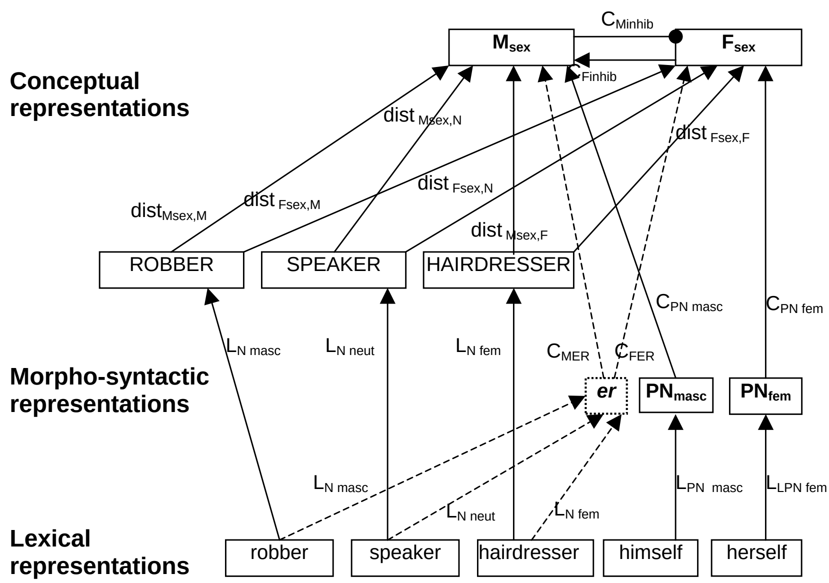

Fig. 3. A diagram showing the basic architecture of the models used in the simulations. The dashed lines together with the dashed box form the *er* structure, which is only present in the German models.

we do not consider any other semantic properties that contribute to the concept denoted by the antecedent nouns presented in our experiment. Fig. 3 depicts the model, with excitatory connections terminating in arrows and inhibitory connections terminating in circles.

Both lexical and conceptual representations are illustrated in Fig. 3: for the antecedent nouns the lexical nodes are labeled *robber*, *speaker*, and *hairdresser*; the corresponding concept nodes are labeled ROBBER, SPEAKER, and HAIRDRESSER. Each concept node is connected to both the male and female sex nodes (labeled "M_{sex}" and "F_{sex}", respectively). The lexical representations of the reflexive pronouns, *himself* and *herself*, are connected to the syntactic representations of masculine and feminine gender (labeled as "PN_m" and "PN_f", respectively). The "gender nodes", in turn, are connected to the corresponding sex nodes. All connections coming from lexical representations are labeled "Lx" (where "x" denotes the syntactic category of the lexical item) and are parameters of the model.

The excitatory weights of the connections between the concept nodes and the male and female sex nodes ("dist" weights) reflect the relative distribution of male and female exemplars in the category corresponding to the concept. For example, the concept associated with *robber* will be strongly associated with male sex to the extent that most exemplars of robbers are males. Similarly, the concept associated with *hairdresser* will be strongly associated with female sex to the extent that most exemplars of hairdressers are female. However, since robbers can also be female and hairdressers can also be male, the corresponding concepts will have connections to both representations of male and female sex. In all of the models presented here, the strength of the connections between the concept nodes and the two sex nodes is based on the participants' average ratings of the stereotypical sex of the nouns' referents. Specifically, the weight of the connection to the female sex node was computed by dividing the average rating for a particular noun by 25; the weight of the connection to the male sex node was computed by subtracting the noun's average rating from 10 and dividing the result by 25 (see Table 1).

As shown in Fig. 3, both sex nodes have mutually inhibitory connections between them, reflecting their mutually exclusive relation (i.e., the token of a human concept is either male or female). Finally, we distinguish models for English participants from those for German–English participants by adding an *er* node at the morphosyntactic level in the bilinguals' models. This node receives activation from the nouns' lexical representations and sends activation to both sex nodes.[5] Given that the agentive *er* morpheme is by default associated with masculine gender, and consequently male sex, in German (as discussed in the introduction), the connection to the male sex node will be much stronger than the connection to the female sex node, which has been added to reflect the few exceptional cases (like "Mutter"—mother or "Schwester"—sister), where agentive *er* nouns denote females in German. The dashed lines in Fig. 3 indicate nodes and connections included in the German versions of the model only.

