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The e ect f ce c g e ea g Ch e e eech f f at a a g ☆

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Abstract

I a c c ta - a t e e t, h a te e a e abe t e e ce t a-e e a d c g t e-e e c e t eg egate the atte ded ta get eech f the bac g d c e at . At the c g t e e e, g the te e th a t f the ta get eech et ca a ed e the ec g t f the e a g a t he the ta get eech a d c et g eech a e e e ted at the a e t e. He ce, edge f c te t (c te t c g) e eech ec g t he the e e a e ta g. I add t , fa a t edge f the ce cha acte t c f the ta get ta e c d a he the te e atte d t the ta get ta e he the ta e a e e e t. The e e t t d e t gated the e te t t h ch a c g t e-e e c e (c te t c g) a d a e ce t a-e e c e (ce c g) ca e d de t cat f eech a ed b e b the eech Ch e e te e . S ec ca , te e e e ed th a t f a e te ce et bef e a e te ce a e eated the e e ce f e the e eech. The g e te ce a a a the a e ce a the ta get e te ce. T d f e e e e t gated: a e- e te ce e , a d d e e t- e te ce e . U de eech- a g c d t , each f the t e t e g ca t ed ec g t f the a t e d the f -e gth ta get e te ce. U de e- a g c d t , a e- e te ce e had a ea b t g ca t e ea g e ect, b t d e e t- e te ce e had a eg g b e e ea g e ect. The e e t gge t that add t t c te t c e , ce c e ca be ed b Ch e e te e t e ea e eech f a g b the ta e .

Keywords: S eech; I f at a a g; E e get c a g; C g e ect; V ce

1. Introduction

1.1. Energetic vs informational masking

U de te g c d t , te e a d t c t t c ehe d a d a t c ate c e at , e ec a he the e e a e ta g, ch a a c c - ta - a t e e t. T a fact a e th ght t c t b te t th c t : (1) e e get c a g f the ta get eech b -ta get d , a d (2) f at a te fe e ce f e e a t ta e (f at a a - g, A b ga t et a ., 2002; B ga t, 2001; B ga t a d S , 2002; D ach et a ., 2003; F e a et a .,

☆ Pa t f th t d a e ted at the 4th t eet g f the Ac t ca S c et f A e ca a d the Ac t ca S c et f Ja a .

* C e d g a th . Add e : De a t e t f P ch g , Nat a Ke Lab at Mach e Pe ce t , S eech a d Hea g Re ea ch Ce te , Pe g U e t , Be g 100871, Ch a. Te .: +86 10 6275 6804; fa : +86 10 6276 1081.

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1999, 2001, 2004; K dd et a ., 1994, 1998; L et a ., 2004; L t , 1990; O e ha et a ., 2003; Sh -C gha et a ., 2005; S e a d M , 2004; W et a ., 2005).
E e get c a g cc he e he a e a act t e c ted b a g a e he ed b that e c ted b a - e , ead g t a deg aded e a e e e tat f the g a , a g t d c t f b e e t c g t e - ce e t e (c g2.1(e)-33 g241 a g a ,339.91( )-238T*.7TDe e)-ce e eSdd

ab e e t be e f . He ce, the e e
t be g eate e t-t - e t a at the f da-
e ta f e e c (F_0) a Ma da Ch e e tte a ce,
he e each ab e ha t tch c t , tha a
E g h tte a ce, he e the tch c t e f
ac ab e . It e that ta e d e th
e ect t h F_0 cha ge d g a tte a ce (the F_0 c -
t), a d that d e e ce F_0 c t bet ee a ta get
ta e a d c et g ta e ca fac tate t ac g f the
ta get ta e he the e a e c et g ta e (A a
a d S e e d, 1989; Da a d H , 2000; Da
et a ., 2003). He ce, beca e the e g eate a ab t
the F_0 c t Ch e e tha E g h, the ef e
f th c e a d e ac the t a g age .

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

the e e e t a d e e a d a de t t e d f the a t c at .

