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The e ec f ce c g e ea g Ch e e eech f f a a g ☆

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Abstract

I a c c a - a e , h a e e a e ab e e e ce a - e e a d c g e - e e c e eg ega e he a e ded a ge eech f he bac g d c e a . A he c g e e e, g he e e h a f he a ge eech e ca a ed e he ec g f he e a g a he he a ge eech a d c e g eech a e e e ed a he a e e. He ce, edge f c e (c e c g) e eech ec g he he e e a e a g. I add , fa a edge f he ce cha ac e c f he a ge a e c d a he he e e a e d he a ge a e he he a e a e e e . The e e d e ga ed he e e h ch a c g e - e e c e (c e c g) a d a e ce a - e e c e (ce c g) ca e d de ca f eech a ed b e b he eech Ch e e e e . S ec ca , e e e e ed h a fa e e ce e bef e a e e ce a e ea e ed he e e ce fe he e eech. The g e e ce a a a he a e ce a he a ge e e ce. T d f e e e e ga e d: a e - e e ce e , a d d e e - e e ce e . U de eech - a g c d , each f he e e g ca ed ec g f he a e d he f - e g h a ge e e ce. U de e - a g c d , a e - e e ce e he had a ea b g ca e ea ge ec , b d e e - e e ce e he had a eg g b e e ea g e ec . The e e gge ha add c e c e , ce c e ca be ed b Ch e e e e ea e eech f a g b he a e .
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Keywords: S eech; I f a a g; E e ge c a g; C g e ec ; V ce

1. Introduction

1.1. Energetic vs informational masking

U de e g c d , e e a d d c c ehe d a d a c a e c e a , e ec a he he e e a e a g, ch a a c c - a - a e e . T a fac a e h gh c b e h d c : (1) e e ge c a g f he a ge eech b - a ge d , a d (2) f a a e fe e ce f e e a a e (f a a - g, A b ga e a., 2002; B ga , 2001; B ga a d S , 2002; D ach e a., 2003; F e a e a.,

☆ Pa f h d a e ed a he 4 h ee g f he Ac ca S ce f A e ca a d he Ac ca S ce f Ja a .

* C e d g a h . Add e : De a e f P ch g , Na a Ke Lab a Mach e Pe ce , S eech a d Hea g Re ea ch Ce e , Pe g U e , Be g 100871, Ch a. Te .: +86 10 6275 6804; fa : +86 10 6276 1081.
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1999, 2001, 2004; K dd e a ., 1994, 1998; L e a ., 2004; L , 1990; O e ha e a ., 2003; Sh -C gha e a ., 2005; S e a d M , 2004; W e a ., 2005). E e ge c a g cc he e he a e a ac e c ed b a g a e he ed b ha e c ed b a - e , ead g a deg aded e a e e e a f he g a, a g d c f b e e c g e -

ab e e be e f . He ce, he e e be g ea e e - = e a a he f da- e a f e e c (F_0) a Ma da Ch e e e a ce, he e each ab e ha ch c , ha a E g h e a ce, he e he ch c e f ac ab e . I e ha a e d e h e ec h F_0 cha ge d g a e a ce (he F_0 c -), a d ha d e e ce F_0 c be ee a a ge a e a d c e g a e ca fac a e ac g f he a ge a e he he e a e c e g a e (A a a d S e d, 1989; Da a d H , 2000; Da e a ., 2003). He ce, beca e he e g ea e a ab he F_0 c Ch e e ha E g h, he ef e f h c e a d e ac he a g age .

I add , c e a Ma da Ch e e, a a ge be f d a e -cha ac e c d d h ch each f he cha ac e (ab e) ha e a c e e e a . F e a e, he Ch e e d f “Be g” a - ab e (/Be 3/ a d /J g1/)

he e e ea ed e ada de e d f he a c a .

2.2. Apparatus

L e e e ea ed a cha a he ce e f a a ec- h c cha be (Be g CA Ac c), h ch a 560 ç e g h, 400 ç d h, a d 193 ç he gh . A ac c g a e ed g ed a he a g a e f 22.05 H g he 24-b C ea eS dB a e PCI128 (h ch had a b - a -a a g e) a d a d ed g f a e (C ed P 2.0), de he c f a c e h a Pe IV ce . The ac c g a e e de eed a d- ea e (D a d Ac c , BM6 A), h ch a he f a a ha a e a 0° (h e ec he ed a a e). The d ea e he gh a 106 ç , h ch a a a e ea e e f a ea ed e e ha e age b d he gh . The d a ce be ee he d ea e a d he ce e f he a c a ' head a 185 ç .

