Prediction of successful reanalysis based on eye-blink rate and reading times

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Introduction. Characterizing individual differences in sentence processing in general, and in recovery from processing difficulty in particular, remains a challenge [1-3]. Previous research has shown that intelligence, language experience and working memory capabilities predict overall comprehension accuracy in Garden Path (GP) sentences [2-3, see also [4] for a study of different sentence structures]; however, online syntactic effects (i.e., reading times) are unreliable as measures of individual differences [3].

In the present work, we aimed to further investigate the characteristics of participants who are (un)able to perform reanalysis of GP sentences, using a paraphrasing task [5]. Specifically, we asked whether participants' capacity to successfully reanalyze the sentence can be predicted based on (i) their reading time (RT) patterns in the critical region of the sentence, and (ii) their tonic dopamine levels, as reflected by their eye-blink rate. The performance of reanalysis in GP sentences requires efficient use of executive functions and allocation of working memory in order to remember the sentence and return to the point of difficulty, inhibit the syntactic structure built during the initial analysis, and flexibly use the new material to find alternative analyses. Working memory updating, inhibition and cognitive flexibility are all assumed to be driven by dopamine (DA) [6-8]. Tonic dopaminergic activity is correlated with resting state (tonic) eye blink rate (EBR) [6]. EBR was shown to be a predictor of individual differences in paradigms requiring inhibition or task switching, where DA followed an inverted u-shaped association with performance, such that medium DA levels corresponded to optimal performance [6-7].

We used Hebrew GP sentences with optionally transitive (OT) verbs varying in their transitivity bias, embedded in a temporal adjunct. The baseline condition included an intransitive (IN) verb (these conditions were part of a larger study with different types of sentences). (See Table 1).

Methods. Ninety-six native Hebrew speakers participated in a self-paced reading experiment with 28 sentence sets and 72 filler sentences. Each target sentence as well as some fillers were followed by an instruction to write the last sentence, without further directions. Prior to the experiment, resting-state EBR was registered with three ocular electrodes above and below the eye while participants fixated at a cross in the middle of the computer screen for 3.5 minutes.

Paraphrases were coded as successfully reanalyzed (R) if the participants introduced a comma or switched the order of clauses, and as non-reanalyzed (N) in cases of a lingering misinterpretation (see Table 2). For each participant, their reanalysis performance (RP) rate was defined as their percentage of successfully reanalyzed sentences out of all GP sentences.

Results. We divided the participants to groups based on their RP for descriptive purposes. EBR results by subject group are presented in Table 3. RT results are presented in Figure 1. We fitted a GLM model for all subjects with paraphrases coded as N or R (N=71), with participants' RP rate as a dependent variable. Average log RT of the critical region across the two conditions, linear and quadratic effects of EBR, and their interaction were entered as fixed effects. We observed a main effect for RT, with longer RTs predicting better reanalysis outcome ($p < .001$). We also found a linear ($p=.019$) and polynomial inverted u-shaped ($p=.033$) effects of EBR on reanalysis performance. The interaction between EBR and average RT was not significant (see Figure 2).

Discussion. Our results show that participants with medium tonic EBR were the most successful reanalyzers, in line with previous results showing that medium dopamine levels predict high performance in tasks requiring inhibition and updating. The results also show that slow reading is associated with success at reanalysis ([9]).

Table 1: Example set, translated from Hebrew

Optionally Transitive (OT)	'After the guests drank cold water flowed from the tap at the farm.'
Baseline Intransitive (IN)	'After the guests woke up cold water flowed from the tap at the farm.'

Note: the critical region is marked in underline

Table 2. Paraphrase coding

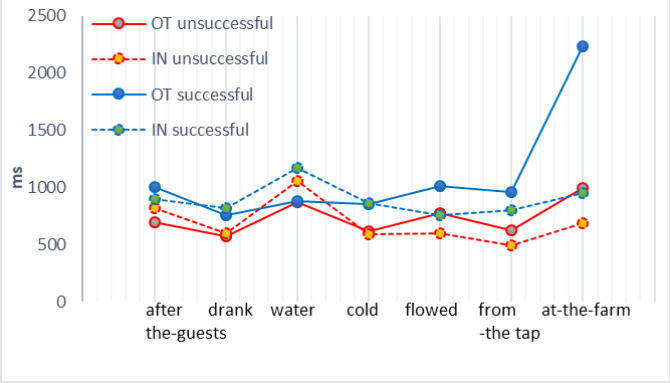
Category	**Example paraphrase**
Successful reanalysis ("R"). 98 sentences (25.5%)	"After the guests drank**,** cold water flowed from the tap." "Cold water flowed from the tap after the guests drank."
Lingering misinterpretation ("N"). 91sentence (23.6%)	"After the guests drank cold water it flowed from the tap." "After the guests drank cold water, cold water flowed from the tap."
195 sentences not coded as R or N, due to obscurity	"After the guests drank cold water flowed from the tap." "Cold water flowed from the tap."

Table 3. Mean EBR by participant group

Group of participants	**Average EBR (SD) (3 min)**
75-100% of a participant's paraphrases exhibited N pattern, **'unsuccessful'** group (N = 17)	83 (50)
Participant's paraphrases exhibited only N pattern, but less than 75% of the time (N = 12)	70 (35)
Participant's paraphrases exhibited both R and N pattern, but less than 75% of each (N = 15)	63 (29)
Participant's paraphrases exhibited only R pattern, but less than 75% of the time (N = 11)	48 (19)
75-100% of a participant's paraphrases exhibited R pattern, **'successful' group** (N = 16)	54 (30)

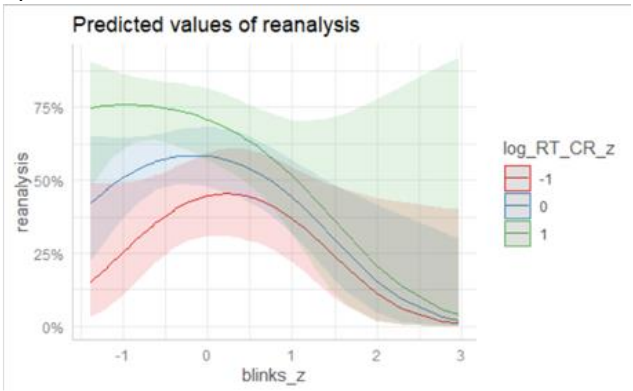
Note: not all participants' paraphrases were coded as either R or N, as in Table 2 above.

Figure 1. Mean RTs of critical region by condition and participants group (successful/unsuccessful)



Note: In Hebrew, both SV and VS orders are possible, especially with unaccusative verbs. This has consequences for the GP effect, the greater processing difficulty appears at the end of the sentence.

Figure 2. Predicted values of reanalysis performance by EBR and RT



Note: log_RT_CR_z represents standardized log RT of the critical region and blinks_z represents standardized EBR

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