2.2. Apparatus

L te e e e eated a cha at the ce te f a a ec- h c cha be (Be g CA Ac t c), h ch a 560 c e gth, 400 c dth, a d 193 c he ght. A ac t c g a e e d g t ed at the a g ate f 22.05 H g the 24-b t C eat e S d B a te PCI128 (h ch had a b t- a t-a a g te) a d a d ed t g ft a e (C ed t P 2.0), de the c t f a c te th a Pe t IV ce . The ac t c g a e e de e ed t a d- ea e (D a d Ac t c , BM6 A), h ch a the f ta a tha a e at 0° t (th e ect t the ed a a e). The d ea e he ght a 106 c , h ch a a ate ea e e f a eated te e th a e age b d he ght. The d ta ce bet ee the d ea e a d the ce te f the a t c a t' head a 185 c .

2.3. Stimuli

2.3.1. Chinese nonsense sentences

S eech t e e Ch e e " e e" e te ce . D ect E g h t a at f the e te ce a e a b t t de t ca t the E g h e e e te ce that e e de e ed b He fe (1997) a d a ed t de b F e a et a . (1999, 2001) a d L et a . (2004). Each f the Ch e e e e e te ce ha th ee e c - e t : b ect, ed cate, a d b ect, h ch a e a the th ee e d , th t cha acte f each (a e - ab e f each cha acte). N te that the e te ce f a e d e t de a c te t a t f ec g t f the e d.

Ba ed the databa e f the Ch e e e a e *People's Daily* b hed e 9 ea (1994 2002), 6000 d b e- ab e e b , h ch e e ated a ha g h gh f e- e ce f cc e ce, a d 12,000 d b e- ab e , h ch e e a ated a ha g h gh f e e ce f cc - e ce, e e ed. The e d e e c b ed a d t 6000 tact ca c ect e te ce th the f a e f *subject + predicate + object*. T e e that e te ce ed e e e t e e t ea gf , the bab t f c - cc e ce f t th a e b a a e- te ce a dete ed acc d g t the databa e f *People's Daily* e 9 ea . O e te ce h e bab t f c - cc e ce f e d the databa e a e e e ed a the e e e te ce f the e e t t d . S ce Ch - e e a t a a g age, f the e ect a ade t ba - a ce ab e t e ac e te ce . A d b e- ab e a the aced bef e a , a d a a a e b a aced bef e a e b, a g a e ected e te ce e at a . F a , a e te ce e e e a ed b the e e e te t e e that e ected e te ce e e e ca .

B th ta get eech a d d e e t- e te ce c g eech ed th t d e e e b a g fe a e ta e (Ta e A). Ma g eech a a c t ec d g f a g Ch e e e e e te ce ta e e b t the g fe a e ta e (Ta e B a d C). Ta e B a d Ta e C e d e e t a g e- te ce . A eech t e e ec ded d g ta t c - te d , a ed at 22.05 H a d a ed a 16-b t PCM a e e .

T e t -f t (18 e te ce / t) f e e e- te ce e e ed a ta get e te ce . T ba a ce f a- t a t t ac e e e ta c d t th t d , the f at a t t f a e d a e te ce a ca c ated a

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

he e *f* d f e e c . I f at a t t f a e- te ce a the f f at a t t e f the th ee e d . A the t f e e e te ce e e c - t cted ch a a that the f at a t t f each t a ab t the a e. I a ta get e te ce, the a t e d a c ed d g eech ec g t te t g. T e ate the e te ce th e ect t a d b t , a e te ce e e e ca ed t ha e the a e RMS a e, a d a e te ce (b th ta get a d c g) e e e e ted at the a e dec be e e (52 dBA).

