'Winner-take-all' competition among real and illusory words

Michael Niedeggen[a], Martin Heil[a] and Catherine L. Harris[b]

[a]Institute of Experimental Psychology, Heinrich-Heine-University, Düsseldorf, Germany and [b]Department of Psychology, Boston University, Boston, Massachusetts, USA

Correspondence and requests for reprints to Dr Michael Niedeggen, Institute of Experimental Psychology, Heinrich-Heine-University, D-40225 Düsseldorf, Germany
Tel: +49 211 8112011; fax: +49 211 8114522; e-mail: michael.niedeggen@uni-duesseldorf.de

The work was carried out in the EEG laboratory of the first author.

Received 5 January 2006; accepted 26 January 2006

'Winner-take-all' networks are an important theoretical construct in visual neuroscience. An implication of winner-take-all networks is that a stimulus that wins the competition for selection receives maximal activation and will be consciously perceived, even when selection was incorrect. In this study, competition was induced between physically presented ('real') and self-constructed ('illusory') words. Semantic activation was probed by recording event-related potential responses to a downstream target word. The results showed that only words reported by participants triggered a spread of activation in the semantic system, whereas non-reported words failed to prime the target. Both effects were independent of whether the potential primes were 'real' or 'illusory'. Our findings indicate that neural 'winner-take-all' networks extend to the processing of lexical units. *NeuroReport* 17:493–497 © 2006 Lippincott Williams & Wilkins.

Keywords: event-related potentials, illusory words, lexical processing, rapid serial visual presentation, visual competition, winner-take-all

Introduction

'Winner-take-all' models have been successfully employed to predict the interaction of neurons in the visual cortex and to account for the modulation induced by selective visual attention [1,2]. The activation of visual filters tuned best to the stimulus at hand will be boosted whereas overlapping visual filters responding relatively poorly will be suppressed. 'Winner-take-all' models have also been applied to lexical processing [3], but empirical evidence is scarce. Moreover, the results from visual masking studies contradict the idea that the stimuli out-competed will not be processed on a higher semantic level. If a visually presented word is not consciously available to the participant, it is nevertheless able to facilitate the processing of a subsequently presented semantically related target word [4,5]. This process of priming can be observed not only at a behavioural level, but also in human brain electrophysiology (event-related brain potentials, ERPs). The ERP response to target words preceded by a semantically related prime word is characterized by a reduced negativity with a latency of about 400 ms (N400 effect) – independently of the conscious access to the prime word [6].

Visual masking, however, does not rely on the competition of lexical stimuli. A more appropriate paradigm is based on the rapid serial visual presentation (RSVP) of multiple words [7]. When participants are instructed to report verbally which words had been detected, errors are likely because the presentation mode degrades the visual quality of each of the successively presented items. Several lexically related word forms will be activated by a degraded representation [8] but only the most active will pass its recognition threshold, which leads to semantic processing.

The illusory words paradigm is a method of biasing the competition between the visual word forms. When two words in the RSVP sequence contain a repeated segment ('creep–sheep'), a partial repetition blindness is induced, making the second word vulnerable to non-report [9]. Observers are likely to detect the first word and another word including the unique letters of the second word ('**sh**ield'). The verbal report, however, can be biased if a word fragment follows the sequence. Participants will frequently recombine the unique letters of the second orthographically similar word ('**sh**') with the fragment ('**ift**'), thus perceiving and reporting the illusory word 'shift' [10].

In the current experiment, illusory words or real words appeared as potential primes of a downstream target. Given that a 'winner-take-all' model can be applied to the competition between the corresponding visual word forms, only the word reported is expected to induce a semantic priming effect. As the competition between the real and illusory words is assumed to take place at an early lexical level [10], we further predicted that the priming effect is expressed independently from the physical entity of the prime word. That is, we hypothesized that priming will be present for words reported irrespective of whether they were real or illusory.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

Methods

Participants

Electroencephalography (EEG) and behavioural data from participants were excluded if the frequency of real or illusory words did not allow the averaging of ERP data. Final data analysis was based on 15 participants (nine female, six male; aged between 21 and 32 years; mean age: 25.2) with German as their mother tongue, and normal or corrected-to-normal vision.

