Speech planning at turn transitions in dialogue is associated with increased processing load

Mathias Barthel[1,*] and Sebastian Sauppe[2]

[1] *Language and Cognition Department, Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands*

[2] *Department of Comparative Linguistics, University of Zurich, Switzerland*

[*] *Correspondence to: mathias.barthel@mpi.nl*

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Abstract

Speech planning is a sophisticated process. In dialogue, it regularly starts in overlap with an incoming turn by a conversation partner. We show that planning spoken responses in overlap with incoming turns is associated with higher processing load than planning in silence. In a dialogic experiment, participants took turns with a confederate describing lists of objects. The confederate's utterances (to which participants responded) were pre-recorded and varied in whether they ended in a verb or an object noun and whether this ending was predictable or not. We found that response planning in overlap with sentence-final verbs evokes larger task-evoked pupillary responses, while end predictability had no effect. This finding indicates that planning in overlap leads to higher processing load for next speakers in dialogue and that next speakers do not proactively modulate the time course of their response planning based on their predictions of turn endings. The turn taking system exerts pressure on the language processing system by pushing speakers to plan in overlap despite the ensuing increase in processing load.

Keywords: turn taking, dialogue, processing load, task-evoked pupillary responses, speech planning, dual task

1 Introduction

Conversation is the most frequent form of human communication (Levinson, 2006), and taking turns at talk is a well practiced task in which different speakers' contributions usually follow one another with only short gaps in between (Stivers et al., 2009). Planning a verbal response, however, is known to take between about 600 ms for single words (Indefrey, 2011; Strijkers & Costa, 2011) to well more than one second for short sentences (Griffin & Bock, 2000; Myachykov, Scheepers,

Garrod, Thompson, & Fedorova, 2013), illustrating that timing a turn at talk in conversation is not a trivial task. To be able to quickly take their turn, next speakers need to start planning their response as early as possible, often in overlap with the incoming turn (Barthel & Levinson, subm.; Barthel, Meyer, & Levinson, 2017; Bögels, Magyari, & Levinson, 2015; Corps, Crossley, Gambi, & Pickering, 2018). Barthel, Sauppe, Levinson, and Meyer (2016) found that response planning was indeed done as early as the incoming turn's message could be conceived, even if the incoming turn did not end at that point.[1]

Planning the next turn while continuously monitoring the incoming turn for completion, and possibly for content, is a demanding dual task situation. Both language comprehension and planning require allocation of central attention (Hagoort, Brown, & Osterhout, 1999; Kemper, Herman, & Lian, 2003; Kubose et al., 2006; Shitova, Roelofs, Coughler, & Schriefers, 2017), and both are known to interfere with concurrent non-linguistic tasks (Boiteau, Malone, Peters, & Almor, 2014; Roelofs & Piai, 2011; Sjerps & Meyer, 2015). The law of least mental effort proposes that humans try to make decisions and form strategies so as to minimize mental workload in order to achieve an efficient work-benefit ratio (Reichle, Carpenter, & Just, 2000; Zipf, 1949). It is thus a central question whether the language processing system is adapted to this highly frequent task or whether planning in overlap leads to increased processing load in the vicinity of turn transitions, the 'crunch zone' of conversation (S. G. Roberts & Levinson, 2017). Using an auditory picture-word interference paradigm, Schriefers, Meyer, and Levelt (1990) compared the effects of concurrent noise versus concurrent speech on speech planning and found that naming latencies did not differ between a silent condition and a condition with distracting noise. With distracting words, however, naming latencies increased by 70 ms even when the words were unrelated to the picture names, indicating general interference of speech comprehension with speech planning. As participants were instructed to ignore any incoming speech and as their own utterances were independent of the presented speech input, the measured interference effects are effects of distraction rather than of the processes of integration of speech input, which is the task next speakers face in turn taking. Instead of trying to ignore incoming speech, interlocutors most of the time have to plan their next turn while concurrently listening to the incoming turn. Fargier and Laganaro (2016) studied picture naming performance with either a concurrent syllable or tone detection task and found longer response latencies and differences in ERP components in the syllable condition as compared to the tone condition, indicating increased interference between two concurrent linguistic tasks. Klaus, Mädebach, Oppermann, and Jescheniak (2017) made used of a dual-task paradigm combining sentence production as task 1 with a concurrent working memory task 2. Participants were instructed to produce subject-verb-object sentences while they had to ignore auditory distractor