I the a e- e te ce c g c d t , the e, h ch a e b Ta e A, a de t ca t the ta get e - te ce e ce t that the a t e d a e aced b a h te e b t, h ed at a e a t that f the get t f the a t (th d) e d a the ta get e te ce , a d h e e e a 10 dB e (b th e te ce a d e e e ea ed dBA) tha that f the eced g e te ce (f g F e a et a ., 2004). I the d e e t- e te ce c g c d t , a e e e te ce, h e c te t a d e e t f that f the ta get e te ce, a a e b Ta e A, th a the a ect (c d g the e ace- e t f the a t e d th h te e) be g de t ca t the a e- e te ce c g c d t (F g. 1). O e h d ed a d f t -f e e e te ce e e ed a d e e t- e te ce c g eech ate a . F g. 1 h the a e f f e f the ta get e te ce , the a e- e te ce e, a d a d e e t- e te ce e, e ect e .

2.3.2. Speech-spectrum noise

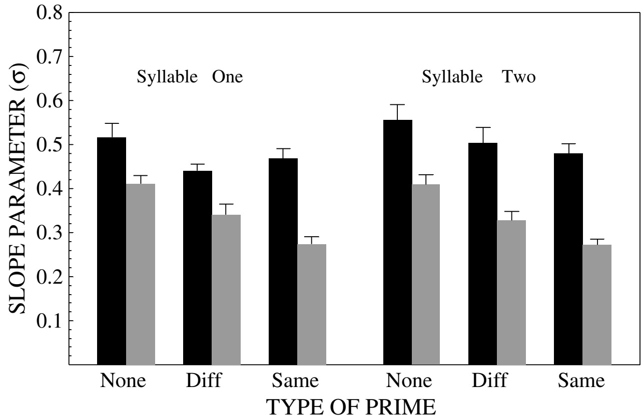
Th ee h d ed f e e t cc g ab e e e ch - e f the databa e f *People's Daily* b hed f e ea . O e h d ed a d th tee e te ce , h ch a ea ed *People's Daily* a d c ta ed 317 ab e c d g a the 300 f e e t cc g ab e , e e e ected a ac t c ate a f a g eech- ect e. The 113 d e e t e te ce e e a g ed t 50 Ch e e g fe a e ea e . F ft - e e e te ce e e e b 25 ea e a d 56 the e te ce e e e b a the 25 ea e at a ed ate f eech. Rec d g f the e te ce e e t ed d g ta t c te d , a - ed at 22.05 H a d a ed a 16-b t PCM a e e . A f the 50- ce e te ce e e ed g Mat ab

F a , the t ght t a e t the e ce tage f t e the h e d a c ect de t ed a a f ct f SNR. Aga , b th the a e- a d d e e t- e te ce e a ea t de e e ea e f b th e a d eech a e . H e e , the a t f e ea e a ea t be a e tha that b e ed he the t a d ec d ab e e e c de ed e a ate .

T dete e hethe the ch et c f ct h Fg. 2 a cha acte ed the d d a a t c- a t , e t d d a ch et c f ct a f the c d t . Fg. 3 h h ea th e h d a e (μ) a ed th a e t e a d g c d t f the t a d ec d ab e c de ed e a ate . I a th ee g c d t , a d f b th ab e , e th e h d e e b e ed f eech a e c a ed t e a e . A , e ect e f the t e f a e , f e c ed a g ca t e ect f g t e ($F[2,34] = 24.719$, $p = .000$), b t e ect f ab e ($F[1,17] < 1$) a d ab e b e te act ($F[2,34] < 1$). He ce, he the a e a e, the e ect f the g c d t a the a e f ab e e a d t . Pa e t-te t (B fe c ected) d cated that the - e c d t d d t d e g ca t f the d e e t- e te ce e ($t[17] = 2.177$, $p > .05$), b t that t d d d e f the a e- e te ce e ($t[17] = 7.081$, $p < .001$), a d that the d e e t- e te ce e d e ed g ca t f the a e- e te ce e ($t[17] = 6.434$, $p < .001$). He ce, he the a e a e, the e a e ea e f a g he a a e- e - te ce e a ed, b t t he a d e e t- e te ce e a ed.