Stimuli and procedure

Words and symbols were presented at a centred position on a 21-inch PC monitor controlled by a VSG 2/5 system (Cambridge Research Systems, Cambridge, UK). Length of real words varied from four to seven letters, and word fragments contained two to four letters. The corresponding retinal size of the stimuli varied between $0.6^\circ \times 0.35^\circ$ (two letters) and $2.1^\circ \times 0.35^\circ$ (seven letters) at a viewing distance of 200 cm. Single letters were printed in white and presented on a grey background resulting in a contrast of 90%.

Each trial started with the presentation of the RSVP sequence defined by five items: a string of identical letters (presented for 90 ms), the first real word (130 ms), the second real word (90 ms), the word fragment (80 ms), and a concluding string of symbols ('&&&&&&&&', presented for 90 ms). The single visual presentations were separated by an interstimulus interval of 30 ms. The exposure durations were defined in pilot studies and ensured a high probability for reporting the first word ($P > 0.85$), and either the second real word or the illusory word ($P > 0.75$). In all trials, the real words shared an orthographic string either at their beginning (crumb–crush) or at their end (creep–sheep). The word fragment was selected so that it would produce a lexically legal word when combined with the unique (non-repeated) letters of the second real word ('sh' + 'ift'='shift', see Fig. 1). Either the real or the illusory word served as a prime that could affect the semantic processing of a target word. The target was presented for 1000 ms immediately after the offset of the RSVP stream. Participants then reported verbally which words had been detected in the preceding trial.

Experimental design and variables

The target word was semantically related to the second real word for 25% of trials (see Fig. 1b), to the illusory word for 25% of trials (see Fig. 1c), and was unrelated to any prior words for 50% of trials (see Fig. 1a). In total, 300 trials were presented to each participant. To control for factors affecting the strength of the priming effect (i.e. differences in the frequency of the prime word; degree of semantic relationship between prime and target), each prime word was presented as a real word in the RSVP sequence as well as an illusory word. The second experimental factor was defined by the observers' perceptual state, as inferred from their verbal report (see Fig. 1).

Data recording and analysis

Biosignals were recorded continuously (EEG-8 amplifiers, Contact Precision Instruments, London, UK), sampled at 250 Hz, and online band-pass filtered (0.03–200 Hz). EEG was recorded at 45 Ag/AgCl electrodes equidistantly positioned on the scalp and referenced to linked mastoids, with impedance kept below 5 kΩ. Vertical and horizontal electrooculograms were recorded to control for ocular artefacts. Offline, EEG data were segmented to epochs extending from −100 to 1000 ms and aligned to the onset of the target word. Each segment was filtered (0.3–30 Hz, −24 dB cut-offs), baseline corrected (−100 to 0 ms), and controlled for muscular or ocular artefacts. For each participant and each electrode, artefact-free trials were averaged according to the verbal report of the participant (real word vs. illusory word) and the corresponding priming condition ('not related' vs. 'related and reported' vs. 'related and not reported'). Care was taken that the signal-to-noise ratio of the ERP signals – determined by the number of trials defining an averaged response – was comparable for each participant between the different