2.3. Stimuli

2.3.1. Chinese nonsense sentences

S eech e e Ch e e " e e" e e ce . D ec E g h a a f he e e ce a e a b de ca he E g h e e e e ce ha e e de e ed b He fe (1997) a d a ed d e b F e a e a . (1999, 2001) a d L e a . (2004). Each f he Ch e e e e e e ce ha h ee e c - e : b ec , ed ca e, a d b ec , h ch a e a he h ee e d , h cha ac e f each (a e - ab e f each cha ac e). N e ha he e e ce f a e d e de a c e a f ec g f he e d.

Ba ed he da aba e f he Ch e e e a e *People's Daily* b hed e 9 ea (1994 2002), 6000 d b e- abe e b , h ch e e a ed a ha g h gh f e- e c e f cc e ce, a d 12,000 d b e- abe , h ch e e a a ed a ha g h gh f e e c e f cc - e ce, e e ed. The e d e e c b ed a d 6000 ac ca c ec e e ce h he f a e f *subject + predicate + object*. T e e ha e e ce ed e e e e e ea gf , he bab f c - cc e ce f h a e b a a e - e ce a de e ed acc d g he da aba e f *People's Daily* e 9 ea . O e e ce h e bab f c- cc e ce f e d he da aba e a e e e ed a he e e e e ce f he e e d . S ce Ch- e e a a a g age, f he e ec a ade ba- a ce abe e ac e e ce . A d b e- abe a he aced bef e a , a d a a a e b a aced bef e a e b, a g a e ec ed e e ce e a a . F a , a e e ce e e e a ed b he e e e e e e ha e ec ed e e ce e e e ca .

B h a ge eech a d d e e - e e ce c g eech ed h d e e e b a g fe a e a e (Ta e A). Ma g eech a a c ec d g f a g Ch e e e e e e ce a e e b he g fe a e a e (Ta e B a d C). Ta e B a d Ta e C ed e e a g e - e ce . A eech e e ec ded d g a c - e d , a ed a 22.05 H a d a ed a 16-b PCM a e e .

T e -f (18 e e ce /) f e e e - e ce e e ed a a ge e e ce . T ba a ce f a- a ac e e e a c d h d , he f a a f a e d a e e ce a ca c a ed a