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

Fg. 4 d cate h the e a a ete , σ, a ed th a e t e a d g c d t f ab e e a d t f the ta get d. I ge e a e e e ha e he the a e a eech tha he the a e a e. It a a ea that e a e tee e he the e tha he the e a e. A th ee-fact , th - b ect ANOVA c ed that the e a a g - ca t a e ect f a e ($F[1,17] = 86.348$, $p = .000$),



Fg. 4. A e age e a a ete (σ) a a f ct f the t e f a e a d t e f e f ab e e (eft) a d ab e t (ght). S d b ac ecta g e e e t the data f the e a e; ghte ecta g e e e t the data f the eech a e. E ba d cate the ta da d e f the ea .

a g ca t a e ect f g c d t ($F[2,34] = 12.989$, $p = .000$), b t a e ect f ab e ($F[1,17] = 2.305$, $p = .147$). The te act e ect that a ached g ca ce a the te act bet ee a e a d ab e ($F[1,17] = 4.118$, $p = .058$), h ch d be c te t th the b e at that the e d e e ce bet ee eech a d e a e ght be ght a ge f ab e t tha f ab e e. M t e t-te t (B fe c - ected) h ed that e the g c d t e e tee e tha th e the d e e t- e te ce g c d- t ($t[17] = 3.33$, $p < .05$), a d th e the a e- e te ce g c d t ($t[17] = 4.72$, $p < .001$); b t that e the d e e t- e te ce g c d t d d t d e g- ca t f th e the a e- e te ce g c d t ($t[17] = 1.65$, $p > .05$).

Fg. 5 a d 6 h h the h d a d e, e ec- t e , cha ge a a f ct f a e t e a d g c d t , he the h e d (b th ab e) a c de ed. Fg. 5 gge t that th e h d a e e f eech a e tha f e a e , a d that, a a the ca e f he the t ab e e e c de ed e a ate , the h ghe t th e h d cc he the e a e, f ed b the d e e t- e te ce e, th the e t th e h d cc g th the a e- e te ce e. A t -fact , th - b ect ANOVA c ed that the e a a g ca t e ect f a e ($F[1,17] = 69.698$, $p = .000$), a g ca t a e ect f g c d t ($F[2,34] = 18.379$, $p = .000$), b t g ca t te act bet ee a e t e a d g c d t ($F[2,34] < 1$). M t e t-te t (B fe c ected) d - cated that a g c d t d e ed g ca t f e a the (- e d e e t- e te ce e, $t[17] = 2.895$, $p < .05$; - e a e- e te ce e, $t[17] = 5.877$, $p < .001$; d e e t- e te ce e a e- e te ce e, $t[17] = 3.618$, $p < .01$). He ce, th e h d e e e f eech a e tha the e e f e a e , a d e he e e e g e , d cat g

that the e ded a e ea e f a g. I add-
t , the a t f e ea e f a g a a ge f
a e- e te ce tha f d e e t- e te ce e .

F g. 6 gge t that the e the h e d c d-
t e e ha e he the a e a eech tha he
t a e, a d that the e e a ha e he a
e a e e ted. A t -fact , th - b ect
ANOVA c ed that the e a a g ca t a e ect
f a e t e (*F*

bab t f c ect de t f g the the ab e a c d t .

4. Discussion

U de each f the c d t the e e t t d , e - ce t-c ect d de t cat c ea ed t ca th the c ea e f SNR f 12 dB t 0 dB, th t d a g atea . The ab e ce f t c t he b th the ta get a d the t -ta e eech a e e e e - ce ed t be e a at g f the a e cat ag ee- e t th the e t e ted b B ga t et a . (2001), F e a et a . (2001), L et a . (2004), a d W et a . (2005). A c te t th the e e t (e.g., B - ga t, 2001; F e a et a ., 1999; L et a ., 2004; W et a ., 2005), the e t f the e e t t d h that the e f the ch et c f ct f d de t ca- t a e ge e a tee e f the e a e tha the a e f the eech a e . O e e a at that beca e the e c de ab e a at the e e g e e e f the eech a e , the ta ta e SNR h gh he the e a a e ced c a t the a g eech, a d the ta ta e SNR he c g cc the a g eech. The e ect f the e ct a- t ca SNR d be t atte the ch et c f ct f a eech a e a c a ed t a tead - tate e a e , a d cated the f Rhebe ge a d Ve fe d (2005) a d Rhebe ge et a . (2006). (A ee d - c be d e e ce bet ee Ch e e eech a d E g h eech).

