ERPs reveal on-line influence of lexical biases on prosodic processing

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ABSTRACT

This ERP study examined how the human brain integrates different types of information when listeners encounter ambiguous ‘garden path’ sentences. Unlike previous studies, we investigated the real-time interaction of (1) structural preferences, (2) lexical transitivity biases, and (3) prosodic information. Data revealed that in *absence* of overt prosodic boundaries, verb-intrinsic transitivity biases influence parsing preferences (late closure) online, resulting in a larger P600 garden path effect for transitive than intransitive verbs. Surprisingly, this lexical effect was found to be mediated by prosodic processing, thus eliciting a CPS brain response in total absence of acoustic boundary markers (for transitively biased sentences only). Our results suggest early interactive integration of hierarchically organized processes rather than purely independent effects of lexical and prosodic information. As a primacy of prosodic cues would predict, *overt* speech boundaries overrode both structural preferences and transitivity biases.

Keywords:

1. Garden path sentences
2. early closure – late closure ambiguity
3. speech
4. event-related brain potentials (ERPs)
5. closure positive shift (CPS)
6. P600
7. N400
8. prosody
9. transitivity
10. lexical bias

INTRODUCTION

Human language processing mechanisms are often confronted with sentences involving syntactic ambiguities, and a number of sometimes radically distinct types of information may facilitate (or impede) their resolution. How and when the brain uses and integrates these various cues in order to generate a consistent interpretation is only poorly understood. Here we present an event-related potentials (ERP) study providing the first evidence of interactions between on-line prosodic phrasing and lexically stored probabilistic structural biases in the processing of auditorily presented closure ambiguities. For example, when the bracketed noun phrase (NP) in (1) is encountered in reading or speech, it can be syntactically integrated in two different ways: as the direct object of *teaching* (late closure, as in (1)a), or as the subject of the upcoming main clause (early closure, as in (1)b).

(1) When Mary was teaching [*the lesson*]...
  a. ...the students paid attention
  b. ...became clear

In the absence of disambiguating cues (a comma after *teaching,* or in speech, a corresponding prosodic break), readers/listeners favor the late closure integration. Behavioral and eye-tracking data reveal processing difficulties (“garden path effects”) when the disambiguating main clause information is encountered in continuations like (1)b but not in continuations like (1)a. This is consistent with the existence of structural parsing heuristics that serve to pick the simplest possible syntactic analyses when ambiguities are encountered [1,2].

However, in addition to highly salient disambiguating cues (e.g., commas, prosodic breaks), other more subtle types of information have been argued to modulate such parsing preferences, including the relative probability with which particular verbs typically occur with direct objects (transitivity bias). Though the role of both prosody and transitivity bias in ambiguity resolution have been investigated separately, no prior study has addressed the question of whether (and how) these factors may interact in the on-line neural dynamics of spoken language comprehension. In one related eye-tracking study probing a very different type of structural ambiguity involving prepositional phrase attachment (e.g., *Tickle/Choose the cow* <u>*with the fork*</u> *[or: He observed the spy* <u>*with binoculars/with a revolver]*</u>), Snedeker and Yuan (2008) argued for independent effects of lexical and prosodic cues [3]. The current study was designed to examine the *interaction* of these factors as reflected in patterns of neurophysiological activity.

Prosody. Behavioral [4-11] and ERP [12,13] studies show that prosodic information guides listeners' interpretation of ambiguous sentences and can prevent garden path effects. Furthermore, the processing of prosodic units has been associated with a distinct ERP component – the Closure Positive Shift (CPS) – which is a positive deflection near the midline elicited at prosodic boundaries. Importantly, this effect is not uniquely tied to actual pauses in speech – other cues signaling prosodic boundaries are sufficient (e.g., boundary acoustic cues, commas in silent reading [14]).

Transitivity Bias. Several studies have suggested that transitivity bias has immediate effects on ambiguity processing [15-21]. In ERPs, such influences are detectable in terms of effects on the P600, a positive-going component with a posterior distribution taken to reflect syntactic processing difficulties and structural reanalysis after the parser has been "led down the garden path" [19]. The P600 has been shown to be modulated by verbal transitivity bias. For example, in processing sentences such as *The doctor believed/charged [the patient] was lying*, the bracketed NP could initially be parsed as the direct object of *believed/charged*, resulting in a "garden path effect" when the auxiliary *was* is encountered (where a P600 should be elicited). However, Osterhout et al. [19] found that P600 effects arise only for transitively-biased verbs (*charged*), and not verbs biased towards clausal complements (*believed*).