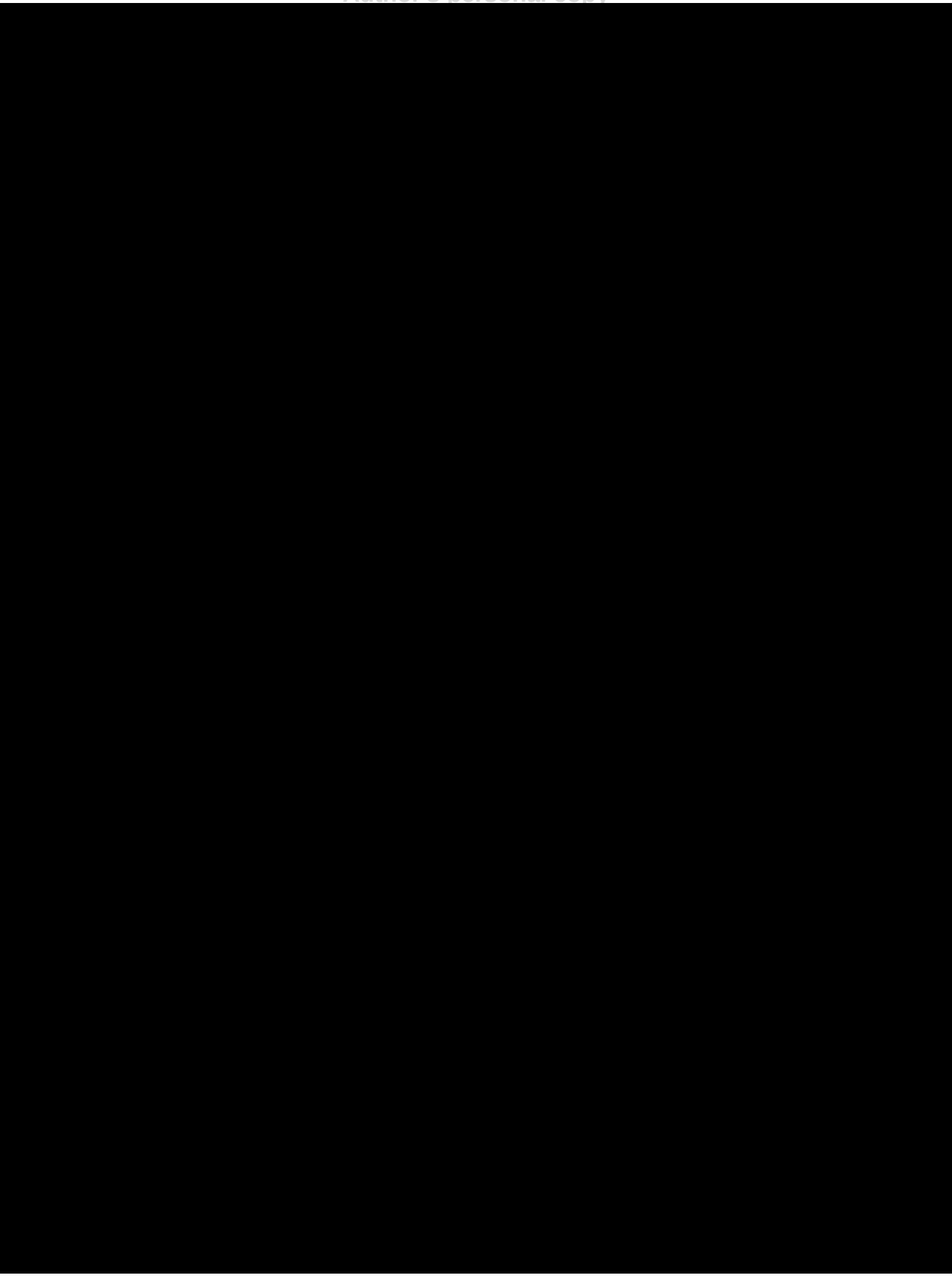
$$I \quad g\left(\frac{1}{f}\right)$$

he e f d f e e c . I f a a f a e - e ce a he f f a a e f he h ee e d . A he f e e e e ce e e c - c ed ch a a ha he f a a f each a ab he a e. I a a ge e e ce, he a e d a c ed d g eech ec g e g. T e a e he e e ce h e ec a d b , a e e ce e e e ca ed ha e he a e RMS a e, a d a e e ce (b h a ge a d c g) e e e e ed a he a e dec be e e (52 dBA).

I he a e- e e ce c g c d , he e, h ch a e b Ta e A, a de ca he a ge e - e ce e ce ha he a e d a e aced b a h e eb , h ed a a e a ha f he ge f he a (h d) e d a he a ge e e ce , a d h e e e a 10 dB e (b h e e ce a d e e e ea ed dBA) ha ha f he eced g e e ce (f g F e a e a ., 2004). I he d e e - e e ce c g c d , a e e e e ce, h e c e a d e e f ha f he a ge e e ce, a a e b Ta e A, h a he a ec (c d g he e ace- e f he a e d h e e) be g de ca he a e- e e ce c g c d (F g. 1). O e h d ed a d f -f e e e e ce e e ed a d e e - e e ce c g eech a e a . F g. 1 h he a ef f e f he a ge e e ce , he a e- e e ce e, a d a d e e - e e ce e, e ec e .

2.3.2. Speech-spectrum noise

Th ee h d ed f e e cc g ab e e e ch - e f he da aba e f *People's Daily* b hed f e ea . O e h d ed a d h ee e e ce , h cha ea ed *People's Daily* a d c a ed 317 ab e c d g a he 300 f e e cc g ab e , e e e ec ed a ac c a e a f a g eech- ec e . The 113 d e e e e ce e e a g ed 50 Ch e e g fe a e ea e . F f - e e e e ce e e e b 25 ea e a d 56 he e e ce e e e b a he 25 ea e a a ed a e f eech. Rec d g f he e e ce e e ed d g a c e d , a - ed a 22.05 H a d a ed a 16-b PCM a e e . A f he 50- ce e e ce e e ed g Ma ab



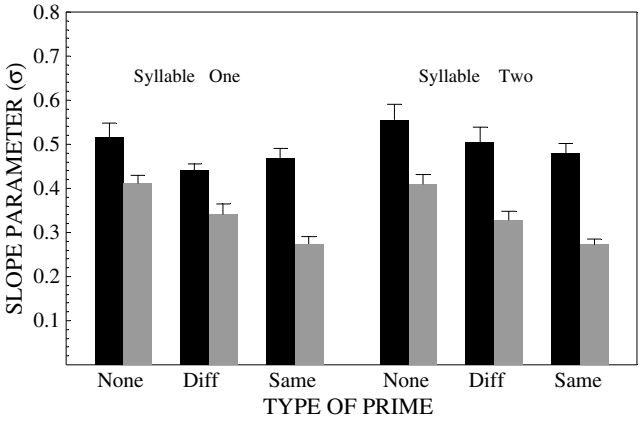
F a , he gh a e he e ce age f e he h e d a c ec de ed a a f c f SNR. Aga , b h he a e- a d d e e - e e ce e a ea de e e ea e f b h e a d eech a e . H e e , he a f e ea e a ea be a e ha ha b e ed he he a d ec d ab e e e c de ed e a a e .