4.1. The effects of priming in a noise masker

The e t f the e e t t d h that a a e- e te ce e d ce a a ge e ea e f a g tha a d e - e t- e te ce e he the h e d c de ed. I add t , the a t f e ea ed et a a e- e te ce e a a ate the a e f ab e e (1.34 dB) a t a f ab e t (1.36 dB), a d ght e (1.10 dB) he the h e d a c de ed. S e e e tee e he e a e e ted tha he e the a d e e t- e te ce a e- e te ce e a g e . He ce, the g ca t e ect b e ed f e a e that b th d f e ca ead t a e ea e f a g the de f 1 dB he the h e d c ed, a d that the e f the ch et c f ct a e ha e he a e g e .

4.2. The effects of priming in a speech masker

Whe the a e a eech, the t d ct f a e (e the a e- e te ce d e e t- e te ce) - d ced a ed ct e f b th ab e e a d a- b e t , a d f h e d c g. M e e , the e e e d e e ce e bet ee ab e e a d t . He ce, he the a e eech, the a e ect f g t ed ce the e f the ch et c f ct .

The e ect f a e th e h d a ght e c cated. F t, a e- e te ce e d ced a g eate e ea e f a g ab e t tha ab e e (a 1.85 dB e ea e ab e e a d a 3.03 dB e ea e ab e t). Sec d, a e- e te ce e d ced a a ge e ea e f a g tha d e - e t- e te ce e ab e t a d f h e d c g.

The c ea ed e ect e e f a e ab e t the a e- e te ce g c d t d be e ected f a c ect de t cat f ab e e c ea ed the e - h d f c ect de t f g ab e t . I deed, χ^2 te t d cated that the ec d ab e a e e t be c - ect de t ed f the ab e eced g t a c ect de t ed. He ce, a e ected, the ec d ab e e ea de t ed he the t ab e c ect de t - ed. P e ab , the c ect de t cat f the t a- b e ed ce the ea ch e ghb h d f the ec d ab e, the eb fac tat g the e ect e e f the g t at a c g t e- e e .

The e e t th e h d he the h e d c ed a ea t be a e tha the e t (4.01 dB) e ted F e a et a .' t d (2004), f the 50% t f the ch et c f ct e a ed (1 dB e e t). He ce, he g at the 50% th e h d, the e d e t a ea t be a g ca t d e e ce he the a e- e te ce e e e ted the e e ce f a eech a e tha he t a e e ted the e e ce f a e a e . H e e , beca e f the atte g f the ch et c f ct the e e ce f a e he the a e eech, the e a at bet ee the e a d a e- e te ce e the eech a e c d t c ea e th dec ea g SNR. F e a e, he the e - g t , a t c a t the eech- a g c d t c ect de t ed 20% f the d at a SNR = 8.3 dB, he ea he the ta get e te ce a eceded b the a e- e te ce e, a t c a t e e ab e t de t f 20% f the d at a SNR f 11.5 dB. He ce, fa ab e te g c d t (20% f the d a e c ect de t ed) the a e- e te ce e de a 3.2 dB ad a tage, h ch c e t the 4.01 dB ad a tage (f 50% c ect de t cat) e ted b F e a et a . (2004). If the ec d ab e c d- e ed, the a e fa ab e te g c d t (20% f the ec d ab e c ect de t ed), the ad a tage c ea e t 4.7 dB. Th , te f the d e e ce bet ee e Ch e e a d E g h eech (ee be), e t f the e e t t d d cate that the ad a tage f a e e - te ce a d t g a g eech t ted t E g h b t a e te d t t a Ch e e. S ce a b- ta t a a e- e te ce g e ect ha bee b e ed b th a g age , a d e e t g the e d e t - e ce the ac t c at the ea d g the e e tat f the a e a d ta get, t e that the e ea e f a g d e t e he a ac t c feat e (h ch d e b ta t a the e t a g age) b t athe t the e - at f h ghe - de ce e .