The present study. We examined ERPs time-locked to the offset of ambiguous NPs (marked by ∢) in three types of auditorily presented sentences (Table 1: A–C) which were part of a larger study (see also Pauker, Itzhak, Baum, & Steinhauer, submitted). Because of their prosodic breaks, Condition A (late closure) and Condition B (early closure) were unambiguous. In contrast, Condition C, which must be resolved as an early closure structure, contained no such disambiguating prosodic break. In the present report we focus on a further manipulation designed to investigate the interaction of prosody and transitivity-bias: half of the verbs occurring in the underlined positions (Table 1) were transitively biased, and half were intransitively biased.

-------------------- Table 1 about here --------------------

***Predictions*.** We expected to observe two types of ERP effects. First, the salient prosodic break (#) after the NP in (A) should yield a CPS which should be absent for both (B) and (C) (as these contain no post-target breaks). Second, given the absence of a prosodic break in (C), the disambiguating second verb (e.g., *seemed*) should elicit a garden path effect (i.e., a P600 relative to (B)). Further, if there are no processing interactions between lexically stored structural biases and prosodic boundary information, then we should find uniform CPS effects within the transitive and intransitive bias sub-conditions. Finally, the absence of an explicit prosodic break in (C) may make it possible for lexical bias to gain influence in parsing decisions, resulting in a stronger garden path effect for the transitive than the intransitive bias conditions.

METHODS

Participants. Twenty-six healthy right-handed native English speaking undergraduates (13 females, age: 18-25, mean: 23, SD: 3.2) participated after giving informed consent. Six (2 female) were excluded from analyses due to excessive EEG artifacts.

Materials. Forty A/B-sentence pairs (**Table 1**) were constructed with the first verb in each optionally transitive (i.e., consistent with both A/B continuations). Transitivity bias was calculated from corpus counts derived from Lapata et al. [22], separately summing token counts for each verb where it appeared with direct objects (transitive) and where it occurred without (intransitive). Transitivity bias was defined as the ratio of transitive over transitive plus intransitive occurrences, yielding a low-to-high range from 0.15 to 0.90 (mean: 0.60, SD: 0.21). A median (0.65) split binned the verbs into two equal-sized groups: transitively biased (0.66-0.90, mean: 0.77, SD: 0.07) and intransitively biased (0.15-0.65, mean: 0.44, SD: 0.16).

The 80 A/B sentences were recorded with normal prosody, i.e., with a boundary after the first verb (*playing*) in B, and a boundary after the ambiguous NP (*the game*) in A (marked by #, Table 1). Forty additional sentences for the garden path C-condition were derived from A/B by digitally cross–splicing the initial portion of the A-items with the final portion of the B-items (illustrated by brackets in Table 1). A fourth condition, not relevant for the present inquiry, was generated by cross-splicing the initial portion of B and the final portion of A (see Pauker et al., submitted), resulting in a total of 160 experimental stimuli. Cue points marking words in each speech file allowed us to time-lock ERP analyses to the critical NP (at the "∢" marks in Table 1).

An additional 160 unrelated filler sentences were included to guard against participants developing processing strategies, consisting of half phrase-structure violations (e.g., *He hoped to *meal the enjoy...*) and half matched correct controls (e.g., *He hoped to enjoy the meal...*). All sentence types were evenly distributed across four blocks of 80 trials intermixed in a pseudo-randomized order. Eight experimental lists were created and evenly assigned across male/female participants.

Procedure. After ten practice trials, participants listened to the sentences in a shielded, sound attenuating chamber, and provided sentence-final acceptability judgments. Short breaks separated the four experimental blocks.

EEG recording. EEG was continuously recorded (500 Hz sampling rate; Neuroscan Synamps2 amplifier) from 19 cap-mounted Ag/AgCl electrodes (Electro-Cap International) referenced to the right mastoid and placed according to the 10-20 System [23] (impedance < 5 kΩ). EOG was recorded from bipolar electrode arrays.

Data analysis. Acceptability judgment data were subjected to repeated-measures ANOVAs with factors Condition (A-C) and Transitivity Bias. EEG data were analyzed using EEProbe (ANT, The Netherlands). Single subject averages were computed separately for six conditions (i.e., A/B/C × Transitive-/Intransitive-bias) following data pre-processing which included filtering (0.16-30 Hz bandpass), artifact rejection, and detrending. The number of trials surviving artifact rejection procedures did not significantly differ between the six conditions (range: 330-353 trials per condition). The detrending procedure subtracted slopes of very slow shifts in the DC recording, with relevant time-windows always including two trials (i.e., ~7 seconds).

