in a double-blind crossover study testing past-tense production. Hormone therapy (compared to placebo) in both sexes increased production of real and novel irregular forms (*break-broke*, *spling-splung*) ($ps < 0.05$), with no placebo/treatment by male/female interaction. Performance at novel regulars (*blick-blicked*) *decreased* with hormone therapy ($p < 0.05$; no interaction with sex), likely due to increased irregularizations (*blick-bluck*). Importantly, accuracy at real regulars (*swayed*) *increased* in women ($p < 0.05$) but *decreased* in men ($p < 0.01$). The study underscores the memorization of real regular past-tenses by women but not men and suggests that sex hormones (estrogen/testosterone) improve lexical retrieval/processing but not rule-based computations.

These experiments support the language sex difference hypothesis, in expressive and receptive language, in morphology and at least in some aspects of syntax; experiment five implicates estrogen in these effects. No performance differences were found in the studies of healthy untreated adults, suggesting that the neurocognitive sex differences do not lead to obvious achievement differences. The data have educational and clinical implications, and strongly suggest that language studies should include sex as a design factor.

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The effect of sex hormones on language processing

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Previous studies suggest a dissociation in the neurocognitive bases of language. The mental lexicon of stored words is an associative memory that depends on the

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well-studied medial/lateral temporal-lobe "declarative memory" system, whereas aspects of grammar underlying the real-time composition of complex representations (*play* + *-ed*) depend upon frontal/basal-ganglia structures (Ullman, 2001). Girls and women are better than boys and men at remembering words ("verbal memory") (Kimura, 1999). This female advantage appears to depend upon the temporal-lobe declarative memory system (Ullman et al., 2001). These language and sex-difference data led us to hypothesize that, because of their superior lexical/declarative memory abilities, girls and women may tend to memorize and/or retrieve at least certain complex representations (*played*) that men compose on-line (*play* + *-ed*). Recent psycholinguistic, neurological, and electrophysiological studies support this view (Ullman et al., 2001).

Here, we probe the cognitive and biochemical mechanisms underlying these sex differences. We focus on two questions: first, do females memorize complex forms at a higher rate than males and/or do both sexes store these forms, while females have superior lexical retrieval/processing abilities? Previous studies have failed to elucidate this issue. Second, do sex hormones, and estrogen in particular, contribute to the sex differences? Previously reported data support this hypothesis. Estrogen improves word and declarative memory abilities in women; moreover, this improvement depends on the medial-temporal-lobe structures (e.g., the hippocampus) that underlie declarative memory (Maki, Zonderman, & Resnick, 2001; Ullman et al., 2001). Estrogen strengthens hemodynamic, physiological, and biochemical correlates of hippocampal learning (Woolley & Schwartzkroin, 1998). Testosterone, which is the main source of estrogen in men, improves their word memory.

Methods

Ten post-menopausal women and 12 age-matched men participated in a randomized, double-blind, placebo-controlled crossover study of the effects of hormone therapy on language processing. Subjects were given hormone replacement therapy (women: conjugated estrogens; men: testosterone) and placebo, each for three months with an interceding three-month washout period. After each three-month hormone or placebo period, subjects were given a past-tense production task containing regular (*sway-swayed*), irregular (*break-broke*), novel regular (whose stems do not rhyme with the stems of irregular verbs; *plag-plagged*), and novel irregular (whose stems rhyme with the stems of irregular verbs; *spling-splung*) verbs presented in sentence contexts (sleep. Every day I sleep in bed. Yesterday I _____ in bed.). Accuracy (percent correct) constituted the dependent variable. For novel irregulars, only irregularizations were considered correct (*spling-splung*); for novel regulars, only regularizations counted (*plag-plagged*).

Results

Hormone therapy (compared to placebo) yielded increased estrogen levels in both sexes ($ps < 0.05$). Hormone therapy also induced an increase in both sexes in the production rate of real and novel irregular past-tenses (*break-broke*, *spling-splung*) ($p < 0.05$; Fig. 1), with no interaction between treatment (placebo/hormone) and sex (male/female). Performance at novel regulars (*plagged*) *decreased* with hormone therapy in both sexes ($p < 0.05$; no interaction with sex), likely due to increased irregularizations (*plag-plog*). Importantly, accuracy at real regulars (*swayed*) *increased* in women but *decreased* in men, as a result of hormone therapy ($ps < 0.05$).

