

Pauses in spontaneous written communication: A keystroke logging study

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Abstract: Spontaneous writing observed in chats, instant messengers, and social media has become established as productive modes of communication and discourse genres. However, they remain understudied from the perspective of writing process research. In this paper, we present an empirical study wherein keystrokes made by chat users in a game were recorded. The distributions of the inter-key intervals were analyzed and fitted with ex-Gaussian distribution equation, and an argument for psycholinguistic interpretation of the distribution parameters is presented. This analysis leads to establishing a threshold of 500 ms for the identification of pauses in spontaneous writing. Furthermore, we demonstrate that pauses longer than 1.2 s may correspond to higher-level linguistic processing beyond a single propositional expression (functional element of the discourse).

Keywords: chat, pauses, hesitation, keystroke logging



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1. Introduction

Although spontaneous writing observed in web chats, instant messengers, and (more recently) social media has become established as productive modes of communication and discourse genres, yet they have received surprisingly little attention from the perspective of writing process research. While keystroke logging data have been collected and distributions of inter-key intervals (IKIs) have been described for both controlled single-word production and written composition tasks (Nottbusch, 2010), it remains unknown whether similar distributions obtained from naturalistic written conversations could shed some light on the latent processes of spontaneous language production.

In this paper, we will explore the IKIs in spontaneous written communication in a Russian web chat setting. The goal of the present study is two-fold: first, by analyzing the properties of IKI distributions, we will attempt to establish a statistically-grounded threshold for the identification of pauses in writing. Second, we will examine the relationship between IKIs and linguistically relevant units of spontaneous written discourse, such as individual words and propositional expressions (PEs).

This paper is organized as follows. We begin with contextualizing the present study within the existing research on spontaneous writing, keystroke logging, and discourse structure, specifically focusing on the properties of spontaneous written communication that make it an appealing topic for psycholinguistic inquiry. After that, we describe the design of the study that facilitated data collection, and finally, present and discuss our findings.

1.1 Spontaneous Writing

For centuries, studies of language were confined to written texts, which supported theoretical generalizations, served as the source of illustrative material, and provided evidence for empirical research. Oral speech, despite its diversity and functional importance, was virtually ignored by scholars of language, and results obtained from analyses of writing were automatically extrapolated to speech and to language in general, as though written and oral language were qualitatively isomorphic and functionally identical. It was not until the early 20th century, that linguistics made a turn to focus on oral speech (Hudyakov, 2005).

With the advent of structural linguistics (Saussure, 1916), researchers started accounting for the differences between writing and speaking (Chafe & Tannen, 1987). Arguably, the most important functional difference is that writing is much less spontaneous than speech. The writer would re-read his or her draft and make multiple revisions before the final version of the text would reach the reader. The absence of an immediate feedback channel in writing, the mismatch between the author and the narrator characteristic of many written genres, and the frequent inability of the reader to

decode the writer's true intention reliably has urged some researchers to deprive written texts of the very status of communication (Dixon & Bortollusi, 2001).

It is not surprising, therefore, that the emerging phenomenon of spontaneous writing in computer-mediated communication (CMC) immediately attracted the attention of researchers in discourse studies and pragmatics (Blyth, 2013; Hård af Segerstad, 2002; Lipinski-Harten & Tafarodi, 2012), who showed that CMC is an effective means of communication with a level of spontaneity reaching that of oral speech. Moreover, despite its written medium, spontaneous CMC was found to be much closer to oral communication than to written composition in terms of its rhetorical organization and functions; as a result, it was claimed that CMC had a hybrid "oral-written" status (Galjashina, 2003; Litnevskaja & Baklanova, 2005; Spitzmüller, 2005; Vojskunsij, 1991), which Day, Crump, & Rickly (1996) conceptualized in terms of Ong's (1982) framework of secondary orality.

The debate about the status of CMC in relation to speech and writing may be resolved by looking at two independent dimensions of communication that are not immediately connected with the physical medium: (1) spontaneity; (2) synchronicity.

Spontaneity characterizes communication, wherein the production of linguistic signals occurs concurrently with the ongoing process of language generation (Goldman-Eisler, 1968; Vereshchagin, 1968). Opposite to spontaneity is preparedness, which involves the use of drafts, or intermediary linguistic products (Lobok, 1996), that may be created orally, mentally (in internal speech), or in writing (Galjashina, 2003; Luria, 2002) and then revised before the message is finalized and transmitted to the recipient. While oral speech demonstrates a much stronger tendency of spontaneous production than writing, both of these modes may be marked by different levels of spontaneity or preparedness (cf. Herrmann & Grabowski, 1995).