Averages were based on all trials independent of the downstream behavioral response (note ERPs did not differ between accepted and rejected trials for any effects reported below). Averages were computed for 1300 ms epochs beginning 100 ms prior to the offset of the target NPs (-100 to +100 baseline). ERP components were quantified by means of amplitude averages in five consecutive 200 ms windows from 150-1150 ms (i.e., 150-350, 350-550, 550-750, 750-950, 950-1150 ms). The first of these was used to test for CPS effects, and the latter four were used to quantify the P600 garden path effects.

ANOVAs for repeated-measures were run separately for midline (Fz/Cz/Pz) and 12 lateral electrodes (F3/4/7/8, C3/4, T3/4/5/6, P3/4, T5/6). ANOVAs for the 150-350 ms time-window (probing CPS effects) included the factor Condition (A-C), and were carried out separately for the intransitive and transitive condition triples. The four subsequent 200 ms time-windows probing for P600 effects compared only the acoustically matched B/C conditions (i.e., for the four windows between 350-1150 ms), again separately for the intransitive- and transitive-biased conditions. Both midline and lateral analyses included the topographical factor Anterior/Posterior (AP: frontal/central/posterior), and lateral analyses additionally included factors Hemisphere (H: right vs. left) and Laterality (L: medial vs. lateral). Greenhouse-Geisser corrections were employed where applicable.

RESULTS

Behavioral results. A Condition main effect [$F(2, 38) = 27.66$, $p < 0.0001$] indicated that acceptability in garden path condition C (53.5%) was lower than both A (87.5%) and B (87.2%), which did not differ ($F < 1$). A Transitivity main effect [$F(1, 19) = 11.95$, $p < 0.005$] reflected a higher overall acceptability of sentences containing intransitively versus transitively biased verbs, especially in condition C (56.4% vs. 50.5%), but no interaction was found. Across verbs, response times for accepted trials were longer in C (956 ms) than A (680 ms) and B (701 ms) [$F(2, 36) = 18.88$, $p < 0.0001$], again reflecting the garden path effect. Finally, participants needed less time to reject trials in C_{trans} (868 ms) than $C_{intrans}$ (987 ms) [$F(1, 17) = 10.98$; $p < .004$], suggesting that transitivity biases resulted in more severe garden path effects.

-------------------- Figure 1 about here --------------------

Event-related potentials. Grand average ERP waves for (A)-(C) are plotted separately for the intransitive-/transitive-biased conditions in **Figure 1** alongside voltage maps showing mean amplitudes of CPS difference-waves. Results of CPS analyses are shown in **Table 2**.

Both the predicted CPS and P600 effects were obtained, and there was an additional quite striking unexpected finding. First, the intransitively biased conditions yielded the expected CPS (150-350 ms) for the (A) condition relative to both (B) and (C). Significant effects in the global ANOVA for this time-window were traceable in follow-up analyses to A/B and A/C differences (Table 2). This CPS effect had a fronto-central maximum (see the A/B and A/C difference maps in Figure 1), as demonstrated by further interactions with Laterality and Anterior/Posterior (Table 2). In contrast, the transitively biased conditions demonstrated statistically indistinguishable CPS-like positive-shifts for *both* the (A) and (C) conditions relative to (B)

(Figure 1/Table 2). This finding is surprising given that the (C) conditions did not contain any overt prosodic boundary information. Though previous work has shown that various factors can induce subvocal prosodic phrasing (and thus CPS effects) in silent reading [14, 24], to our knowledge no one has ever suggested that non-prosodic information might elicit such effects in the processing of connected speech.

-------------------- Table 2 about here --------------------

Turning to the P600 for the intransitively-biased conditions, although B/C × Laterality interactions obtained in the two final time-windows, [750-950: $F(1, 19) = 6.12$, $p < 0.05$; 950-1150: $F(1, 19) = 8.07$, $p < 0.05$], there were no significant effects on the midline and follow-up analyses conducted for lateral/medial electrodes separately showed no significant B/C effects.