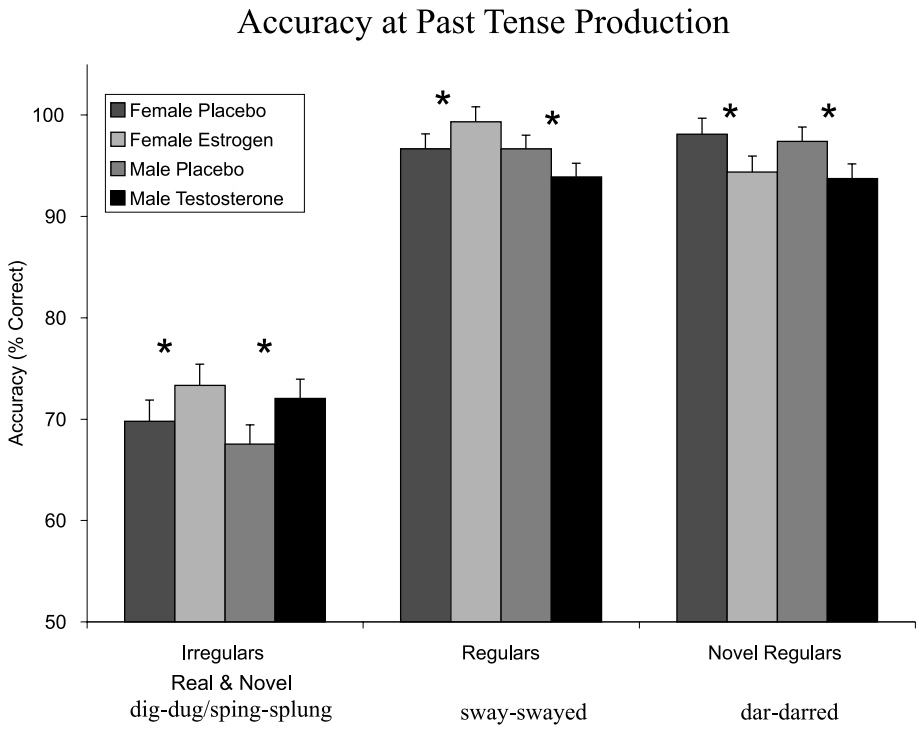

Fig. 1. Hormone therapy improved accuracy for real and novel irregulars. Hormone therapy decreased performance on novel regulars and differentially affected real regulars by sex. Females showed improvement on real regulars, while males showed decreased performance.

Discussion

The finding that estrogen in women and testosterone in men increase the production rate of real/novel irregular past-tense forms suggests that these sex hormones improve the retrieval/processing of existing memorized lexical representations and of novel forms whose processing is posited to depend on pre-existing similar memory traces (e.g., *spling-splung* cf. *fling-flung*, *wring-wrung*) (Ullman, 2001). The decrease in performance of novel regulars with hormone therapy in both sexes supports the view that these forms are computed by neural mechanisms distinct from those that underlie the processing of real and novel irregulars. This finding supports the dual-system "declarative/procedural model" described above, and poses a challenge to recent connectionist models of past-tense processing, which assume that all novel past-tense forms are similarly computed (Joanisse & Seidenberg, 1999). The absence of a treatment-by-sex interaction for either real/novel irregulars or novel regulars indicates that the two hormones have similar effects, suggesting the same mechanism—presumably estrogen-modulated—in both sexes. These estrogen effects have important implications for the recovery of language following brain-damage, suggesting the use of estrogen as a neuropharmacological therapeutic agent.

The finding that hormone therapy led to an increase in the production rate of regular past-tenses in women, but a decrease in men, shows that in women these forms pattern with the memory-dependent irregulars, whereas in men they pattern with the compositional novel regulars. This underscores the validity of our previous

studies that suggested that women tend to retrieve regular past-tenses that men compose on-line. Moreover, the current study suggests that these previous results are *not* attributable to both sexes storing these forms, with females having superior lexical retrieval/processing abilities. If men did store regular past-tenses we would expect to see an increase in their production rate of these forms with hormone therapy (like irregulars) rather than a decrease (like novel regulars). Rather the sex difference that we previously observed may be attributable to the prior memorization of complex forms by girls, presumably during childhood. This might or might not be explained by sex-differences in estrogen levels, which could affect brain organization in utero and/or learning during childhood; future studies will address this issue.

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Inhibition and proactive interference effects in impaired semantic short-term memory of aphasic patients

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Recent research demonstrates that short-term memory (STM) consists of dissociable phonological and semantic buffers that serve to store language representations

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