Each processing unit is taken to be a simplified variant of the well-known "interactive activation and competition" units used for word recognition (e.g., see Rumelhart & McClelland, 1986). The change in activation of units employed in our model is given by Eq. (1):

$$\frac{\partial \mathrm{act}}{\partial t} = \mathrm{netin} - \mathrm{act}(\mathrm{netin} + \mathrm{decay}) \tag{1}$$

where "act" is the activation of the unit, "netin" the summed weighted input to the unit and "decay" is a constant set to 0.01 for all nodes (all of which are in $[0, 1]$). The basic model of the two sex nodes for the English subjects is then given by the above equation together with the differential equations determining the change in net input to both sex nodes as shown in Eq. (2):

$$\begin{aligned}\frac{\partial \mathrm{netin}_{\mathrm{Msex}}}{\partial t} &= \mathrm{dist}_{\mathrm{Msex,N}} \times \mathrm{act}_{\mathrm{N}} + C_{\mathrm{PNmasc}} \times \mathrm{act}_{\mathrm{PNmasc}} - C_{\mathrm{Finhib}} \times \mathrm{act}_{\mathrm{Fsex}} \\ \frac{\partial \mathrm{netin}_{\mathrm{Fsex}}}{\partial t} &= \mathrm{dist}_{\mathrm{Fsex,N}} \times \mathrm{act}_{\mathrm{N}} + C_{\mathrm{PNfem}} \times \mathrm{act}_{\mathrm{PNfem}} - C_{\mathrm{Minhib}} \times \mathrm{act}_{\mathrm{Msex}}\end{aligned} \tag{2}$$

where the subscripts indicate the kind of node ("Msex" for "male sex node", "Fsex" for "female sex node", and "N" for the antecedent noun), the "dist" parameters are the given distributions of male and female members of the group denoted by the antecedent noun (scaled in the above mentioned way), and "PNmasc" and "PNfem" denote the masculine and feminine reflexive pronoun nodes, respectively. The four constants scaling the contributions from the reflexive pronouns (C_{PNmasc} and C_{PNfem}) and the mutual inhibition of the sex nodes (C_{Minhib} and C_{Finhib}) are parameters of the model.

In the German version of the model, the change in net input to the male sex node can be obtained from Eq. (2) by adding as additional inputs to the male and female sex node the scaled output from the *er* node:

$$\begin{aligned}\frac{\partial \mathrm{netin}_{\mathrm{Msex}}}{\partial t} &= \mathrm{dist}_{\mathrm{Msex,N}} \times \mathrm{act}_{\mathrm{N}} + C_{\mathrm{MER}} \times \mathrm{act}_{\mathrm{ER}} + C_{\mathrm{PNmasc}} \times \mathrm{act}_{\mathrm{PNmasc}} - C_{\mathrm{Finhib}} \times \mathrm{act}_{\mathrm{Fsex}} \\ \frac{\partial \mathrm{netin}_{\mathrm{Fsex}}}{\partial t} &= \mathrm{dist}_{\mathrm{Fsex,N}} \times \mathrm{act}_{\mathrm{N}} + C_{\mathrm{FER}} \times \mathrm{act}_{\mathrm{ER}} + C_{\mathrm{PNfem}} \times \mathrm{act}_{\mathrm{PNfem}} - C_{\mathrm{Minhib}} \times \mathrm{act}_{\mathrm{Msex}}\end{aligned} \tag{3}$$

where "ER" denotes the *er* node and C_{MER} and C_{FER} are constants scaling the contribution of the *er* node to the male and female sex node, respectively. C_{MER} and C_{FER} are additional model parameters for the German extension of the English model.