In contrast, the transitively-biased comparison in the 3 final time-windows yielded interactions of B/C with both anterior/posterior [550-750: $F(2, 38) = 3.94$, $p < 0.05$; 750-950: $F(2, 38) = 5.28$, $p < 0.05$] and laterality [950-1150: $F(1, 19) = 10.03$, $p < 0.01$]. And here there were also B/C × anterior/posterior interactions on the midline [750-950: $F(2, 38) = 5.13$, $p < 0.05$; 950-1150: $F(2, 38) = 5.10$, $p < 0.05$]. These interactions reflected the emergence of a broadly posterior P600 garden-path effect (Figure 1) which in the final time-window showed larger amplitudes closer than further from the midline.

DISCUSSION

First, our data show that in absence of overt prosodic boundaries (condition C), the listener's parser relies on the same heuristics that lead to garden path effects in reading data [25]. However, transitivity bias has a clear impact, reflected by both a larger P600 deflection (replicating reading findings [19]) and by shorter rejection times.

Second, the influence of transitivity bias on the severity of the garden path effect may be mediated by prosodic phrasing. CPS effects were observed, not only for the A-condition containing a prosodic break, but also for the transitively biased (but not the intransitively biased) C-condition. It was already known that CPS effects are elicited in the absence of overt acoustic prosodic information, as they manifest even in silent reading in connection with the processing of commas [14,24]. What is new and striking about the present finding is that a prosodic boundary was apparently established because both the initial parsing preference (for late closure) and the lexical bias (for transitivity) strongly supported a syntactic boundary that usually coincides with a prosodic boundary. The combined evidence was sufficient to drive the brain systems in charge of prosodic constituency to impose a boundary after the target NP despite the absence of any boundary markers in the speech signal. Moreover this processing appears to take place with a time-course that yields a CPS profile that is statistically indistinguishable from the effects elicited by stimuli which actually contain overt prosodic breaks (condition A). Finally, the absence of any such CPS effect in the intransitively biased C condition shows that the structural bias for late closure is, on its own, insufficient to establish the corresponding prosodic constituency.

Elsewhere [12] *reduced* CPS amplitudes have been shown at *overt* prosodic boundaries if preceding discourse contexts allowed listeners to anticipate the boundary based on syntactic expectancies. The findings here are complementary: probabilistic lexico-syntactic co-occurrence information can initiate prosodic phrasing *in the absence* of relevant acoustic cues in the speech stream. Combined, both studies strongly suggest an immediate interactive mapping of syntactic and prosodic representations.

Third, our data also show that overt prosodic boundaries provide the strongest cues for parsing decisions and completely override both initial structural preferences (such as the late closure principle) and lexical biases. Thus, the early boundary in condition A prevented any garden path effect, irrespective of verb biases.

CONCLUSIONS

Our data suggest a hierarchical order of cues that listeners rely on when processing structurally ambiguous sentences. Overt prosodic boundaries elicit CPS responses and provide the dominant cue that overrides competing information and can reliably prevent misunderstandings (condition A). In absence of speech boundaries, listeners follow the same parsing principles as readers (e.g., the Late Closure principle) that can cause P600 garden path effects (condition C). Lexical transitivity biases modulate parsing preferences. When they support the initial preference, the accumulated evidence may be sufficient to initiate prosodic phrasing (CPS components in absence of acoustic cues), which then affects the strength of garden path effects. Thus, at least in closure ambiguities, the human brain seems to integrate various types of information on-line and interactively, rather than processing them independently and in parallel to one another.

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References

[1] Frazier L, Fodor JD. The sausage machine: A new two-stage parsing model. *Cognition* 1978; **6**: 291-325.

[2] Gorrell P. *Syntax and parsing.* Cambridge: Cambridge U Press; 1995.

[3] Snedeker, J. & Yuan, S. (2008). Effects of prosodic and lexical constraints on parsing in young children (and adults). *J Mem Lang*, 58(2): 574–608.

[4] Beach CM. The interpretation of prosodic patterns at points of syntactic structure ambiguity: Evidence for cue trading relations. *J Mem Lang* 1991; **30**: 644-663.

[5] Carlson K, Clifton C, Frazier L. Prosodic boundaries in adjunct attachment. *J Mem Lang* 2001; **45**: 58-81.

[6] Clifton C, Carlson K, Frazier L. Informative prosodic boundaries. *Lang Speech* 2002; **45**: 87-114.

[7] Frazier L, Carlson K, Clifton C. Prosodic phrasing is central to language comprehension. *Trends Cogn Sci* 2006; **10**: 244-249.

[8] Kjelgaard MM, Speer SR. Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *J Mem Lang* 1999; **40**: 153-194.

[9] Marslen-Wilson WD, Tyler LK, Warren P, Grenier P, Lee CS. Prosodic effects in minimal attachment. . *Q J Exp Psychol* 1992; **45A**: 73-87.