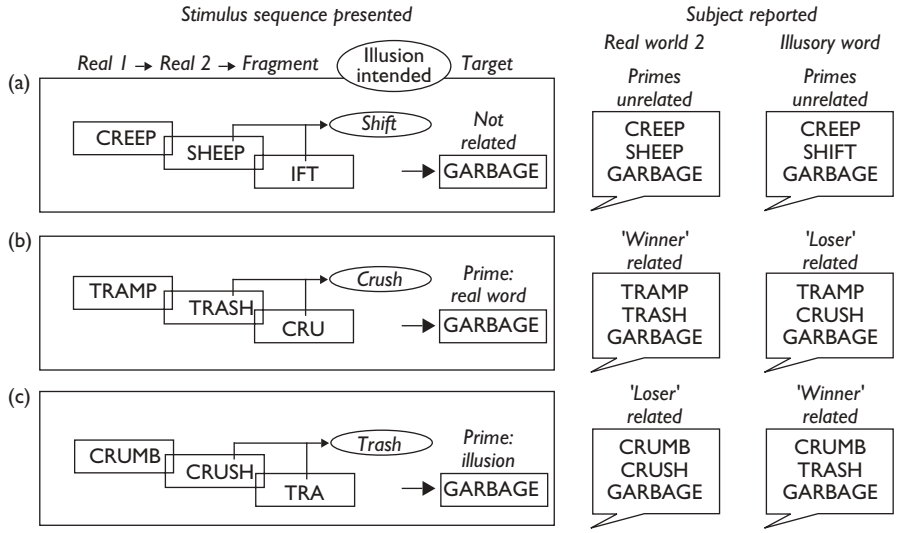

Fig. 1 Samples of the three priming conditions realized in the experiment. The initial words and the fragment were presented in a rapid serial visual presentation mode, and were followed by the target word. Participants were instructed to report the words detected. (a) In 50% of the trials, the target word was not semantically related to one of the preceding words. In the remaining trials, either the second real word (b) or the illusory word (c) was semantically related to the target. Participants' verbal report determined which prime word was categorized as 'winner' or 'loser'.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

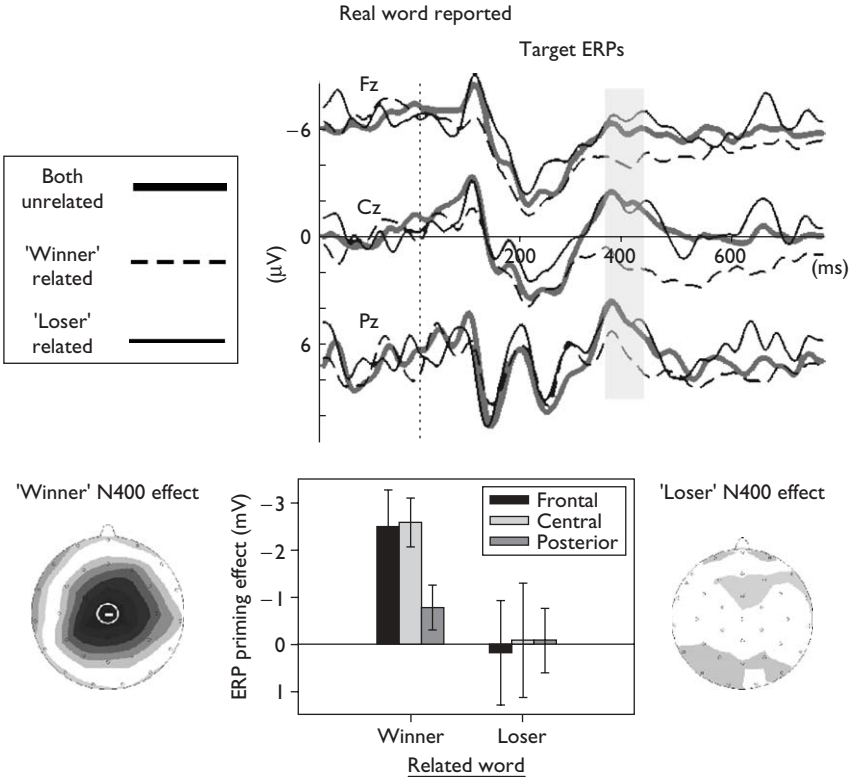

Fig. 2 Event-related potential (ERP) effects associated with the verbal report of the real word (REAL2). Upper part: grand averaged ERPs for target words recorded at midline electrodes Fz, Cz, and Pz. ERP priming effects were obtained if the target word was preceded by a semantically related real word ('winner related'), but not if the related real word was overruled by a semantically related illusory word ('loser related'). Lower part: mean amplitude of the N400 effect (unrelated–related) defined in the time range 350–450 ms separated for the caudal electrode clusters. Error bars indicate SEM. The corresponding ERP topography is depicted for the 'winner' and the 'loser' N400 effect.

experimental conditions. Participants' data were discarded when the averaged response was based on an insufficient number of single trials (<25). The strength of the ERP priming effect (difference wave *'related – not related'*) was defined in terms of the mean amplitude in a time range extending from 350 to 450 ms, which also indicated the maximum of global field power [11]. To account for topographical differences, electrodes were assigned to the spatial factors defined by the anterior–posterior axis ('caudality') and the left–right axis ('laterality'). Each of the nine resulting electrode clusters was defined by four active electrodes.