3.2. Parameters for the English and German models

The purpose of the proposed model is (1) to verify the overall architecture (as depicted in Fig. 3) given the results of the experiment reported above, and (2) to confirm our proposal that morphosyntactic representations are accountable for the difference in the pattern of mismatch exhibited by the German–English bilinguals versus the English monolinguals. Specifically, the goal of the models was to predict the two language groups' difference in total fixation times on himself versus herself in the three sex conditions. Hence, models were constructed for both English and German–English participants with 15 parameters total in the English model and 20 parameters total in the German–English models, of which the *dist* and lexial weights (i.e., 11 and 14 parameters, respectively), are determined from the experimental data. The remaining free parameters (4 and 6, respectively), namely the conceptual weights C_{Minhib}, C_{Finhib}, C_{PNmasc} and C_{PNfem} in both models and C_{MER} and C_{FER} only in the German–English models cannot be obtained from empirical data and need to be estimated to provide a good fit of the models.

Since stereotypically male, neutral, and female antecedent nouns of both masculine and feminine reflexive pronouns are considered for both English and German–English participants, 12 different versions of the models were created. We computed the *dist* parameters of both models from the subjects' ratings in the way indicated above. Although there are 12 *dist* parameters, given that we have three noun categories and two sex nodes for the English and German models, only six are independent (hence only three need to be fixed for each model). Table 1 shows the subjects' ratings for stereotypically female, male, and neutral nouns as well as the respective *dist* weights (to male and female sex nodes) in the German and English models for the three antecedent nouns.

In addition, all weights from lexical representations to concepts need to be fixed for all models. These weights reflect the time it takes, given a lexical representation, to sufficiently activate a concept node for the eye to be able to advance to the next lexical item. Hence, fixation times of lexical items needed to be mapped onto update cycles of the network in order to be able to simulate the temporal sequence of reading words and the sequence of internal events during the processing of sentences. This translation was achieved by dividing the respective fixation times by 10 and rounding to the nearest whole number.

Furthermore, a general criterion is needed for advancing the eye once a lexical item has been recognized (i.e., at the lexical and conceptual level). Since the degree of activation of concept nodes reflects the extent to which a concept denoted by a lexical item has been recognized or processed, we introduce an activation-based "recognition threshold" θ for concept nodes: if the threshold is surpassed, the eye will typically advance to the next item (unless additional advancement criteria, which may be defined for a lexical item are not met—see below).

Using the mapping from fixation times onto update cycles, the weights between lexical and conceptual representations are determined based on the human data as follows: each weight is chosen so that applying an input of 1 to a lexical node for *n* update cycles will result in an activation level greater than $\theta = 0.6$ of the corresponding concept node, while the activation is

Table 2
The lexical weights for the English and German models

Sex—pronoun	Verb		Noun	
	English	German–English	English	German–English
Female—herself	0.0290	0.0224	0.0325	0.0260
Female—himself	0.0285	0.0220	0.0330	0.0252
Neutral—herself	0.0295	0.0228	0.0239	0.0202
Neutral—himself	0.0300	0.0218	0.0247	0.0200
Male—herself	0.0300	0.0206	0.0285	0.0260
Male—himself	0.0355	0.0220	0.0305	0.0200

In the German models these weights also connect nouns to the *er* node.

less than $\theta = 0.6$ for all update cycles less than n. This is unproblematic for nouns and verbs, where the fixation time reflects the time it takes subjects to recognize the lexical item and to some extent process its meaning. Here, we can take the average fixation on nouns and verbs, averaged over all nouns in each of the three sex conditions and across subjects within in each of the two subject groups. Table 2 shows the lexical weights for the German and English models.

For pronouns, however, the situation is more complicated. Since there are significant differences in fixation times on the reflexive pronouns in the different sex conditions that include contributions from other (semantic) processes—contributions we want to model—the averages over all conditions cannot be used, for the differences of interest would otherwise disappear. Furthermore, if these additional contributions do not come from the lexical level, but from semantic processes as we predict, the lexical weights must not reflect them. Hence, it is necessary to dissociate the lexical influence on fixation duration from other factors. We exclude the mismatch conditions, where fixation durations are prolonged on the reflexive pronouns, and take the average of the match conditions in the male and female conditions as well as the neutral conditions. This step is supported by the empirical data, where there is no significant difference between fixation times on pronouns in the matching conditions (neither for the English, nor for the German subjects). This way we get one unique lexical weight for both pronouns for each class of models ($L_{\text{PNmasc}} = L_{\text{PNfem}} = 0.0305$ for the English and $L_{\text{PNmasc}} = L_{\text{PNfem}} = 0.0254$ for the German–English models) that can be used in all conditions (rather than slightly different lexical weights for each condition). Note that this approach eliminates the possibility that different fixation times on pronouns are the result of or are influenced by a difference in lexical weights between masculine and feminine reflexive pronouns. It is also worth pointing out that this difference between the English and German lexical weights mirrors almost exactly the difference in overall subject reading times, i.e., the fact that the English subjects read about 20% faster than the German subjects.