[1] The study reported here presents pupillometric data from Barthel et al. (2016), which focused on eye movements.

words that were either phonologically or semantically related to either the subject or the object of the sentence. The concurrently performed working memory task was either visuospatial or verbal in nature. Under visuospatial load, both types of relatedness had effects on both the subject and object of the sentence. The pattern of results was similar under verbal load. Here however, only phonological relatedness to the subject but not to the object affected sentence production performance, showing that verbal load reduced participants' phonological planning scope. These findings make it plausible to assume that next speakers postpone stages of formulation when planning in conversation in order to avoid inefficient processing due to interference. Barthel and Levinson (subm.), however, show that next speakers in a quiz-like situation engage in phonological planning as early as possible and in overlap with the incoming question. To date, evidence on the timing of the different processing stages in conversation is scarce, but the fact that response planning is frequently initiated in overlap with listening to the incoming turn is largely undisputed (but see Heldner & Edlund, 2010).

The observation that planning in overlap is common can be accounted for in two ways. One account highlights the mechanisms of turn allocation and the time pressure at turn transitions. According to the simplest systematics of turn taking (Sacks, Schegloff, & Jefferson, 1974), the first participant that speaks up when a turn transition becomes relevant gains the right to take the next turn. While language production and comprehension are assumed to engage—at least partly—the same cognitive resources (Hagoort & Indefrey, 2014; Kempen, Olsthoorn, & Sprenger, 2012; Menenti, Gierhan, Segaert, & Hagoort, 2011; Silbert, Honey, Simony, Poeppel, & Hasson, 2014), potentially increased processing load due to parallel processing of the two might be traded for the benefit of early planning, leading to shorter turn transition times (Barthel et al., 2017, 2016). The alternative account questions the assumption that the simultaneity of comprehension and production in conversation drastically increases processing load. Previous research shows that participants prefer to use parallel processing over serial processing in dual tasks (Hübner & Lehle, 2007). To investigate the reasons for this tendency, Lehle, Steinhauser, and Hübner (2009) instructed participants explicitly to apply either a parallel or a serial processing strategy when giving parity judgments on two numbers. Lehle et al. found that while a parallel processing strategy increased reaction times and error rates, it decreased processing load, which might be the main reason for preferring parallel over serial processing. Consequently, planning in overlap might not be associated with any significant increase in processing load, especially since turn taking is a highly practiced dual task and cognitive tasks become less demanding with increasing proficiency (Donovan & Radosevich, 1999; Hampton Wray & Weber-Fox, 2013; Neubauer & Fink, 2009; Van Selst, Ruthruff, & Johnston, 1999; Weber-Fox, Davis, & Cuadrado, 2003).

Here, we test whether planning a response while simultaneously comprehending an interlocutor's turn imposes increased processing load on speakers as compared to non-overlapping response planning by analyzing task-evoked pupillary responses from an experiment employing a dialogic paradigm. Changes in pupil diameter in response to task-induced cognitive processes are a reliable indicator of processing load (Beatty, 1982; Beatty & Lucero-Wagoner, 2000; Sirois & Brisson, 2014). The analysis of task-evoked pupillary responses allows studying differences in task demands, i.e. the amount of overall cognitive resources that need to be allocated in order to master a task (Hess & Polt, 1964; Kahneman, 1973; Laeng, Sirois, & Gredebäck, 2012). Most studies using task-evoked pupillary responses to measure processing load in language processing have focused on comprehension (Engelhardt, Ferreira, & Patsenko, 2010; Just & Carpenter, 1993; Koch & Janse, 2016; Kuchinke, Vo, Hofmann, & Jacobs, 2007; Schmidtke, 2014; Tromp, Hagoort, & Meyer, 2016; Zekveld, Kramer, & Festen, 2010, *inter alia*), and there are only few studies that have investigated language production (Papesh & Goldinger, 2012; Sauppe, 2017). If planning in overlap leads to increased processing load, task-evoked pupillary responses should have larger amplitudes as compared to planning in silence, whereas they are not predicted to differ if overlap does not increase processing load during response planning.