Statistical effects of the corresponding ERP data were tested in a multivariate analysis of variance including the repeated-measure factors 'verbal report' (real word vs. illusory word), 'related prime reported' (yes vs. no), 'caudality' (anterior vs. central vs. posterior), and 'laterality' (left vs. middle vs. right). In the case of significant interactions, the corresponding post-hoc tests were computed.

Results

Behavioural data

The analysis of the behavioural data supported the notion that perception of real or illusory words within RSVP trials is based on competition. In most cases, participants reported either the illusory word (49.6% of trials) or the real word (28.3% of trials). A failure to report either the real or the illusory word occurred in 18.3% of trials. The verbal report of both items, however, was negligible (3.8% of trials). Furthermore, the downstream target did influence this competition, consistent with prior findings on sentence-context effects on visual word recognition [12]. If the prime word was semantically related to the target, the probability for its verbal report was significantly enhanced in contrast to an unrelated target (effect for illusory words: 58.4% vs. 43.4%; effect for real word: 37.3% vs. 23.9%). The significant priming effect [$F(1,14)=102.65$, $P<0.001$, $\eta^2=0.88$] was expressed for real and illusory prime words to the same degree.

Event-related potential data

ERPs to target words were analysed according to whether participants reported the real word or the illusory word (see Figs 2 and 3). ERP priming effects were defined by the difference waves between target ERPs preceded by a semantically unrelated and related prime word. To examine competition between real and illusory words, we analysed the ERP priming effect separately for the related prime word reported (**winner**) and the related prime word not reported (**loser**).

The most sensitive time range for targets ranged from 350 to 450, matching the properties of the N400 component [13]. Target words preceded by a semantically unrelated prime word were characterized by a more negative-going ERP wave. When participants reported the real but not the illusory word (Fig. 2), the ERP priming effect (unrelated–related) was present for the 'winner' (related real word), but absent for the 'loser' (related illusory word). If the prime word was related and reported, it elicited a highly

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

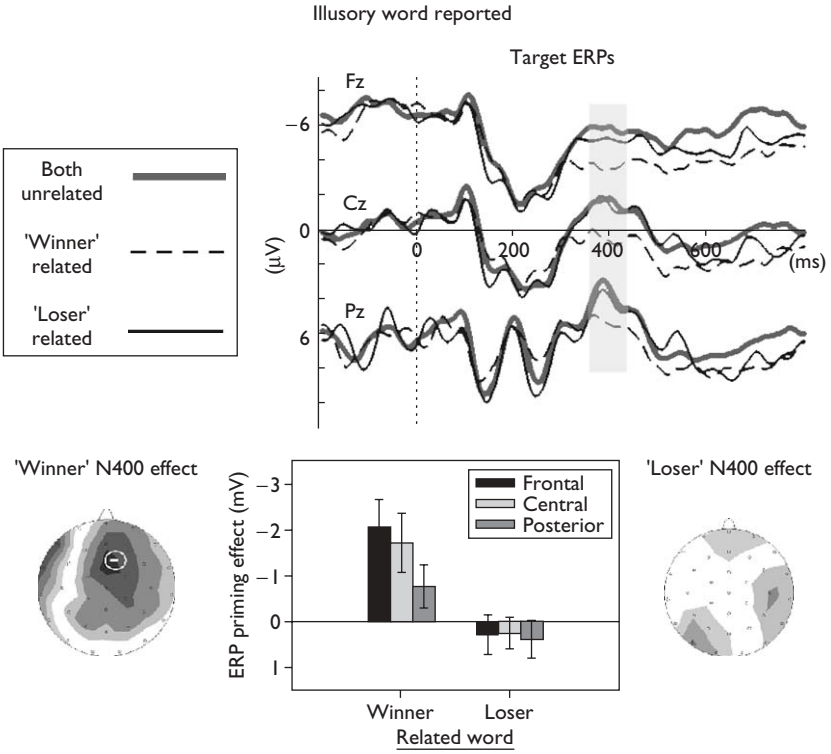

Fig. 3 Event-related potential (ERP) effects associated with the verbal report of the illusory word (Illusion). Upper part: ERP priming effects were obtained for the semantically related illusory word ('winner related'), but not for related illusory word overruled by the real word ('loser related'). Lower part: mean amplitude of the N400 effect (unrelated–related, time range: 350–450 ms) at the three caudal electrode clusters, and the corresponding topographical distribution. Error bars indicate SEM.