The dimension of *synchronicity* is described in terms of two features (Hård af Segerstad, 2002): cotemporality (i.e., when the receiver receives the messages at roughly the same time as they are produced) and simultaneity (i.e., when the interlocutors can send and receive messages at once and simultaneously, e.g., when a hearer smiles as a speaker speaks). When both features are present in a mode of communication, it is said to be fully synchronous; if neither of the features is present, the communication is said to be asynchronous; if cotemporality is present, but not simultaneity, the communication is said to be quasi-synchronous (Dürscheid, 2003; Hård af Segerstad, 2002). Although higher synchronicity tends to lead to higher spontaneity, synchronous prepared communication (e.g., lectures), as well as asynchronous spontaneous communication (e.g., voicemail) do exist and are quite productive (Chukharev, 2007).

Based on the above, we believe that granting a special "hybrid status between orality and literacy" to spontaneous CMC would lead to unnecessary terminological complications (cf. Koch & Oesterreicher, 1985), and it is both simpler and safer to distinguish between written and oral communication just on the basis of their physical modality, as suggested by the terms themselves. It is also evident that different types of

CMC (such as email, chats, blogs, etc.) exhibit different levels of spontaneity and synchronicity.

The property of spontaneity has long been central to studies in psycholinguistics (Herrmann & Grabowski, 1995; Vereshchagin, 1968), forensic linguistics (Galjashina, 2003) and applied linguistics (Vermeer, 2000). Understandably, most studies have focused on oral spontaneous speech. Researchers' attention has been drawn to observable features of spontaneity, especially filled and unfilled pauses marking speaker's hesitation (Adell, Escudero, & Bonafonte, 2012; Boomer, 1965; Boomer & Dittmann, 1962; Hawkins, 1971), which can be studied to gain insights into the underlying psycholinguistic mechanisms of speech production. In her landmark work on spontaneous speech, Goldman-Eisler (1968) treated pauses as a manifestation of the more general blocking of activity which occurs when organisms are confronted with situations of uncertainty, and when taking the next step requires a choice. Spontaneous speakers keep making three kinds of choices while producing utterances: a) content decisions, which can be either completely non-verbal or tied to key words standing out as semantic landmarks without any syntagmatic ties; b) syntactic choices, which are crucial for any kind of coherent speech; c) lexical choices, that is selecting words to fit the syntactic framework in accordance with the semantic plan. It has been shown that all three types of choices made in the course of spontaneous speech must be accompanied by an arrest of the speech objectification process (i.e., by pausing).

In writing research, pauses have also been "assumed to provide us with a window to the cognitive processes underlying language production" (Wengelin, 2006, p. 108). However, disfluencies in traditional prepared writing have been explained in terms of planning and revisions (Spelman Miller, 2006), processes that are distinct from those in spontaneous communication (Garmash, 1999; Hudyakov, 2000; Hudyakov & Chukharev, 2010; Van Waes & Schellens, 2003). This distinction once again suggests the need for analysis of spontaneous writing: it is important to establish the kinds of disfluencies in spontaneous versus prepared writing that may help unveil the underlying cognitive processes. In this context, it is important to note that repairs in spontaneous speech are accomplished synchronously and are observed by the recipient, while revisions in writing tend to be more complex, may involve restructuring of the text, and almost always rely on drafts (Lobok, 1996; Luria, 2002). While repairs are treated as signals of spontaneity (Garmash, 1999; Goldman-Eisler, 1968), revisions are thought to manifest the construct of preparedness (Galjashina, 2003; Luria, 2002). Therefore, it is not entirely clear if editing behavior in chat should be treated as revisions or repairs.

Another reason why CMC is an appealing focus for research into spontaneous discourse is because it does not require transcription. However accurate it may be, transcription of oral speech inevitably fails to render every detail of intonation or capture non-verbal cues with complete precision. A log of a chat conversation, on the contrary, contains all information that was actually exchanged by the interlocutors in the course of conversation in a machine-readable form suitable for quantitative analysis. On the other hand, the quasi-synchronous nature of chats implies that,

although the sender is likely to pause while typing the message, these pauses will remain unseen by both the recipient and the meta-observer studying the raw message logs (Beißwenger, 2003). Therefore, the only way to detect pauses in chat conversations is by observing how participants produce their messages via keyboard typing. In the following section, we will discuss methods of collecting and analyzing this kind of data.