We report a dialogic experiment in which participants took turns with a confederate describing arrays of objects. Participants' pupil diameter was measured as they listened and responded to pre-recorded critical utterances from the confederate. These utterances were designed to on the one hand either allow for response planning in overlap or not and on the other hand to contain either a predictable or a non-predictable ending. In this way, the effects of planning in overlap as compared to planning in silence on task-evoked pupillary responses were tested in the context of predictable and non-predictable overlapping speech input.

2 Methods and Materials

2.1 Participants

Forty-eight German native speakers (mean age = 26.3 years, SD = 7.6 years, 30 female) who reported to have normal hearing and vision participated in the experiment for payment. Eight participants were excluded from the analyses because they reported during a post-test questionnaire that they had noticed the presence of pre-recorded material. Two participants were excluded due to technical failures of recording equipment, leaving 38 participants for analysis. Participants gave informed consent and the experiment was approved by the Ethics Committee of the Faculty of Social Sciences, Radboud University Nijmegen.

2.2 Apparatus

Participant and confederate were placed in separate sound-proof booths that were equipped with headphones and microphones with which they could communicate with one another. Visual stimuli were presented on a 21" computer screen at a distance of approximately 60 cm. Participants' pupil size was recorded with an SMI RED-m remote eye tracker at 120 Hz sampling rate. Light conditions remained constant across participants.

2.3 Stimuli

2.3.1 Visual Stimuli

Coloured pictures of 468 objects were used to generate the visual stimuli.Ninety-six critical stimulus displays showing between three and five objects (32 displays each) were generated. Irrespective of the number of objects shown in an item display, each object filled approximately two degrees of visual angle and was located about four centimeters away from its neighbours, so that participants had to shift their gaze in order to foveally fixate individual objects. Between none and three of the objects had to be named by participants (24 displays each), the remaining objects were named by the confederate (cf. Section 2.4).

2.3.2 Auditory Stimuli

Each of the 96 critical stimulus displays was accompanied by a German sentence in one of four conditions that were pre-recorded by the confederate and crossed according to whether the sentence ended in a verb or not (verb position) and whether it was predictable or not that the sentence would end with or without a final verb (end predictability; see Table 1). The presence of a sentence-final verb made planning in overlap possible, since all that participants needed to know to plan their response was which of the displayed objects they would have to name. When a sentence did not end in a verb, it ended in an object noun that was relevant for preparing the response, so that planning could only take place in silence after the turn ended. In predictable sentences, participants could know in advance whether the last word would be a verb or an object noun, since different verbs in second position (before the list of objects) either required another verb form in sentence-final position (such as the modal verb *'can'*) or not (such as the main verb *'see'*). In contrast, non-predictable sentences contained *'have'* in second position, which is ambiguous between being a main verb or an auxiliary and consequently either does or does not call for a sentence-final participle. Four pseudo-randomized lists were constructed, so that each item appeared in only one condition per list and the same number of items per condition appeared in each list.

		End predictability	
		unpredictable	predictable
Verb position	not final	Ich habe einen Schlüssel, einen Lenkdrachen und einen Rubin.	Ich sehe einen Schlüssel, einen Lenkdrachen und einen Rubin.
	final	Ich habe einen Schlüssel, einen Lenkdrachen und einen Rubin besorgt.	Ich kann einen Schlüssel, einen Lenkdrachen und einen Rubin besorgen.

Table 1: Example sentences of the four conditions used in the experiment. 'I have/have gotten/see/can get a key, a kite, and a ruby.'