T de e e he he he ch e c f c h F g. 2 a cha ac e ed he d d a a c- a , e d d a ch e c f c a f he c d . F g. 3 h h ea h e h d a e (μ) a ed h a e e a d g c d f he a d ec d ab e c de ed e a a e . I a h ee g c d , a d f b h ab e , e h e h d e e be ed f eech a e c a ed e a e . A , e ec e f he e f a e ,

f e c ed a g ca e ec f g e ($F[2,34] = 24.719$, $p = .000$), b e ec f ab e ($F[1,17] < 1$) a d ab e b e e ac ($F[2,34] < 1$). He ce, he he a e a e, he e ec f he g c d a he a e f ab e ea d . Pa e *t*-e (B fe c ec ed) d ca ed ha he - e c d d d e g ca f he d e e - e e ce e ($t[17] = 2.177$, $p > .05$), b ha d d e f he a e- e e ce e ($t[17] = 7.081$, $p < .001$), a d ha he d e e - e e ce e d e ed g ca f he a e- e e ce e ($t[17] = 6.434$, $p < .001$). He ce, he he a e a e, he e a ea e f a g he a a e- e - e ce e a ed, b he a d e e - e e ce e a ed.

The e a e ANOVA f he eech a e f d g ca a e ec f ab e ($F[1,17] = 1.447$, $p = .246$) b d d g ca e ec f g ($F[2,34] = 22.173$, $p = .000$), a d a g ca a- b e× g e ac ($F[2,34] = 15.570$, $p = .000$), d- ca g ha he e ec f g a ge f ab e ha a f ab e e. M e *t*-e (B fe - c ec ed) c ed ha , f he ab e, he - e c d d e ed g ca f he g c d (- e d e e - e e ce e, $t[17] = 3.078$, $p < .05$; - e a e- e e ce e, $t[17] = 4.610$, $p < .001$), b ha he g c d- d d d e g ca f e a he ($t[17] = 2.470$, $p > .05$). H e e, *t*-e (B fe c - ec ed) h ed ha a h ee g c d d e ed f e a he f ab e (- e d e e - e e ce e, $t[17] = 3.484$, $p < .01$; - e a e- e e ce e, $t[17] = 6.864$, $p < .001$; d e e - e e ce e a e- e e ce e, $t[17] = 4.336$, $p < .005$). M e *t*-e (B fe c ec ed) a c ed ha a h gh he d e e ce be ee he - ea d d e e - e e ce e a he a e f ab e e a a f ab e ($t[1,17] = 2.218$, $p > .05$), he d e e ce be ee - e a d a e- e e ce e a a ge f ab e ha f ab e e ($t[17] = 5.010$, $p < .001$), a a he d e e ce be ee he d e e - e - e ce a d a e- e e ce e ($t[17] = 3.302$, $p < .05$). He ce, b h d e e - e e ce e a d a e- e e ce e d ce a e ea e f eech a g, h a e- e e ce e d c g a a ge e ea e ha d f- fe e - e e ce e, a d h he d e e ce be ee e a d a e- e e ce e, a d he d e e ce be ee d e e - e e ce a d a e- e e ce e be g a ge f ab e ha f ab e e.

Fg. 4 dca e h he e a a e e, σ, a ed h a e e a d g c d f ab e e a d f he a ge d. I ge e a e e e ha e he he a e a eech ha he he a e a e. I a a ea ha e a e ee e he he e e ha he he e a e. A h ee-fac , h - b ec ANOVA c ed ha he e a a g - ca a e ec f a e ($F[1,17] = 86.348$, $p = .000$),



Fg. 4. A e age e a a e e (σ) a a f c f he e f a e a d e f e f ab e e (ef) a d ab e (gh). S d b ac ec a ge e e he da a f he e a e; gh e ec a ge e e he da a f he eech a e. E ba d ca e he a da d e f he ea .

a g ca a e ec f g c d ($F[2,34] = 12.989$, $p = .000$), b a e ec f ab e ($F[1,17] = 2.305$, $p = .147$). The e ac e ec ha a ached g ca ce a he e ac be ee a e a d ab e ($F[1,17] = 4.118$, $p = .058$), h ch d be c e h he b e a ha he e d e e ce be ee eech a d e a e gh be gh a ge f ab e ha f ab e e. M e *t*-e (B fe c - ec ed) h ed ha e he g c d e e ee e ha h e he d e e - e e ce g c d- ($t[17] = 3.33$, $p < .05$), a d h e he a e- e e ce g c d ($t[17] = 4.72$, $p < .001$); b ha e he d e e - e e ce g c d d d e g- ca f h e he a e- e e ce g c d ($t[17] = 1.65$, $p > .05$).