1.2 Keystroke Logging

Investigating how the process of keyboard typing unfolds in time has long been of scientific interest (Dvorak, Merrick, Dealey, & Ford, 1936; Gentner, 1983; Rumelhart & Norman, 1982; Sullivan & Lindgren, 2006; Viviani & Laissard, 1996), with motion photography and keystroke logging as the main methods of data collection. With the advent of affordable personal computers keystroke logging has become the most practical method, its applications ranging from biometric identification (Bergadano, Gunetti, & Picardi, 2002; Gunetti & Picardi, 2005; Guven & Sogukpinar, 2003) to research in psychology and linguistics. It is important to note that keystroke logging is a non-invasive data collection method which can be used in naturalistic settings.

In a detailed review, Nottbusch (2010) notes two well-established and distinct strands of keystroke logging research: single word studies and typewritten composition. In most single word studies, participants react to carefully crafted stimuli by typing words on a computer keyboard in a controlled environment. In such studies, all inter-key intervals (IKIs), or the times between pairs of successive keystrokes, are recorded and analyzed to unveil their motor and linguistic determinants, such as keyboard skills (Grabowski, 2008; Wengelin, 2006), individual typing styles (Güven & Sogukpinar, 2003), digraph frequencies (Gentner, 1983), as well as morpheme and syllable boundaries (Weingarten, Nottbusch, & Will, 2004).

In composition studies, on the other hand, higher-level analyses are performed, which disregard individual differences in motor performance, and only consider IKIs above a specific threshold (typically 1–2 seconds) as pauses that separate bursts of writing activity (Alves, Castro, de Sousa, & Stromqvist, 2007; Olive, Alves, & Castro, 2009; Van Waes & Schellens, 2003). Once bursts and pauses are identified, they are analyzed, for instance, to explore the effects of micro- and macro-contexts on pauses (Wengelin, 2006), or to identify writing styles (Tillema, van den Bergh, Rijlaarsdam, & Sanders, 2011).

There have not been many attempts to bridge the gap between these two “worlds” of keystroke logging research. For one, Nottbusch (2010) investigated sentence production in a study that combined the controllability of single word typing with complex syntactic structures participants were prompted to produce. However, to date researchers have not conducted analyses of keystroke patterns in spontaneous text-based conversations, which is surprising given the popularity of spontaneous CMC. Indeed, if each keystroke is recorded along with a precise timestamp when the key was depressed, released, or both, pauses may be identified as prolonged IKIs. Unlike

composition studies, where it is safe to establish a (somewhat arbitrary) cut-off value for pauses, the spontaneous nature of chats calls for more detailed statistical analyses of individual IKIs, similar to those carried out in single-word studies.

Once pauses are identified, the next task that is undertaken in keystroke logging research is to interpret the pauses in relation to the linguistic structures or discourse moves with which they are associated. In the next section, we will focus on the approaches to interpreting the locations of pauses within the text.

1.3 Interpretation of Pause Locations

Pausological research of written language production has focused on quantifying the frequencies of pauses at various linguistically relevant locations. Such locations have been primarily defined in terms of surface-level and grammatical features, such as paragraphs, sentences, T-units, clauses, and phrases (Spelman Miller, 2006). However, research on Russian spoken colloquial discourse demonstrates that syntactic segments (e.g., clauses or T-units) may be challenging to identify due to the heavy use of simplified and incomplete syntactic structures (Kibrik, 2003; Lapteva, 1976). Kibrik and Podlesskaya (2009) proposed the use of prosodic and semantic cues to improve the reliability of segmentation when incomplete or ambiguous syntactic structures are encountered. As we will see below, similar issues arise during segmentation of chat messages.

To overcome such challenges, we adopt Hudyakov's (2000) functional framework of *sentential semiosis* which established theoretical grounds for reliable semantics-based segmentation of discourse. The framework emphasizes the central role of situations (i.e., acts, events, states of affairs, etc.) in the human perception, conceptualization and categorization of the world. Linguistically, situations are signified (named) by *propositional expressions (PEs)*, which are theorized to be the main constituents of the discourse. The prototypical (i.e., the most common) embodiment of the PE in real language data is the clause (cf. Kibrik & Podlesskaya, 2009; Thompson & Couper-Kuhlen, 2005); however, there are other means of naming situations, including propositional nouns, also called "event names" (e.g., *war*, *attack*, etc.), and other similar non-predicative units. The local structure of a discourse, then, comprises units of two types: PEs, such as clauses, propositional noun phrases, etc., and extra-propositional discourse operators (cf. Polanyi, 2003). The latter do not denote any situations per se, but rather they establish coherence of the discourse or contribute additional senses to the utterance.

As functionally defined units, PEs may or may not correspond to the surface syntactic structure of the sentence. Additionally, the notional predicate, or "vertex," of a PE may or may not coincide with the syntactic predicate of the clause. Specifically, in Slavonic languages the verb is frequently delexicalized (Hajrov, 1985), and a noun assumes the role of the semantic center (vertex) of the PE.