2.4 Procedure

Prior to the experiment, participants were shown all objects in a booklet and asked to name them. Participants and the confederate were instructed as follows. In each trial, they would see a number of objects they could get and the confederate should tell the participant what objects she could get, so that the participant could tell the confederate what *further* objects he could get, only listing the objects that had not already been named by the confederate (all objects named by the confederate were also visible on the participant's display). Participants triggered the beginning of each trial by looking at a fixation cross at the center of the screen. Each trial began with a preview of 600–1000 ms of the stimulus display before the critical sentence was played. The experiment started with twelve practice trials that were of the same structure as experimental trials.The eye-tracker was (re-)calibrated four times at equal intervals during the experiment. The experiment lasted approximately 30 minutes and was followed by a computerized questionnaire asking participants whether they had noted the presence of pre-recorded material.

2.5 Data Preprocessing and Analyses

Preprocessing of pupil data and statistical analyses were carried out in R (R Core Team, 2018). Samples recorded with low validity (as indicated by SMI's recording software) and during blinks or saccades were treated as missing values and linearly interpolated separately for each eye. Pupil diameters of both eyes were averaged before time-locking to the offset of the last noun in the confederate turn. For each trial, pupil diameter was baselined by subtracting the mean diameter during a baseline period spanning the 500 ms preceding the offset of the last noun in the confederate turn. Mean task-evoked pupillary response amplitude was calculated for a time window of 3000 ms after the time-lock point and peaks in pupil diameters were identified in this time window (Borchers, 2015).

The data set contained 2736 trials in which both confederate and participant named at least one object. Trials in which participants did not name the correct objects or responded in overlap and

trials with more than 30% missing values before interpolation in samples recorded between −500 and 3000 ms relative to the offset of the confederate's last noun were excluded from statistical analyses (319 trials). Forty-three additional trials were excluded because their verbal response time was more than 3 SD longer than the participant's mean response time—measured manually in Praat (Boersma & Weenink, 2015) from the offset of the incoming turn to the onset of the first object noun in the participants' turn. Additional items in which sentences were produced live by the confederate (see Barthel et al., 2016) were not considered for analyses (341 trials). On balance, 2377 trials remained for analysis (13.12% of trials were excluded).

Three linear mixed effects regression models were fitted (Bates, Mächler, Bolker, & Walker, 2015) with mean amplitude, peak amplitude, and peak latency as dependent variables. The underlying assumption is that differences in mean and peak amplitude and peak latency relate to differences in processing load and reflect differences in task difficulty (Beatty & Lucero-Wagoner, 2000). While peak amplitude is a good measure for processing load, accurate peak detection is not straightforward, as the location of peaks is susceptible to noise in the recorded signal (Luck, 2014). Mean amplitude is a more conservative measure for processing load, since it takes into account the whole analysis window and is thus less susceptible to noise. Differences in the latency of peaks between conditions relate to differences in task difficulty, reflecting differences in the time it takes to do the necessary computations in order to give a response. Converging results in these measures is desirable when drawing inferences on cognitive demand on the basis of task-evoked pupillary responses. Verb position and sentence end predictability as well as their interaction were the predictors of interest. Their statistical significance was assessed using F-tests with Kenward-Roger approximations of degrees of freedom (Fox & Weisberg, 2011; Halekoh & Hojsgaard, 2014; Kenward & Roger, 1997). The maximal random effects structures as justified by design which allowed models to converge were used (Barr, 2013; Barr, Levy, Scheepers, & Tily, 2013). A number of nuisance variables were included in the fixed effects structure of the models (Sassenhagen & Alday, 2016): the duration of the confederate turn, since the pre-recorded sentences differed in complexity; the number of objects to be named by the participant, since task difficulty increases with the number of choices (Hick, 1952); trial number, to account for changes over the course of the experiment; and a binary variable indicating whether the sentence structure of the confederate turn was re-used in the response turn, since processing load might be influenced by structural priming (Pickering & Ferreira, 2008; Segaert, Menenti, Weber, Petersson, & Hagoort, 2012). The statistical significance of nuisance variables was not assessed. Categorical predictors were deviation coded (−0.5 and 0.5) and continuous predictors were mean centered.