While reaching the recognition threshold of a concept node is sufficient to advance the eye for both nouns and verbs, we require that an additional activation-based *gender consistency criterion* be met for reflexive pronouns before the eye can move to the next lexical item: the sex node not corresponding to the gender of the reflexive pronoun must have an activation of less than 0.25. Otherwise, the eye will remain on the pronoun (despite the possibility that the gender node might have reached an activation greater than θ) until the gender consistency criterion

Table 3
The English and German–English participants' average total fixation durations (ms) on words in sentences with stereotypical female, neutral, or male nouns that were antecedents of *herself* or *himself* and the corresponding number of update cycles in the model simulations

Data	Region		
	Noun	Verb	Pronoun
	Male—herself		
English	410	438	484
English model	41	44	48
German–English	733	499	668
German–English model	73	50	67
	Male—himself		
English	331	338	377
English model	33	34	38
German–English	652	537	519
German–English model	65	54	52
	Neutral—herself		
English	420	575	436
English model	42	57	44
German–English	610	763	544
German–English model	61	76	54
	Neutral—himself		
English	414	535	402
English model	41	54	40
German–English	657	766	509
German–English model	66	77	51
	Female—herself		
English	427	369	386
English model	43	37	39
German–English	633	503	504
German–English model	63	50	50
	Female—himself		
English	436	360	453
English model	44	36	45
German–English	655	516	492
German–English model	65	52	49

is met. Note that the criterion will always be met at some point as the sex node receiving activation from the gender node will continue to suppress the "non-matching" sex node and eventually push its activation level below 0.25. Table 3 shows the English and German–English participants' average total fixation durations on words in sentences containing female, male, and neutral nouns as antecedent nouns of *himself* or *herself* as well as the number of update cycles corresponding to the human data and the weights connecting lexical and concept nodes based on these update cycles.

Finally, in addition to the *dist* and *lexical weights*, the remaining conceptual weights, four in the English and six in the German model, need to be chosen. To reduce the number of free parameters, we chose symmetric weights whenever possible, thus leaving only two free parameters for the English model and one subsequent free parameter for the German model, as the parameters from the English model are also used in the German model. Fixing the mutually inhibitory weights among the mutually exclusive sex nodes at $C_{\text{Minhib}} = C_{\text{Finhib}} = 0.3$ (for all models), we determined the best C_{PNmasc} and C_{PNfem} for the English model to fit the human data: $C_{\text{PNmasc}} = C_{\text{PNfem}} = 0.5053$. Once these parameters were fixed, we applied them in the German models and chose the C_{MER} and C_{FER} parameters to find the best fit for the German–English data. We present two sets, one with and one without a positive C_{FER} connection: for $C_{\text{FER}} = 0$, we set $C_{\text{MER}} = 0.19$, and for $C_{\text{FER}} = 0.01$, we set $C_{\text{MER}} = 0.21$.

3.3. Simulation results

Using the above parameters, the models were used to predict the *mismatch effect* found in the human subjects. We ran simulations for each of the six conditions for both the English and German versions of the models for both sets of models. Furthermore, we ran the same simulations for the German model without the *er structure* (i.e., without the *er* node and the connecting lexical and conceptual weights). The results of the simulations are shown in Fig. 4