significant ERP effect [$F(1,14)=13.94$, $P<0.01$, $\eta^2=0.50$], whereas the effect was absent for a related prime word not reported [$F(1,14)=0.36$, NS, $\eta^2=0.02$]. The topography of the 'winner' N400 effect was broadly distributed with a maximum at central electrode positions and a shift to right-hemispheric leads (prime × caudality × laterality: $F(4,11)=5.73$, $P<0.05$, $\eta^2=0.67$]. When participants reported the illusory word but not the real word (Fig. 3), ERP priming was also restricted to the 'winner' of the competition. Illusory prime words modulated the target's ERP amplitude significantly [$F(1,14)=7.71$, $P<0.05$, $\eta^2=0.36$]. This was not true for the related but missed real prime words [$F(1,14)=0.44$, NS, $\eta^2=0.03$]. The topography of the ERP priming effect induced by illusory words was focused at frontal and central leads, and was larger at right than at left hemispheric leads [prime × caudality × laterality: $F(4,11)=6.18$, $P<0.01$, $\eta^2=0.69$].

This pattern of results obtained for real and illusory words reported was also compared directly. The 'winner' N400 effects induced by real prime words and by illusory words did not differ with respect to amplitude or topography [$F(1,14)=0.61$, $P=0.45$, $\eta^2=0.04$]. For trials on which the related word was not reported, the 'loser' N400 effects were also comparable for real and illusory words [$F(1,14)=0.16$, $P=0.90$, $\eta^2=0.00$].

Discussion

The data presented substantiate the idea that illusory words indeed share the properties of real words in the lexical system. The ERP priming effects driven by real and illusory words were comparable with respect to amplitude and latency, implying that the representation of an illusory word does not differ on a neural level from real words perceived.

Recently, it has been argued that illusions are the product of a post-lexical reconstruction process [14,15]. According to this idea, misreports during RSVP occur when observers attempt to make sense of fragmented visual input in order to generate a meaningful word. These top-down processes may result in an illusory word being retrieved from semantic memory as the best bet based on the fragments available. Consequently, the reconstruction process is assumed to take place at the time of the verbal report, which is generally at least 1 s beyond the presentation of the target word.

The ERP priming effect induced by an illusory word, however, indicates that a set of associated lexical entries has been activated before the onset of the target word. This finding confirms and extends our previous ERP study [16] that probed the processing level of the illusory word by prime words preceding the RSVP sequence. For an illusory target word, a significant N400 effect was elicited depending on its semantic relationship to the preceding prime word. Thus, our ERP findings support the 'lexical activation account' [10,17] which considers that illusory words are generated by an activation process time-locked to the presentation of the word fragment. According to this view, each word fragment – presented or induced in the RSVP sequence – will automatically activate corresponding cohorts of words. The common entry has some probability of passing the recognition threshold. An implication of this

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

view is that the semantic activation of the illusory word might differ minimally from activation of a physically presented word.

More importantly, our data also indicate that in case of a visual competition words not reported will not be processed semantically. The ERP priming effect was absent for related prime words out-competed in the RSVP sequence. Note that this pattern of results was consistently observed for the verbal report of the real as well as of the illusory word, respectively, and that the statistical effect size of the N400 effect induced by the corresponding 'loser' was negligible in both cases (η^2=0.02 and 0.03). Thus, we conclude that a prime word not reported is not represented on a semantic level and therefore cannot induce a facilitatory priming effect.

The fate of the 'loser' constitutes additional evidence in favour of the 'lexical activation account' [10,17], which predicts that only the visual word form with the highest level of activation will activate its semantic representation. In contrast, it contradicts priming studies in which conscious access to the prime word was prevented by visual or attentional masking [4,5,18–20]. It must be noted, however, that the illusory word paradigm is more comparable to the binocular rivalry paradigm [21] with respect to the competition of visual information. Here, an absence of semantic priming when primes could not be consciously reported has also been found [22].