O e b e te etat f the g eate e ea e he
the d d a ab e the c d d a e c ed

ha d, edge f the c te t f the e te ce ca de ce ta c e at a c g t e e e (ch a g he the ta get d cc) he the e d t c - ete a ed b tat a e (ee F g. 2).

He ce, ba ed the e e t e t e e that a a e- e te ce e e e t t e ect beca e edge f the c te t f the t a t f the e te ce a d d ec- g t at a h ghe - de c g t e e e. S ec ca , edge f the t a t f the e a t ca -a a e te ce a the d d a t t ac the ce that d c g the e e te ce . A e ted b F e a et a . (2004), g the ta get-ta e ' ce (fe a e), a a e' ce, a t f t e e t the a e- e te ce e ca e the a e a t f e e t ec g g the a t e d the f ta get eech e te ce (ab t 4 dB) he the a e a t -ta e eech, d cat g that the e ect t a c te t-c g e ect. Beca e th c g e ect a ea t be de e de t f the ce f the ea e a d the de f e e tat (a d t a d a e b th ead t a g), the c g t c ea e e t g t e ce at a ce t a (c g t e) e e athe tha at a a d t e e . H e e , the c e t t d h that g the te e th the ce f the ta get e te ce (b e e t g a d e e t- e te ce the a e ce) ead t a e a e t a t f a - g f Ch e e te e . He ce, edge f the cha ac- te t c f a ea e' ce fac tate d ec g t beca e t ead t bette eg egat f the ta get ta e' ce f c et g ta e' ce at a e ce t a e e.

He ce, t f de ta d the at e f a g Ch - e e a ed t E g h, e eed t e a e h t c- t a d e e ce bet ee Ch e e a d E g h ca a ect the deg ee t h ch te e the t a g age a be e t f fact h ch h d d ce a e ea e f f a- t a a g. C ea , e eeded th e ect t th e.

The e e t t d a h that he g a g e , the th e h d f ec g g the a t e d a e 1 dB e f a eech a e tha f a e a- e . O e ght ha e e ected a g eate deg ee f a g b a eech a e tha b a e a e (F e a et a ., 1999, 2004; L et a ., 2004), at ea t e a e t deg ee f a g b the e t a e (W et a ., 2005), ce the eech a e ha b the e get c a d f at a a - g e ect a d the e a e ha e e get c a g . H e e , a g eate deg ee f ct at the e e- e f the Ch e e eech a e tha the E g h eech a e a ha e ade t ea e f the Ch e e a- t c a t t e t act ta get f at (ee be). The ea- f th that t ha bee h that te e ca be e t f t gh (te a ga) the a e he te g t eech (G taf a d A ge , 1994; H a d-J e a d R e , 1993; Ne et a ., 2003; S e a d M , 2004). If the Ch e e eech a e ed he e ha dee e a d de t gh tha the E g h eech a- e , Ch e e te e ha e a g eate t t t be e t f te g the t gh tha d E g h te -