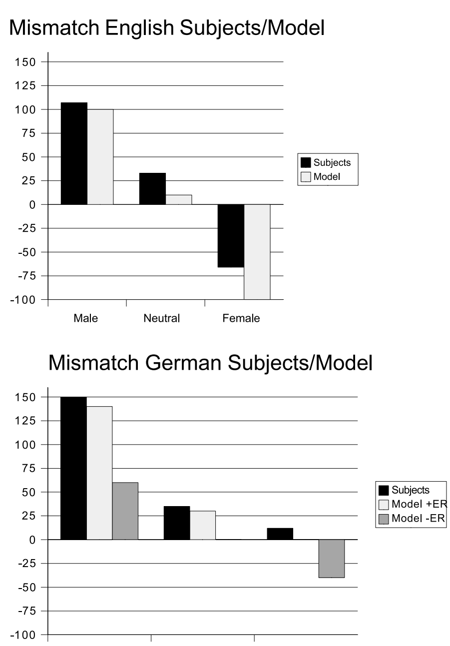

Fig. 4. The results of the model simulations. *Top*: The English monolinguals' average difference between the total fixation duration on herself versus himself compared to the English models' data. *Bottom*: The German–English bilinguals' average difference between the total fixation duration on herself versus himself in the three stereotypical sex conditions compared to the German–English models with and without the *er* structure.

and are identical for both sets, which indicates that the results are independent of assumptions about whether the *er* node influences only the male sex node or is capable of influencing both sex nodes. This is exactly what one would expect given the way competition between male and female sex nodes works: the influence of the *er* node on the female sex node exerted through the (small) C_{FER} weight can be compensated by a larger weight C_{MER} weight.[6]

For both sets of parameters, the model is able to predict closely the human fixation times on the pronouns for both English and German–English subjects, and consequently the mismatch effect. Furthermore, the model exhibits the same relationship among the means that we found between English and German–English subjects: the decrease in the English mismatch is more linear than the decrease in the German–English mismatch—we will come back to this point shortly. Most importantly, the simulation results verify our prediction that the additional *er* structure is required to exhibit the effects found in the German–English subjects, since the models without the *er* structure did not fit the human data. In fact, the German model without *er* structure looks very “English-like” (as it exhibits the right mismatch effects as well as a linear decrease among the three sex conditions like the English subjects and models).

To ensure that the results about the necessity of the *er* structure in the German–English models are not dependent on the difference in subject ratings between the English and the German–English subjects, all simulations were repeated with English *dist* weights for all German models and the outcomes were essentially the same, only differing in the male conditions, where the pronoun difference is reduced by 1 for both sets of weights (for C_{FER} and C_{MER}). This implies that the small male bias in the German–English ratings does not contribute to the observed mismatch effect.

3.4. Discussion

In sum, our predictions about the influence of the morphosyntactic *er* representation are confirmed by the model simulations. Specifically, the model simulations confirm the expected mismatch effects in the male and female conditions and the absence of the mismatch effect in the neutral condition for the English monolinguals. For the German–English bilinguals, the model simulations confirm the presence of a mismatch effect in the male condition and the absence of the mismatch in the female condition. More importantly, the model simulations provide explanations for two experimental findings that were inconsistent with the predictions for the German–English bilinguals that: (1) the German–English bilinguals’ mismatch effect in the male condition was not significantly more positive than the English monolinguals’ mismatch effect, and (2) the German–English bilinguals’ failed to show a reliable positive mismatch effect in the neutral condition.

With respect to (1), it is possible for the German–English model to produce the predicted larger mismatch effect in the male condition and a non-negligible mismatch effect in the neutral condition by adjusting the C_{MER} and C_{FER} weights while keeping all other parameters constant. For example, a $C_{MER} = 0.4$ and a $C_{FER} = 0$ result in a mismatch effect of 21 cycles (or 210 ms) in the male condition, which is two times greater than the mismatch effect of 10 cycles (or 100 ms) in the English model and a non-negligible mismatch effect of 7 cycles (or 70 ms) in the neutral condition. Thus, these simulation results suggest that the German–English bilinguals did not exhibit the predicted larger mismatch effects in the male and neutral conditions than the English monolinguals because the bias from the association of the masculine *er* ending with male sex was not sufficiently strong.