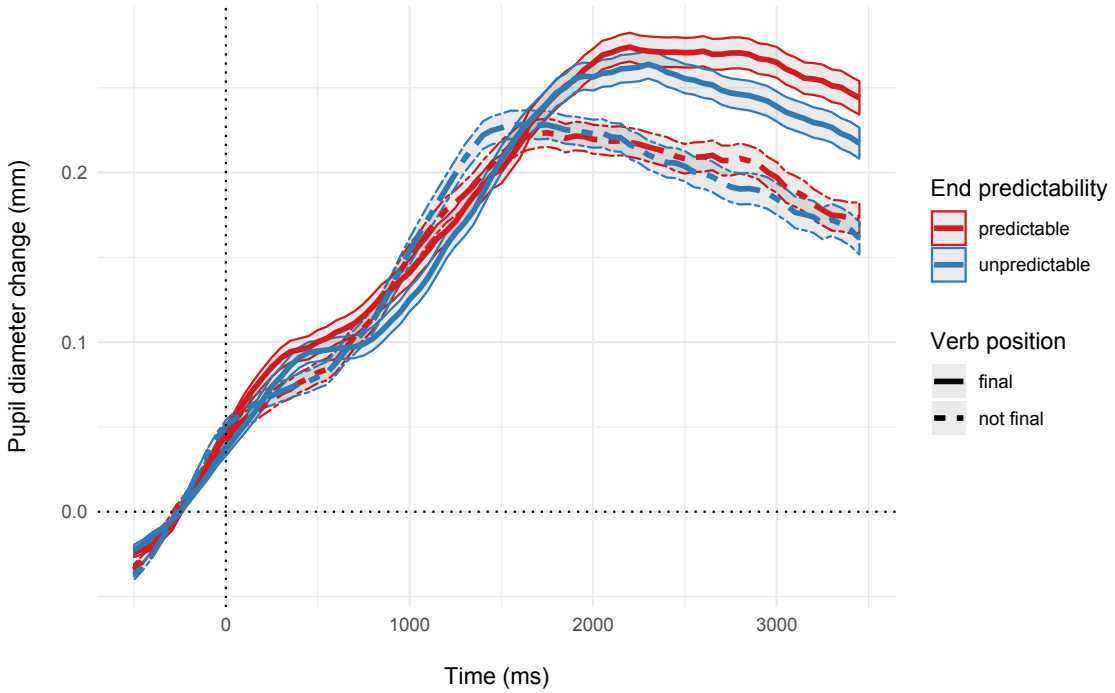

Figure 1: Grand average changes in pupil diameter (task-evoked pupillary responses) in mm, time-locked to the offset of the last noun of the confederate's turn (dashed vertical line). Ribbons indicate 95% confidence intervals. The analysis time window ranged from 0–3000 ms. For plotting only, samples were averaged into 50 ms bins within each trial to align time steps across trials before grand averaging.

condition	peak amplitude in mm	mean amplitude in mm	peak latency in ms
no final verb/unpredictable	0.409 (0.231)	0.167 (0.198)	1850 (782)
no final verb/predictable	0.412 (0.222)	0.165 (0.185)	1868 (825)
final verb/unpredictable	0.432 (0.226)	0.179 (0.188)	2030 (756)
final verb/predictable	0.446 (0.241)	0.190 (0.196)	2041 (782)

Table 2: Means (standard deviations in parentheses) of peak and mean amplitudes, and peak latencies by condition.

3 Results

Average task-evoked pupillary responses are shown in Figure 1 and descriptive statistics are presented in Table 2.

Linear mixed effects regressions revealed that task-evoked pupillary responses in the verb-final conditions had statistically significantly higher mean amplitudes, higher peak amplitudes, and greater peak latencies than in non-final conditions. Neither the main effect of predictability, nor its interaction with verb position reached statistical significance in any of the three models (Table 3).