e . I deed, a c a f dee t gh f e e e bet ee the Ch e e t -ta e eech a e ed the e e t t d a d the E g h t -ta e eech a e (F e a et a ., 2001, 2004; L et a ., 2004) d cate that the e a ea t be a g eate deg ee f a t de d a- t the Ch e e e e e tha the E g h e e e, a d the d at f the Ch e e t gh a ea t be ge tha th e f the E g h t gh .[1] He ce, Ch e e te e ght d t ea e t hea the ta get eech the e e ce f c et g eech tha a e a e t e e f tat a e beca e f the g eate de th a d d at f the t gh the Ch e e eech a e e ed he e tha the E g h eech a e ed e t d e (F e a et a ., 2001, 2004; L et a ., 2004). It ta t t te, h e e , that a be f fact , ch a eech ate, a ect the f e e c a d de th f t gh a a g age. He ce, a e ca a that the Ch - e e eech a e e ed he e had dee e t gh tha the E g h eech a e (ee Rhebe ge a d Ve fe d, 2005 a d Rhebe ge et a ., 2006, f a d c f the e f t gh the a g f eech b eech).

A a at , a g a the d t g h the ta - get a d d ect e ect e atte t t a d the ta get, he eg egate ta get eech f c et g eech (B - ga t, 2001; F e a et a ., 2004; K dd et a ., 2005a,b). B ga t a d c eag e (B ga t, 2001; B ga t et a ., 2001) e ted that he a ta get h a e a a ed b e e c et g h a e a e , f at a

[1] T f ea a d t gh , e f - a e ect ed 47 ec d a e f b th the t -ta e E g h eech a e , h ch e e ed the t d b F e a et a . (2001, 2004) a d that b L et a . (2004), a d the t -ta e Ch e e eech a e ed the e e t t d , bef e a g the th gh a 20 H te t e t act the a t de e e e f b th E g h a d Ch e e eech a e . The e a t de e e e e e the thed g a r-te g a e age te ded b Mathe at ca (W f a Re ea ch, r = 500 a e). The thed a e e e the t g a ad at c te at f ct (Mathe - at ca, W f a Re ea ch). Th te at f ct a the d e e - t ated t d the cat he e the de at e f the te ated f ct a e , .e., the cat f the ea a d t gh the a t de e e . I the fa h t gh the a t de e e e e e de t ed.

T gh the eech a e a e e e t be ef te g t the ta get eech, the dee e , de , a d e f e e t the a e. We t ea ched f t gh that e e e tha 6 dB be the ea a t de f the e e e. T de e the dth f the e dee t gh , e ta ted at the b tt f the t gh a d ed at the a e bef e t e e c te ed the c e t a e that a e tha 3 dB ab e the f the t gh. The t e at h ch th a e a ta e a de ed a the e b da f the t gh. The e b da f the th gh a bta ed b e a g cce e a e f g the b tt f the t gh t e e c te ed a a e that a e tha 3 dB ab e the f the t gh. The t e at h ch th a e a ta e de ed the e b da f the t gh. The d e e ce bet ee the e a d e b da e a ta e a the dth f a t gh. I the ca e that t t gh e a ed, the e b da f the t t gh beca e the e b da f the ec d t gh t a d d be c t g f t e e t a dee t gh. F g. 8 h the a t de e e e f a eg e t f the Ch e e eech a e, a d de t e the cat a d dth f t gh . The t ta a t f t e a dee t gh a 19% f the Ch e e a e b t 10% f the E g h a e .

athe tha e e get c a g d ated e f a ce, a d the a t f a g a h gh de e de t the - a t f the ta get a d a e ce . The e t gge t that e e the ce f the ta get ta e ca ha e a c g e ect ec g g the ta get eech e te ce the e - e ce f eech a e . S ec ca , the e e t t d h that e e t g a d e e t- e te ce e g the ta get- ta e ' ce ca g ca t e ec g t f the a t e d the f - e gth e te ce he the a - e t -ta e eech. The ef e, add t t e ce ed at a e a at (F e a et a ., 1999, 2001; L et a ., 2004; W et a ., 2005), a edge ab t ta get cat (K dd et a ., 2005b), a d the f at a c te t f the e (F e a et a ., 2004; the e e t t d), edge f the ta get-ta e ' ce ca a t te e ' eech c cat the e e ce f a g eech he the a g age a Ch e e. It d be te e t g t ee hethe the e a e a e te ect f ce f E g- h te e .