There are two possible mutually non-exclusive reasons why the bilinguals' association of the masculine *er* ending with male sex may not have been sufficiently strong to produce the larger mismatch effects. First, the association may have been weakened as a result of the German–English participants' average of 9 years of experience with English (via formal instruction). If experience with the lack of an association of masculine gender—and hence male sex—with the *er* ending of agentive nouns weakens the association that was acquired through experience with agentive *er* nouns in German, then German–English bilinguals who have less experience with English should exhibit the predicted larger mismatch effects in the male and neutral conditions. The second possible reason for the German–English bilinguals' failure to exhibit larger mismatch effects is that, even with respect to processing *er* nouns in German, there must be a limit to the strength of the association of the masculine *er* with male sex to allow for the activation of female sex for the few German *er* nouns, where female sex is an obligatory semantic feature, such as *Mutter* (mother), *Schwester* (sister), *Tochter* (daughter), *Jungfer* (damsel).[7]

The model's basic assumptions also provide an explanation for the apparent nonlinear relation between the German–English bilinguals' average mismatch effect and their average stereotypical sex ratings of the *er* nouns, shown in Figs. 1 and 2. Specifically, according to the model's assumptions, the mismatch effects in the empirical data are not a true measure of the additional time that is required to update the sex of the antecedent noun's concept when the pronoun's gender mismatches the sex that is stereotypically associated with the noun's concept. There are two main factors in the model simulations that determine the length of the fixation on a pronoun: the *recognition threshold* and the *consistency criterion*. When the pronoun's gender matches the stereotypical sex of the antecedent noun, the consistency criterion is met before the recognition threshold is reached. However, when the pronoun's gender mismatches the stereotypical sex of the antecedent noun, the recognition threshold is reached before the consistency criterion is met. Thus, the fixation durations on the pronoun are simulated by the function *max*(*time-to-reach-recognition-threshold, time-to-reach-consistency-criterion*). Consequently, the difference between the fixation durations on *himself* versus *herself* in the empirical data does not provide a true measure of the difference in the time required for the consistency criterion to be met in each case, which is the difference that corresponds to the process of updating the sex node. A detailed discussion of this argument can be found in a supplementary section in the online Annex (http://cognitivesciencesociety.org/supplements/).

Although the model simulations provide insight into the basic factors assumed to contribute to the differences between the English monolinguals' and German–English bilinguals' mismatch effects, the simplifying assumptions made with respect to the architecture and processing in the models limit their ability to provide an account of other factors that are known to influence fixation durations and may contribute to the mismatch effects. For example, differences between the bilinguals' frequency of experience with the English *er* nouns should affect the relative durations of their fixations on the nouns, and, thus the amount of processing that they receive. The current model does not predict fixation times on nouns based on experience. In addition, the models do not simulate whether the total fixation durations are due to a single fixation on the pronoun or multiple fixations that result from regressive eye movements. Regressive eye movements that result in a re-fixation of the antecedent *er* noun would be expected to re-activate the morphosyntactic representation masculine gender associated with *er* in German, and thus, the corresponding association with male sex. This reactivation would be expected to prolong the process of updating the sex of the antecedent noun's concept more so than when there is no re-fixation of the antecedent *er* noun. Thus, the next step in the modeling process will be to expand the above models by simulating patterns of fixations (e.g., Rayner, 1998; Reichle et al., 1998). In fact, our current models suggest that regressive eye movements are likely to occur when the difference in activation levels between the male and female sex nodes is small after the processing of the reflexive pronoun. Preliminary simulation experiments with regressive eye movements using this mechanism look very promising.

4. General discussion

The findings of a male bias in the German–English bilinguals' interpretation of agentive *er* nouns in English and the model simulations of that bias together support an interactive view of the processing in bilingual lexicon. In particular, the results of the empirical study and the model simulations imply that German–English bilinguals who begin acquiring their proficiency in English at age 8 or later should exhibit a male bias from the association of masculine gender with *er* in German. If they do not exhibit a male bias, then, according to the account proposed here, it will be due to weakening the association of masculine gender with *er*, in which case, the German–English bilinguals would exhibit a significantly reduced bias to interpret German agentive *er* nouns as referring to a male relative to the bias that would exhibited by German monolinguals.