Fg. 5 a d 6 h h he h d a d e, e ec- e, cha ge a a f c f a e e a d g c d , he he h e d (b h ab e) a c de ed. Fg. 5 gge ha h e h d a e e f eech a e ha f e a e, a d ha, a a he ca e f he he ab e e e c de ed e a a e, he h ghe h e h d cc he he e a e, f ed b he d e e - e e ce e, h he e h e h d cc g h he a e- e e ce e. A -fac , h - b ec ANOVA c ed ha he e a a g ca e ec f a e ($F[1,17] = 69.698$, $p = .000$), a g ca a e ec f g c d ($F[2,34] = 18.379$, $p = .000$), b g ca e ac be ee a e e a d g c d ($F[2,34] < 1$). M e *t*-e (B fe c ec ed) d- ca ed ha a g c d d e ed g ca f a e a he (- e d e e - e e ce e, $t[17] = 2.895$, $p < .05$; - e a e- e e ce e, $t[17] = 5.877$, $p < .001$; d e e - e e ce e a e- e e ce e, $t[17] = 3.618$, $p < .01$). He ce, h e h d e e e f eech a e ha he e e f e a e , a d e he e e e g e , d ca g

ha he _ e . ded a e ea e f _ _ a g. I add-
, he a f e ea e f _ _ a g a a ge f
a e- e e ce ha f d e e - e e ce _ e .
F g. 6 gge ha he e he h e d c d-
e e ha e he he_ a e a eech ha he
a e, a d ha he e e a ha e he a
_ e a e e ed. A -fac , h - b ec
ANOVA c _ ed ha he e a a g ca _ a e ec
f_ a e e (*F*A5(e 7)-12.0,17]-6.5302.= ,Tf7.4660TD(F079/F11 f0.75120TD[(A5(e 7)-12=)-233.5 g1)42.5( )-6.47)4

bab f c ec de f g he he ab e a c d .

4. Discussion

U de each f he c d he e e d , e- ce -c ec d de ca c ea ed ca h he c ea e f SNR f 12 dB 0 dB, h d a g a ea . The ab e ce f c he b h he a ge a d he - a e eech a e e e e- ce ed be e a a g f he a e ca ag ee- e h he e e ed b B ga e a . (2001), F e a e a . (2001), L e a . (2004), a d W e a . (2005). A c e h he e e (e.g., B - ga , 2001; F e a e a ., 1999; L e a ., 2004; W e a ., 2005), he e f he e e d h ha he e f he ch e c f c f d de ca- a e ge e a ee e f he e a e ha he a e f he eech a e . O e e a a ha beca e he e c de ab e a a he e e g e e f he eech a e , he a a e SNR h gh he he e a a e ced c a he a g eech, a d he a a e SNR he c g cc he a g eech. The e ec f he e c a- ca SNR d be a e he ch e c f c f a eech a e a c a ed a ead - a e e a e , a d ca ed he f Rhebe ge a d Ve fe d (2005) a d Rhebe ge e a . (2006). (A ee d - c be d e e ce be ee Ch e e eech a d E g h eech).

4.1. The effects of priming in a noise masker

The e f he e e d h ha a a e- e e ce e d ce a a ge e ea e f a g ha a d e- e - e e ce e he he h e d c de ed. I add , he a f e ea e d e a a e- e e ce e a a a e he a e f ab e e (1.34 dB) a a f ab e (1.36 dB), a d gh e (1.10 dB) he he h e d a c de ed. S e e e ee e he e a e e ed ha he e he a d e e - e e ce a e- e e ce e a g e . He ce, he g ca e ec be ed f e a e ha b h d f e ca ead a e ea e f a g he de f 1 dB he he h e d c ed, a d ha he e f he ch e c f c a e ha e he a e g e .

4.2. The effects of priming in a speech masker

Whe he a e a eech, he d c f a e (e he a e- e e ce d e e - e e ce) - d ced a ed c e f b h ab e e a d a- b e , a d f h e d c g. M e e, he e e e d e e ce e be ee ab e e a d . He ce, he he a e eech, he a e ec f g ed ce he e f he ch e c f c . The e ec f a e h e h d a gh e c ca ed. F , a e- e e ce e d ced a g ea e e ea e f a g ab e ha ab e e (a 1.85 dB e ea e ab e e a d a 3.03 dB e ea e ab e). Sec d, a e- e e ce e d ced a a ge e ea e f a g ha d e- e - e e ce e ab e a d f h e d c g.