[10] Schafer AJ, Speer SR, Waren P, White DS. Intonational disambiguation in sentence production and comprehension. *J Psycholinguist Res* 2000; **29**: 169-182.

[11] Stirling L, Wales R. Does prosody support or direct sentence processing? *Lang Cogn Process* 1996; **11**: 193-212.

[12] Kerkhofs R, Vonk W, Schriefers H, Chwilla DJ. Discourse, syntax, and prosody: The brain reveals an immediate interaction. *J Cogn Neurosci* 2007; **19**: 1421-1434.

[13] Steinhauer K, Alter K, Friederici AD. Brain potentials indicate immediate use of prosodic cues in natural speech processing. *Nat Neurosci* 1999; **2**: 191-196.

[14] Steinhauer K. Electrophysiological correlates of prosody and punctuation. *Brain Lang* 2003; **86**: 142-164.

[15] Burkhardt P, Fanselow G, Schlesewsky M. Effects of (in)transitivity on structure building and agreement. *Brain Res* 2007; **1163**: 100-110.

[16] Garnsey SM, Pearlmutter NJ, Myers E, Lotocky MA. The contribution of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *J Mem Lang* 1997; **37**: 58-93.

[17] Jennings F, Randall B, Tyler LK. Graded effects of verb subcategory preferences on parsing: Support for constraint-satisfaction models. *Lang Cogn Process* 1997.

[18] Mitchell DC, Holmes VM. The role of specific information about the verb in parsing sentences with local structural ambiguity. *J Mem Lang* 1985; **24**: 542-559.

[19] Osterhout L, Holcomb PJ, Swinney DA. Brain potentials elicited by garden-path sentences: Evidence of the application of verb information during parsing. *J Exp Psychol Learn Mem Cogn* 1994; **20**: 786-803.

[20] Staub A. The parser doesn't ignore intransitivity, after all. *J Exp Psychol Learn Mem Cogn* 2007; **33**: 550-569.

[21] Trueswell JC, Tanenhaus MK, Kello C. Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. *J Exp Psychol Learn Mem Cogn* 1993; **19**: 528-553.

[22] Lapata M, Keller F, Schulte im Walde S. Verb frame frequency as a predictor of verb bias. *J Psycholinguist Res* 2001; **30**: 419-435.

[23] Jasper HH. The 10-20 electrode system of the International Federation. *Electroencephalogr Clin Neurophysiol* 1958; **10**: 371.

[24] Steinhauer K, Friederici AD. Prosodic boundaries, comma rules, and brain responses: The closure positive shift in ERPs as a universal marker for prosodic phrasing in listeners and readers. *J Psycholinguist Res* 2001; **30**: 267-295.

[25] Frazier L, Rayner K. Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cogn Psychol* 1982; **14**: 178-210.

TABLES

Table 1. Example Stimuli

(A)	[While Billy was <u>playing</u> t]he game≺ # the rules seemed simple	**LATE CLOSURE**
(B)	While Billy was <u>playing</u> # t[he game≺ seemed simple]	**EARLY CLOSURE**
(C)	[While Billy was <u>playing</u> t][he game≺ seemed simple]	**GARDEN PATH**

Notes: (i) bracketed [ ] portions of (A)/(B) conditions were digitally cross-spliced to generate the stimuli for (C); (ii) transitivity bias was manipulated for the underlined subordinate clause verbs (see Methods); (iii) ≺ marks the positions (offset of ambiguous NP) to which ERP's analyzed below were time-locked; (iv) # = prosodic break.

Table 2. Results of CPS Analyses (150-350 ms)

	GLOBAL ANOVA		Pair-wise Follow-up	
Intransitive	Cond (A/B/C)	6.05**	AB	9.21**
	C x Lat	2.99+	AB x Lat	5.22*
	C x AP	4.85**	AB x AP	7.81**
	C x H	—	AC	10.73**
	C x L x AP	—	AC x Lat	4.57*
	C x L x H	—	AC x AP	—
	C x AP x H	—	BC	—
	C x L x AP x H	—	BC x Lat	—
			BC x AP	—
	midline			
	C	5.93**	AB	8.84**
	C x AP	—	AC	11.51**
			BC	—
Transitive	Cond (A/B/C)	—	AB	3.66+
	C x Lat	5.96**	AB x Lat	10.07**
	C x AP	2.68+	AB x AP	3.78+
	C x H	—	AC	—
	C x L x AP	—	AC x Lat	—
	C x L x H	—	AC x AP	—
	C x AP x H	2.34+	BC	—
	C x L x AP x H	—	BC x Lat	9.07**
			BC x AP	—
	midline			
	C	2.91*	AB	5.98*
	C x AP	—	AC	—
			BC	4.09*