As discussed in the introduction, the interactive view predicts that complete independence in processing L2 words is unlikely to occur when the L2 words are similar in form (i.e., orthography and phonology) to L1 words. However, in the case of German–English false cognates, such as *teller*, the interactive view predicts that German–English bilinguals may selectively access the language-appropriate meaning of the false cognate if the frequency of its association with the L1 meaning and L2 meaning is equal, which is most likely to result from extensive L2 experience (and, hence proficiency). Thus, like homographs whose meanings are equal in frequency, false cognates in a bilingual lexicon that are associated with L1 and L2 meanings with equal frequency result in indeterminacy in the form–meaning mapping, thereby, making this association a weaker constraint than it otherwise would be. Consequently, the association between one of a false cognate's meanings and the other words can selectively constrain the form–meaning mapping.

However, the conditions that are predicted to lead to selective access of the language appropriate meaning of a false cognate are not possible with the agentive *er* morpheme examined here. Specifically, the association of male sex with the masculine *er* morpheme in German represents a form–meaning constraint that exists in German but is absent in English. Consequently, the absence of an association of *er* with a semantic gender representation in English that can directly compete with the association of *er* with male sex in German means that the influence of the constraint in German will be difficult, if not impossible to overcome, even with extensive experience or proficiency in English. This issue also raises the question concerning whether proficient German–English bilinguals will exhibit a male bias in interpreting agentive er nouns in their native English language as a consequence of acquiring the masculine/male association with the *er* morpheme in German.

However, it is possible that proficient bilinguals who began learning L2 at a very early age may exhibit modular or independent processing of L1 and L2 words. This possibility is suggested by evidence from a number of studies indicating that the ultimate level of L2 proficiency that is attained is highest when the age of onset of L2 experience is before age 7; thereafter the level of L2 proficiency that is attained decreases with as age of L2 onset increases (for a review, see Birdsong, 1999). Other evidence comes from a brain-imaging study by, Kim, Relkin, Lee, and Hirsch (1997) that showed different regions of activity during the processing of L1 and L2 words for proficient bilinguals whose L2 experience began in infancy versus proficient bilinguals whose L2 experience began at an average age of 11. Thus, German–English bilinguals whose experience with English began early in life may exhibit no male bias in interpreting agentive *er* nouns in English while at the same time exhibiting an appropriate male bias when interpreting agentive *er* nouns in German.

The results presented here also have implications for applied aspects of L2 acquisition. German learners of English as an L2 may occasionally make incorrect assumptions about the sex of the referent of an English agentive *er* noun. For example, in a conversation about a *speaker*, a German–English bilingual may interpret the referent's sex to be male because of the masculine gender associated with the *er* ending. The question then is to what extent does this male bias impact ordinary discourse and to what extent can strategies or instructional techniques reduce the bias.

5. Conclusion

The effects of the association of masculine gender with *er* in German on German–English bilinguals' processing of *er* nouns in English are likely to be exhibited in other cases in which a morpheme is associated with a gender in L1 but not in L2 (e.g., Portin & Laine, 2001), such as the masculine gender associated with "*-or*" in German (e.g., *Kurator*—curator), or, similarly, "*-ore*" in Italian (e.g., *dottore*—doctor). Investigating the interference or facilitation that results from processing L1 and L2 words with varying degrees of similarity in their linguistic representations provides insight into not only factors that affect fluency in bilingual language processing but also the larger theoretical questions concerning the extent to which language processing, in general, is modular versus interactive. Although the results reported here are consistent with an interactive view, they do not exclude the possibility that results from an analogous task with very early L2 learners may be consistent with a modular view. However, the interactive account of the empirical results reported here, which was explored in greater detail through model simulations, suggests that, for later L2 learners (e.g., age 8 or later), high levels of L2 proficiency or experience are unlikely to result in modular-like processing of the asymmetrical form–meaning associations that exist in L1 versus L2 examined here.