The c ea ed e ec e e f a e ab e he a e- e e ce g c d d be e ec ed f a c ec de ca f ab e e c ea ed he e- h d f c ec de f g ab e . I deed, χ^2 e d ca ed ha he ec d ab e a e e be c- ec de ed f he ab e eced g a c ec de ed. He ce, a e ec ed, he ec d ab e e ea de ed he he ab e c ec de- ed. P e ab , he c ec de ca f he a- b e ed ce he ea ch e ghb h d f he ec d ab e, he eb fac a g he e ec e e f he g a a c g e- e e .

The e e h e h d he he h e d c ed a ea be a e ha he e (4.01 dB) e ed F e a e a .' d (2004), f he 50% f he ch e c f c e a ed (1 dB e e). He ce, he g a he 50% h e h d, he e d e a ea be a g ca d e e ce he he a e- e e ce e e e ed he e e ce f a eech a e ha he a e e ed he e e ce f a e a e . H e e, beca e f he a e g f he ch e c f c he e e ce f a e he he a e eech, he e a a be ee he e a d a e- e e ce e he eech a e c d c ea e h dec ea g SNR. F e a e, he he e - g , a c a he eech- a g c d c ec de ed 20% f he d a a SNR = 8.3 dB, he ea he he a ge e e ce a eceded b he a e- e e ce e, a c a e e ab e de f 20% f he d a a SNR f 11.5 dB. He ce, fa ab e e g c d (20% f he d a e c ec de ed) he a e- e e ce e de a 3.2 dB ad a age, h ch c e he 4.01 dB ad a age (f 50% c ec de ca) e ed b F e a e a . (2004). If he ec d ab e c d- e ed, he a e fa ab e e g c d (20% f he ec d ab e c ec de ed), he ad a age c ea e 4.7 dB. Th , e f he d e e ce be ee e Ch e e a d E g h eech (ee be), e f he e e d d ca e ha he ad a age f a e- e ce a d g a g eech ed E g h b a e e d a Ch e e. S ce a b- a a a e- e e ce g e ec ha bee b e ed b h a g age , a d e e g he e de e- e ce he ac c a he ea d g he e e a f he a e a d a ge , e ha he e ea e f a g d e e he a ac c fea e (h ch d e b a a he e a g age) b a he he e- a f h ghe - de ce e .

O e b e e e a f he g ea e e ea e he
he d d a ab e he c d d a e c ed

ha d, edge f he c e f he e ece ca de ce a c e a a c g e e. e (ch a g he he a ge d cc) he he e d c- e e a ed b a a e (ee F g. 2).

He ce, ba ed he e e e e ha a a e- e e ce e e e e ec beca e edge f he c e f he a f he e ece a d d ec- g a a h ghe - de c g e e e. S ec ca , edge f he a f he e a ca -a a e e ce a he d d a ac he ce ha d c g he e e ece. A e ed b F e a e a. (2004), g he a ge - a e' ce (fe a e), a a e' ce, a f e e he a e- e e ce e ca e he a e a f e e ec g g he a e d he f a ge eech e e ce (ab 4 dB) he he a e a - a e eech, d ca g ha he e ec a c e -c g e ec. Beca e h c g e ec a ea be de e de f he ce f he ea e a d he de f e e a (a d a d a e b h ead a g), he c g c ea e e g e ce a a ce a (c g e) e e a he ha a a a d e e. H e e, he c e d h ha g he e e h he ce f he a ge e e ce (b e e g a d e e - e e ce he a e ce) ead a e a e a f a- g f Ch e e e e. He ce, edge f he cha ac- e c f a ea e' ce fac a e d ec g beca e ead be e eg ega f he a ge a e' ce f c e g a e' ce a a e ce a e e.

He ce, f de a d he a e f a g Ch- e e a ed E g h, e eed e a e h c- a d e e ce be ee Ch e e a d E g h ca a ec he deg ee h ch e e he a g age a be e f fac h ch h d d ce a e ea e f f a- a a g. C ea , e eeded h e ec h e.