Figure captions:

Figure 1. Grand average waveforms and voltage maps for sentence types (A)-(C) containing intransitively biased (i)/(left panel) and transitively-biased (t)/(right panel) subordinate clause verbs. Waveforms are time-locked to the offset of the critical ambiguous noun phrase (from -100 to 1200 ms). Voltage maps show CPS (150-350 ms) differences for (A)/(B) and (A)/(C) for both intransitive- (Ai/Bi/Ci) and transitive-biased (At/Bt/Ct) conditions.

FIGURES

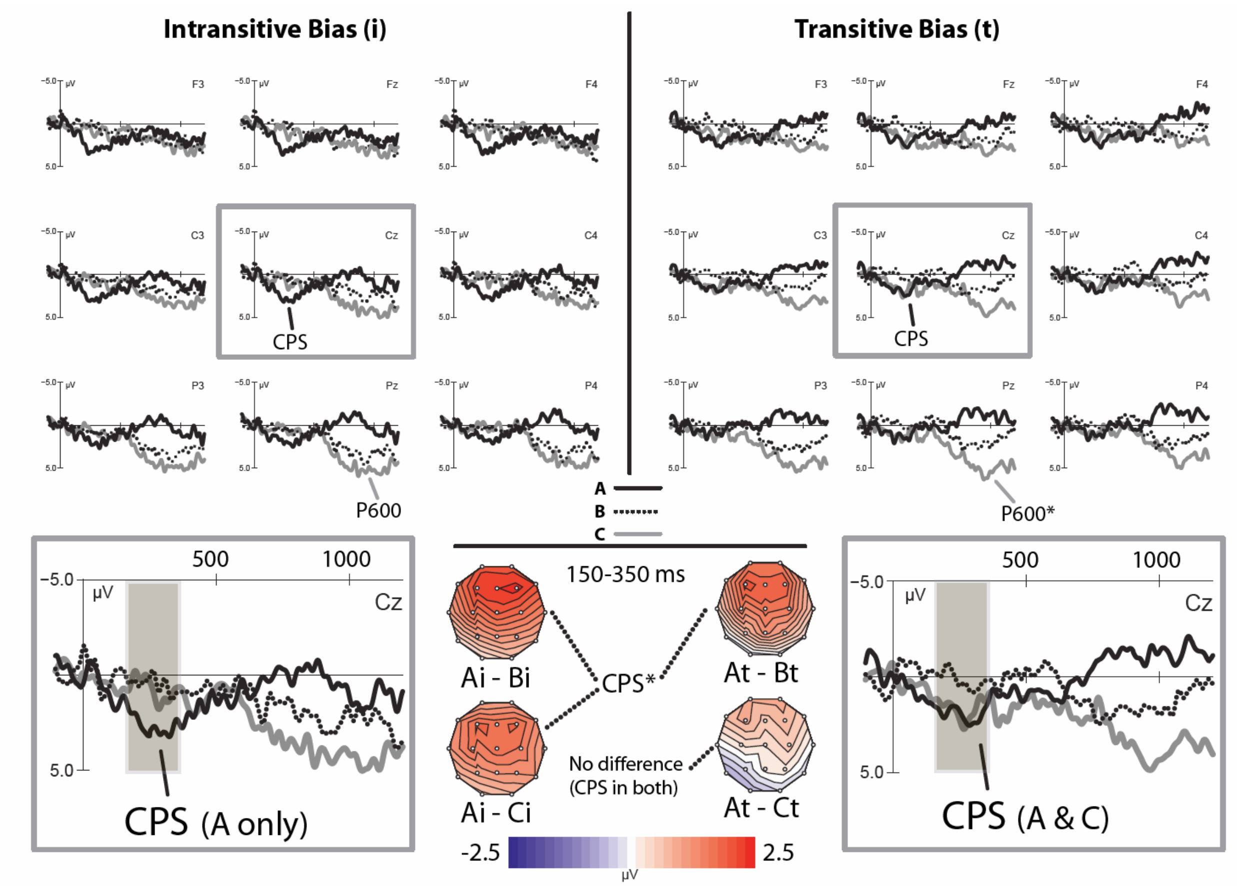

Figure 1.