	Mean amplitude (mm)				Peak amplitude (mm)				Peak latency (logarithm of ms)			
	$\hat{\beta}$	$\lvert t \rvert$	F	p	$\hat{\beta}$	$\lvert t \rvert$	F	p	$\hat{\beta}$	$\lvert t \rvert$	F	p
Intercept	0.175	12.366			0.425	21.313			7.397	182.183		
Verb position (= final)	0.023	2.788	7.847	0.006**	0.034	3.647	13.327	<0.001***	0.114	3.507	12.323	<0.001***
End predictability (= predictable)	0.006	0.789	0.617	0.438	0.009	1.182	1.393	0.238	-0.012	0.374	0.140	0.708
Verb position × End predictability	0.009	0.674	0.453	0.501	0.004	0.268	0.072	0.789	0.012	0.185	0.034	0.853
Structural priming (= yes)	0.009	1.116			0.016	1.754			-0.011	0.317		
Sentence duration (z)	-0.002	0.235			<0.001	0.022			0.081	2.716		
Trial number (z)	-0.015	4.270			-0.016	3.858			-0.060	3.844		
Delta of objects (z)	0.007	0.700			0.013	1.191			0.099	3.329		

Table 3: Linear mixed effects regression models predicting mean task-evoked pupillary response amplitude (in mm), peak task-evoked pupillary response amplitude (in mm), and peak task-evoked pupillary response latency (in ms). Statistical significance based on Type II F tests with Kenward-Roger degrees of freedom (Kenward & Roger, 1997).

4 Discussion

We investigated the level of processing load in next speakers in the vicinity of turn transitions in dialogue to answer the question whether planning a turn at talk in overlap with the incoming turn leads to higher processing load than planning it in silence. Task-evoked pupillary responses recorded during a dialogic list-completion task were analyzed, and mean amplitudes and peak amplitudes were found to be higher and peak latencies to be longer when planning was done in overlap than when it was done in silence. While the sentences in conditions that allowed for early planning in overlap were often slightly more complex than the sentences in conditions that did not allow for early planning, the differences in sentence complexity were much greater within than between conditions. Whether a sentence ended in a verb or not influenced pupillary responses beyond the influence of sentence duration, which was included as a nuisance variable to account for the length of a sentence and thereby its complexity. Taken together, the presented results show that planning in overlap is more demanding than planning in silence.

In their analyses of eye-movements from the experiment here, Barthel et al. (2016) found that participants started to plan their response as early as possible, i.e., as soon as they had identified the last noun of the incoming turn—irrespective of another verb form following before the end of the turn or not. Consequently, participants generally started planning their response in overlap with the incoming turn in verb final conditions and in silence in conditions without a final verb. When planning in overlap, the time gained by starting to plan early was not fully reflected in the reduction of turn-transition times. When participants planned their response in overlap, planning overlapped with turn final verbs which were about 600 ms long. In these cases, however, gaps between turns were shorter by only approximately 100 ms. This means that participants spent considerably more time planning their response when planning started in overlap than when planning was done in silence. The reported pattern of task-evoked pupillary responses sheds light on the cause of this discrepancy: The increase in planning time was due to higher processing load in planning in overlap as compared to planning in silence.

Given that planning in overlap is the norm in conversation, the finding that it is a more demanding strategy as compared to planning in silence shows that the requirements of the systematics of turn taking in conversation (Sacks et al., 1974) receive precedence over the minimization of mental effort. The culturally developed turn taking system exerts pressure on the cognitive mechanisms of language processing, enforcing strategies that raise processing load in order to meet the requirements set by the rules of turn allocation and the semiotics of turn timing. Increased processing load for the sake of finely attuned temporal alignment of turns thus appears to be a cornerstone in the organization of turn allocation: If you want to take a turn at talk, you need to push your language processor in order to speak up before other participants. Trading high processing load for shorter turn transitions is a pre-requisite for the timing of turns to become a meaningful source of information. If the next speaker does not claim her turn in time, she can be interpreted as lacking interest in the conversation, its topic, or her interlocutor, as having trouble understanding the previous turn or parts of it (Kendrick, 2015; Schegloff, Jefferson, & Sacks, 1977), as being unwilling to comply with a request or as preparing to disagree with an assessment (Kendrick & Torreira, 2014; F. Roberts & Francis, 2013; F. Roberts, Margutti, & Takano, 2011). In that way, turn timing is meaningful in itself, irrespective of the content of the following turn, with a long gap before a turn leading the recipient to expect a dis-preferred response, e.g., a rejection of an invitation (Bögels, Kendrick, & Levinson, 2015). With the timing of turn taking being a source of information that is analyzed by listeners, more information can be inferred from a single unit of talk. This enriches social interaction in conversation but comes at the cost of increased processing load for the individual speaker.