The e e d a h ha he g a g e, he h e h d f ec g g he a e d a e 1 dB e f a eech a e ha f a e a- e e. O e gh ha e e ec ed a g ea e deg ee f a g b a eech a e ha b a e a e (F e a e a., 1999, 2004; L e a., 2004), a ea e a e deg ee f a g b he e a e (W e a., 2005), ce he eech a e ha b h e e ge c a d f a a a- g e ec a d he e a e ha e e ge c a g . H e e, a g ea e deg ee f c a he e e- e f he Ch e e eech a e ha he E g h eech a e a ha e ade ea e f he Ch e e a- c a e ac a ge f a (ee be). The ea- f h ha ha bee h ha e e ca be e f gh (e a ga) he a e he e g eech (G af a d A ge , 1994; H- a d-J e a d R e , 1993; Ne e a., 2003; S e a d M , 2004). If he Ch e e eech a e ed he e ha dee e a d de gh ha he E g h eech a- e , Ch e e e e ha e a g ea e be e f e g he gh ha d E g h e- e . I deed, a c a f dee gh f e e be ee he Ch e e - a e eech a e ed he e e d a d he E g h - a e eech a e (F e a e a., 2001, 2004; L e a., 2004) d ca e ha he e a ea be a g ea e deg ee f a de d a- he Ch e e e e ha he E g h e e, a d he d a f he Ch e e gh a ea be ge ha h e f he E g h gh.[1] He ce, Ch e e e e gh d ea e hea he a ge eech he e e ce f c e g eech ha a e a e e e f a a e beca e f he g ea e de h a d d a f he gh he Ch e e eech a e e ed he e ha he E g h eech a e ed e de (F e a e a., 2001, 2004; L e a., 2004). I a e, h e e, ha a be f fac , ch a eech a e, a ec he f e e c a d de h f gh a a g age. He ce, a e ca a ha he Ch- e e eech a e e ed he e had dee e gh ha he E g h eech a e (ee Rhebe ge a d Ve fe d, 2005 a d Rhebe ge e a., 2006, f a d c f he e f gh he a g f eech b eech).

A a a , a g a he d g h he a- ge a d d ec e ec e a e a d he a ge, he eg ega e a ge eech f c e g eech (B- ga , 2001; F e a e a., 2004; K dd e a., 2005a,b). B ga a d c eag e (B ga , 2001; B ga e a., 2001) e ed ha he a a ge h a e a a ed b e e c e g h a e a e, f a a

[1] T f ea a d gh, e f - a e ec ed 47 ec d a e f b h he - a e E g h eech a e, h ch e e ed he d b F e a e a. (2001, 2004) a d ha b L e a. (2004), a d he - a e Ch e e eech a e ed he e e d, bef e a g he h gh a 20 H e e ac he a de e e e f b h E g h a d Ch e e eech a e . The e a de e e e e e he hed g a *r*- e g a e age e ded b Ma he a ca (W f a Re ea ch, $r = 500$ a e). The hed a e e e he g a ad a c e a f c (Ma he- a ca, W f a Re ea ch). Th e a f c a he d e e- a ed d he ca he e he de a e f he e a ed f c a e , e., he ca f he ea a d gh he a de e e e. I he fa h gh he a de e e e e e de ed.

T gh he eech a e a e e e be ef e g he a ge eech, he dee e , de , a d e f e e he a e. We ea ched f gh ha e e e ha 6 dB be he ea a de f he e e e. T de e he d h f he e dee gh, e a ed a he b f he gh a d ed a he a e bef e e e c e ed he c e a e ha a e ha 3 dB ab e he f he gh. The e a h ch h a e a a e a de ed a he e b da f he gh. The e b da f he h gh a b a ed b e a g cce e a e f g he b f he gh e e c e ed a a e ha a e ha 3 dB ab e he f he gh. The e a h ch h a e a a e de ed he e b da f he gh. The d e e ce be ee he e a d e b da e a a e a he d h f a gh. I he ca e ha gh e a ed, he e b da f he gh beca e he e b da f he ec d gh a d d be c g f e e a dee gh. F g. 8 h he a dee e e f a eg e f he Ch e e eech a e , a d de e he ca a d d h f gh . The a a f e a dee gh a 19% f he Ch e e a e b 10% f he E g h a e .

a he ha e e ge c a g d a ed e f a ce, a d he a f a g a h gh de e de he - a f he a ge a d a e ce . The e gge ha e e he ce f he a ge a e ca ha e a c g e ec ec g g he a ge eech e e ce he e - e ce f eech a e . S ec ca , he e e d h ha e e g a d e e - e e ce e g he a ge - a e ce ca g ca e ec g f he a e d he f - e g h e e ce he he a - e - a e eech. The ef e, add e ce ed a a e a a (F e a e a., 1999, 2001; L e a., 2004; W e a., 2005), a edge ab a ge ca (K dd e a., 2005b), a d he f a a c e f he e (F e a e a., 2004; he e e d), edge f he a ge - a e ce ca a e e eech c ca he e e ce f a g eech he he a g age a Ch e e. I d be e e g ee he he he e a e a e ec f ce f E g- h e e .