Conclusion

Taken together, our data follow the predictions of an interactive activation model of word recognition [3,23], which assumes that mental representations accrue activation from bottom-up signals and compete for selection. We provide empirical evidence that a semantic activation of a non-recognized word will be prevented.

Acknowledgements

This work was supported by a grant from the Deutsche Forschugsgemeinschaft (DFG NI 513/7-1) to MN and MH.

References

1. Desimone R, Duncan J. Neural mechanisms of selective visual attention. *Ann Rev Neurosci* 1995; **18**:193–222.
2. Lee DK, Itti L, Koch C, Braun J. Attention activates winner-take-all competition among visual filters. *Nat Neurosci* 1999; **2**:375–385.
3. McClelland JL, Rumelhart DE. An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychol Rev* 1981; **88**:375–407.
4. Carr TH, Dagenbach D. Semantic priming and repetition priming from masked words: evidence for a center-surround attentional mechanism in perceptual recognition. *J Exp Psychol Learn Mem Cogn* 1990; **16**:341–350.
5. Fowler CA, Wolford G, Slade R, Tassinary L. Lexical access with and without awareness. *J Exp Psychol Gen* 1981; **110**:341–362.
6. Kiefer M, Spitzer M. Time course of conscious and unconscious semantic brain activation. *Neuroreport* 2000; **11**:2401–2407.
7. Forster KI. Visual perception of rapidly presented word sequences of varying complexity. *Percept Psychophys* 1970; **8**:215–221.
8. Grainger J. Word frequency and neighborhood frequency effects in lexical decision and naming. *J Mem Lang* 1990; **29**:228–244.
9. Kanwisher NG. Repetition blindness: type recognition without token individuation. *Cognition* 1987; **27**:117–143.
10. Morris AL, Harris CL. A sublexical locus for repetition blindness: evidence from illusory words. *J Exp Psychol Hum Percept* 1999; **25**:1060–1075.
11. Lehmann D, Skrandies W. Spatial analysis of evoked potentials in man – a review. *Prog Neurobiol* 1984; **23**:227–250.
12. Potter MC, Moryadas A, Abrams I, Noel A. Word perception and misperception in context. *J Exp Psychol Learn Mem Cogn* 1993; **19**:3–22.
13. Kutas M, Hillyard SA. Reading senseless sentences: brain potentials reflect semantic incongruity. *Science* 1980; **207**:203–205.
14. Masson ME, Caldwell JI, Whittlesea BW. When lust is lost: orthographic similarity effects in the encoding and reconstruction of rapidly presented word lists. *J Exp Psychol Learn Mem Cogn* 1998; **26**:1005–1022.
15. Whittlesea BW, Wai KH. Reverse 'repetition blindness' and release from 'repetition blindness': constructive variations on the 'repetition blindness' effect. *Psychol Res* 1997; **60**:173–182.
16. Niedeggen M, Heil M, Ludowig E, Rolke B, Harris CL. Priming illusory words: an ERP approach. *Neuropsychologia* 2004; **42**:745–753.
17. Harris CL, Morris AL. Illusory words created by repetition blindness: a technique for probing sublexical representations. *Psychonom Bull Rev* 2001; **8**:118–126.
18. Greenwald AG, Klinger MR. Visual masking and unconscious processing: differences between backward and simultaneous masking? *Mem Cognit* 1990; **18**:430–435.
19. Shapiro K, Driver J, Ward R, Sorensen RE. Priming from the attentional blink: a failure to extract visual tokens but not visual types. *Psychol Sci* 1997; **8**:95–100.
20. Sternberg G, Lindgren M, Johansson M, Olsson A, Rosen I. Semantic processing without conscious identification: evidence from event-related potentials. *J Exp Psychol Learn Mem Cogn* 2000; **26**:973–1004.
21. Blake R. A neural theory of binocular rivalry. *Psychol Rev* 1989; **96**: 145–167.
22. Zimba LD, Blake R. Binocular rivalry and semantic processing: out of sight, out of mind. *J Exp Psychol Hum Percept* 1983; **9**:807–815.
23. Movellan JR, McClelland JL. The Morton–Massaro law of information integration: implications for models of perception. *Psychol Rev* 2001; **108**:113–148.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.