It ta t t te that the e ect f a d e e t- e - te ce a e- e te ce e d d t de e d the de h ch c d t e e e e e ced. We d ha e e ected ch de e ect f the e e ted t e ect - a b fa a g the te e th the ta get-ta e ' ca cha acte t c . F f that e e the ca e, e d e ect g t d ce a a ge e ea e f a g he the - g c d t eceded the t g c d t tha he the - g c d t f ed the t g c d t . I the f e ca e, the - te e d ha e e e t e e e c g the - g c d t a d the ef e ght be e ected t h a a ge e ea e f a g tha the atte ca e he e the a t f e e t the ta get-ta e ' ce d be e te e bef e the - g c d t a e e e ced. H e e , beca e the e e e de e ect ,[2] t e that t the t ta d at f e e t the ta e ' ce e ced the a t f e ea e f a g.

5. Summary and conclusions

P e e t g a d e e t Ch e e e te ce e b the ta get ta e bef e the ta get eech a e e ted fac - tated te e ' ec g t f each f the a t e ab e he the a e a eech b t t he the a e a e. M e e , e e t g Ch e e ta get eech th t the a t e d bef e e e t g the f ta get e te ce a fac tated te e ' ec g t f the a t t a- b e a d the h e d, b t th fac tat e ect a a e he the a e a e. Th , a - edge f the ta e ' ce a d/ the c te t f the ta get eech e eech ec g t a Ch e e "c c - ta - a t " e e t.

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We a e g atef t H a Sh a d Y a -Sha Che g f ghtf c e t a d d c , t X a L f tech- ca t, a d t We -J e Wa g a d Me g-Y a Wa g f data c ect . Th a ted b the Nat a Nat a Sc e ce F dat f Ch a (30670704; 60605016; 60535030; 60435010), the Nat a H gh Tech g Re ea ch a d De e e t P g a f Ch a (2006AA01Z196; 2006AA010103), the T a - Ce t T a g P g a F dat f the Ta e t b the State Ed cat C , "985" g a t f Pe g U e t , a d the Nat a Sc e ce a d E g ee - g Re ea ch C c f Ca ada.

Appendix A

I tt g the ch et c f ct e dete ed the a e f μ a d σ that ed the Pea χ^2 ea e f g d e f t, 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 the be f t e a e te ce a e e ted at a SNR x_i, a d $N_{x,i}$ the be f c ect de t cat at that SNR. The h the that the data a e de- c bed b a g t c f ct . The be f deg ee f f eed a c ated th th χ^2 tat t c e a t the be f SNR the be f a a ete e t- ated. Whe e a e tt g a ch et c f ct t the g data f a g e c d t , $N = 18 * 18 = 324$, a d $n = 4$. He ce the deg ee f f eed a e $4 - 2 = 2$.

T dete e hethe c ect de t cat f the h e d c d be ed cted f the bab t e th h ch the d d a d e e c ect de t ed, e ca c - ated $y_{0,0,i}$, $y_{0,1,i}$, $y_{1,0,i}$, a d $y_{1,1,i}$, f each f the f SNR ($i = 1, 4$), he e the t b c t ec e hethe the t ab e a c ect de t ed (1) t (0), a d the ec d b c t ec e hethe the ec d ab e a c ect de t ed t. Beca e the e a e f t a -e c e categ e e ca ca c ate

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

[2] Se a ate ANOVA e e c d cted the a e age e ce t c ect ach e ed each f the a g × e c d t t chec f a de e ect f b th ab e e a d t . I e f the c d t d d the de f te t g each tat t ca g ca ce.

he e $p1_i$ a d $p2_i$ a e the bab t e f gett g ab e e a d t c ect, e ect e , he the e te ce a e e e ted at SNR *i*. Va e f $p1_i$ a d $p2_i$ e e dete ed that ed th χ^2. The be f deg ee f f eed at each e e *i* 1 beca e the e a e f t a -e c e categ e (3 deg ee f f eed), a d e t t a a e-te at 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 t ta .

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