I a e ha he e ec f a d e e - e - e ce a e- e e ce e d d de e d he de h ch c d e e e e e ced. We d ha e e ec ed ch de e ec f he e e e ed e ec - a b fa a g he e e h he a ge - a e ca cha ac e c . F f ha e e he ca e, e d e ec g d ce a a ge e ea e f a g he he - g c d eceded he g c d ha he he - g c d f ed he g c d . I he f e ca e, he - e e d ha e e e e e e c g he - g c d a d he ef e gh be e ec ed h a a ge e ea e f a g ha he a e ca e he e he a f e e he a ge - a e ce d be e e e bef e he - g c d a e e e ced. H e e, beca e he e e e de e ec ,[2] e ha he a d a f e e he a e ce e ced he a f e ea e f a g.

5. Summary and conclusions

P e e g a d e e Ch e e e e ce e b he a ge a e bef e he a ge eech a e e ed fac - a ed e e ec g f each f he a e ab e he he a e a eech b he he a e a e. M e e, e e g Ch e e a ge eech h he a e d bef e e e g he f a ge e e ce a fac a ed e e ec g f he a a - b e a d he h e d, b h fac a e ec a a e he he a e a e. Th , a - edge f he a e ce a d/ he c e f he a ge eech e eech ec g a Ch e e "c c - a - a " e e .

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We a e g a ef H a Sh a d Y a -Sha Che g f gh f c e a d d c , Xa L f ech- ca , a d We -J e Wa g a d Me g-Y a Wa g f da a c ec . Th a ed b he Na a Na a Sc e ce F da f Ch a (30670704; 60605016; 60535030; 60435010), he Na a H gh Tech g Re ea ch a d De e e P g a f Ch a (2006AA01Z196; 2006AA010103), he T a - Ce T a g P g a F da f he Ta e b he S a e Ed ca C , "985" g a f Pe g U e , a d he Na a Sc e ce a d E g ee - g Re ea ch C c f Ca ada.

Appendix A

I g he ch e c f c e de e ed he a e f μ a d σ ha ed he Pea χ^2 ea e f g d e f , he e

$$\chi^2 \sum_{i=1}^{n} \frac{\left(N_{x,i} - \frac{N}{1+e^{\sigma x_i - \mu}}\right)^2}{\left(\frac{N}{1+e^{\sigma x_i - \mu}}\right)} + \sum_{i=1}^{n} \frac{\left(\frac{N}{1+e^{\sigma x_i - \mu}} - N_{x,i}\right)^2}{\left(N - \frac{N}{1+e^{\sigma x_i - \mu}}\right)},$$

N he be f e a e e ce a e e ed a a SNR x_i, a d $N_{x,i}$ he be f c ec de ca a ha SNR. The h he ha he da a a e de- c bed b a g c f c . The be f deg ee f f eed a c a ed h h χ^2 a c e a he be f SNR he be f a a e e e - a ed. Whe e a e g a ch e c f c he g da a f a g e c d , $N = 18 * 18 = 324$, a d $n = 4$. He ce he deg ee f f eed a e 4 2 = 2.

T de e e he he c ec de ca f he h e d c d be ed c ed f he bab e h h ch he d d a d e e c ec de ed, e ca c - a ed $y_{0,0,i}$, $y_{0,1,i}$, $y_{1,0,i}$, a d $y_{1,1,i}$, f each f he f SNR ($i = 1, 4$), he e he b c ec e he he he ab e a c ec de ed (1) (0), a d he ec d b c ec e he he he ec d ab e a c ec de ed . Beca e he e a e f a -e c e ca eg e e ca ca c a e

$$\chi^2 \sum_{i=1}^{n} \frac{\left(y_{0,0,i} - N * (1 - p1_i) * (1 - p2_i)\right)^2}{N * (1 - p1_i) * (1 - p2_i)} + \sum_{i=1}^{n} \frac{\left(y_{1,0,i} - N * p1_i * (1 - p2_i)\right)^2}{N * p1_i * (1 - p2_i)} + \sum_{i=1}^{n} \frac{\left(y_{0,1,i} - N * (1 - p1_i) * p2_i\right)^2}{N * (1 - p1_i) * p2_i} + \sum_{i=1}^{n} \frac{\left(y_{1,1,i} - N * p1_i * p2_i\right)^2}{N * p1_i * p2_i}$$

[2] Se a a e ANOVA e e c d c ed he a e age e ce c ec ach e ed each f he a g× e c d chec f a de e ec f b h abe e a d . I e f he c d d d he de f e g each a ca g ca ce.

he e $p1_i$ a d $p2_i$ a e he bab e f ge g ab e e a d c ec , e ec e , he he e ce a e e e ed a SNR i. Va e f $p1_i$ a d $p2_i$ e e de e ed ha ed h χ^2. The be f deg ee f f eed a each e e i 1 beca e he e a e f a -e c e ca eg e (3 deg ee f f eed), a d e a a e- e a each e e f SNR ea g 1 deg ee f f eed f each SNR e e , a d 4 deg ee f f eed a .

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