Notes

1. The sentences used in this study can be found in the online Annex at http://cognitivesciencesociety.org/supplements/.
2. The English monolinguals also exhibited the predicted negative mismatch effect in their average initial fixation durations (or first-past reading times) on the pronouns in the female condition. Specifically, a 2×2 ANOVA of the average initial fixation durations resulted in a significant interaction between pronoun and language in the analysis by subjects ($F1(1, 38) = 7.85$, $p < .01$; $F2(1, 7) = 1.26$). The interaction reflected a significant negative mismatch effect of -53 ms for the English monolinguals (paired subjects $t(19) = 2.62$, $p < .01$, one tailed; paired items $t(7) = 1.84$, $p = .05$, one tailed) and a nonsignificant positive mismatch effect of 31 ms for the German–English bilinguals (paired subjects $t(19) = 1.40$, $p = .18$, two-tailed; paired items $t(7) < 1$). Neither of the main effects was significant (Fs < 1). In contrast to the female condition, there were no significant mismatch effects in the analyses of the average initial fixation durations in either the male condition or neutral condition. Only the main effect of language was significant in the analyses in these conditions, reflecting shorter overall initial fixation durations on the pronouns by the English monolinguals than the German–English bilinguals. Although comprehension difficulties may be reflected in either initial fixation durations or total fixation durations (e.g., Rayner & Sereno, 1994; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989), the analyses of total fixation durations are reported here because incongruencies at the pragmatic or discourse level, of which a mismatch between a pronoun's gender and an antecedent noun's stereotypical sex are an example, have been shown to be exhibited in total fixation durations if not also in the initial fixation durations (e.g., Boland & Blodgett, 2001; Braze, Shankweiler, Ni, & Palumbo, 2002).
3. To ensure that differences in the strength of the two groups' association of a stereotypical sex with the nouns do not account for the differences in the groups' mismatch effects, ANCOVAs were conducted on the participants data in the male and female conditions, respectively, with the participants' average stereotypical sex ratings of the critical nouns in each condition as a covariate. The results of the ANCOVAs were the same as the results of the ANOVAs. Specifically, the analysis of the male condition yielded neither a significant interaction between the participants' average ratings and their language nor a significant interaction between the participants' language and the gender of the pronoun (Fs < 1). When these interaction terms were removed, the main effect of the covariate was not significant ($F1(1, 76) = 1.56$, $p > .05$), but, as in the ANOVA, the main effect of the pronoun's gender (himself vs. herself) was significant ($F1(1, 76) = 10.62$, $p < .01$) and the main effect of the participants' language was significant ($F1(1, 76) = 15.81$, $p < .01$). The results of the analysis of the female condition yielded no significant interaction between the participants' ratings and their language ($F1(1, 72) = 1.51$, $p > .05$). When this interaction was removed, the main effect of the covariate (participants' ratings) was not significant ($F1(1, 73) = 1.88$, $p > .05$). In addition, as in ANOVA, neither the main effect of the pronoun's gender was significant ($F < 1$) nor was the main effect of the participants' language ($F1(1, 73) = 1.37$). However, the interaction

between the participants' language and the pronoun's gender was marginally significant ($F1(1, 73) = 3.77$, $p = .06$), reflecting a mismatch effect for the English monolinguals but not the German–English bilinguals in this condition.

4. Nothing hinges upon the fact that we employ a localist representation of concepts in our model, i.e., no claims about the interference of morphosyntactic representations in one language on the processing of form-related lexical representations in another language depend on our use of localist representations. Specifically, the localist representations in our models do not reflect any assumptions about the representation of concepts in humans nor do the simulation results depend on our use of localist representations of concepts as the same results are likely to occur if distributed representations were used instead. Thus, our use of localist representations is merely for ease of exposition.
5. The masculine gender associated with the *er* morpheme of nouns denoting inanimate concepts (e.g., *Drucker* (*printer*)) would not be assumed to have an associative connection to the representation of male sex at the conceptual level.
6. Note that since there are only a few German agentive *er* nouns that, by definition, denote females and, therefore, are grammatically feminine, the gender ratio of 1:25 between masculine and feminine agentive *er* nouns in German used by the model overestimates the true ratio in German.
7. We assume that the feminine *in* node is represented analogous to the masculine *er* node and that, in the case of German nouns such as *Räuberin* (female robber), the strength of the *in* node's connections to the female sex node enable the activation level of this node to overcome the combined influence of the masculine *er* node and the stereotypical male bias reflected in the $\text{dist}_{\text{Msex}}$ weights. In addition, at the morphosyntactic level, the *in* node may have a direct one-way inhibitory connection to the *er* node, which prevents the *er* node from activating the male sex node.

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