As processing load is high at turn transitions due to time pressures, next speakers might develop strategies to distribute processing load evenly over time when planning their turn. Based on findings that participants in dual tasks can to some degree choose to apply different processing strategies (Hübner & Lehle, 2007; Miller, Ulrich, & Rolke, 2009; Navon & Gopher, 1979; Navon & Miller, 2002; Tombu & Jolicœur, 2005), one conceivable way to avoid high peaks in processing load would be to apply a 'proactive planning' strategy in cases when incoming turns contain highly predictable turn-final words. If predictability of a turn-final word leads to effective changes in response planning, processing load in sentences with predictable turn ends should be lower than in sentences with unpredictable turn ends. However, none of the analyzed pupillary response measures (peak amplitude, mean amplitude, and peak latency) were significantly affected by predictability, lending no support to the hypothesis that participants applied a proactive planning strategy in order to keep processing load low at turn transitions. We take this as evidence that next speakers did not utilize the predictability of incoming verbal material to adapt the time course of their response planning (cf. also Huettig & Mani, 2016). In order to meet turn timing requirements,

next speakers seem to aim to plan their contribution as early and fast as possible, accepting increased processing loads during response planning to avoid risking the consequences of being too slow to take their turn.

By planning their response in overlap with comprehending the incoming turn, participants' behaviour agrees with the general tendency to choose parallel processing over serial processing in dual tasks (Hübner & Lehle, 2007); they do not postpone encoding processes until after a predictable final word. In our experiment, however, the reason for this choice cannot have been reduced processing load, as our analyses of task-evoked pupillary responses show that planning a response in overlap induces *higher* processing load than planning in silence. Instead, participants' motivation was more likely to reduce the length of gap after the incoming turn. Intending to take a well-timed turn, next speakers employed a planning strategy that at the same time took them longer to plan their response and was more demanding as compared to delaying response planning. While it remains possible that the choice of processing strategy is a question of preference of individual speakers (Bögels, Casillas, & Levinson, 2018) or the demands of the dual task situation (Lehle & Hübner, 2009; Reissland & Manzey, 2016), parallel processing appears to be the standard strategy in dialogue.

In sum, the turn taking system requires next speakers to accept higher processing loads induced by planning in overlap in order to be able to respond as fast as possible to an incoming turn so as to avoid the social consequences ensuing from noticeable gaps between turns of talk. In the words of Kahneman (1973), participants in a conversation are forced to trade *efficiency* in terms of processing load for *effectiveness* in terms of short gaps between turns. This means that the turn taking system is not optimized for next speakers' processing, but for overall effectiveness in social interaction. While putting pressure on cognitive processing in individual speakers, the turn taking system allows for a dense semiotics of turn timing that organizes and enriches social interaction in conversation. In addition to viewing the turn taking system as shaping the evolution of aspects of grammar (Auer, 2005; Ford & Thompson, 2003; S. G. Roberts & Levinson, 2017), the need to meet the timing demands in turn taking might also be shaping the design of the cognitive system. The study presented in this paper shows that examining task-evoked pupillary responses during speech planning is a promising technique to further investigate the mechanisms of speech processing in conversation.

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Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability

Raw data and analysis scripts are available from https://osf.io/pf2br/.

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