Let us consider the following utterances taken from our corpus of chat communication (see "Materials and Methods" below for details).

(CG-17:15)	совершенно	верно	:)	за	исключением	последних	минут	10
	soveršenno	verno	:	za	iskl'učenijem	poslednix	minut	10
	absolutely	right	:	except for		the last	minutes	10
	'you are absolutely right :) except for the last 10 minutes or so'							

From the formal viewpoint, utterance (CG-17:15) contains two unrelated noun phrases, which do not form a clause. From the functional point of view, however, the utterance contains two distinct PEs: (1) "you are absolutely right" and (2) "[I haven't watched the game] except for the last 10 minutes or so." Neither of the PEs contains an explicit vertex.

(CG-17:126)	что	еще	неустойчивое	-	меняет*	направление
	čto	eščë	neustojčivoje		men'ajet	napravl'enije
	what	else	unstable		changes	direction
	'what else can be unstable? changing direction?'					

Utterance (CG-17:126) is, too, syntactically incomplete. If we treat this utterance as an ellipsis and attempt at reconstructing the full syntactic structure by inserting the "missing" words, depending on the choices we make, the result may be a single clause, or a clause with an embedded clause, or two independent clauses. Semantically, the utterance contains two PEs (marked with rectangles), because it describes two situations. The second PE has an explicit vertex (marked with *).

An important reason why Hudyakov's theoretical framework is especially relevant for our purposes is that it accounts for the temporal factor in sentence production. Motivated by the speaker's communicative intention, units of knowledge about the linguistic system and the extra-linguistic world are retrieved and activated in operational memory, followed by a sequence of mental operations leading to the creation of a proposition and the linearization of the same into the final linguistic output (Hudyakov, 2000). Specifically, the model of sentential semiosis predicts that producing the vertex would require greater cognitive load as compared to other parts of the PE.

In summing up, we note that spontaneous CMC has not been studied from the temporal perspective, although a number of factors indicate the need to investigate temporal aspects of spontaneous CMC. First of all, disfluencies in spontaneous oral speech proved to be a valuable source of indirect data about covert mental processes; by analogy, the study of pauses in spontaneous written conversations should be able to contribute to the study of cognitive processes in writing. Secondly, keystroke logging is a well-established procedure that allows for the collection of data in naturalistic

settings, where spontaneous speech is especially productive. Thirdly, although identifying syntactic constituents in spontaneous conversations is challenging, functional approaches to language study allow for meaning-based identification of discourse constituents. Finally, discourse constituents are predicted to be associated with hesitation disfluencies, and empirical data may therefore either support or refute the corresponding theoretical models.

To articulate specific research questions for the present paper, we turn to Wengelin's (2006) review of the theory and methods of research into the temporal aspects of written text production, which she concluded by outlining three important aspects of pausing in writing that need further investigation: (1) What is a pause in writing? (2) How does the pause behavior interact with the genre of the writing task? (3) What is the writer doing during the pause? With the exception of the second aspect (as it involves comparing different genres of writing, and thus falls outside of the scope of the present paper), the remaining two create a framework for our **research questions**:

1. What constitutes a pause in spontaneous CMC-based writing?
2. How are pauses in spontaneous CMC associated with linguistically relevant units, such as tokens and PEs, and what does this association tell us about mental processes that occur while the typing is paused?

In the rest of the paper, we describe how these questions were addressed in an empirical study focusing on spontaneous CMC in a text-based web chat. Native speakers of Russian communicated in a highly engaging and naturalistic multi-party web chat environment, during which all of their IKIs were recorded in a log for further analysis. After describing our data collection and analysis methods, we will conclude the paper by discussing our findings in respect to the research questions.

2. Materials and Methods

2.1 Data Collection Instrument

To preserve the naturalistic setting of the present study, we decided against using a stand-alone key-logging software program, such as InputLog (Leijten & Van Waes, 2013); instead, we developed a web chat application with built-in keystroke logging capabilities. The application allowed participants to hold multi-party conversations in chatrooms, as well as send private messages to one another (Figure 1). At the top of the screen, the current time (left) and the chatroom name (center) are displayed, followed by the "Help" and "Exit the room" links (right). Below, the chat log is shown (left) next to a list of all participants in the chatroom (right). The text box in the bottom part of the screen is where participants type their messages. The two buttons on the right-hand side of the input box are "Say" (used to send a message) and "Clear" (used to clear the input box and start composing a new message). Logs of all conversations were kept on the

server, and at any time participants could retrieve logs of the messages they had received while chatting on-line.

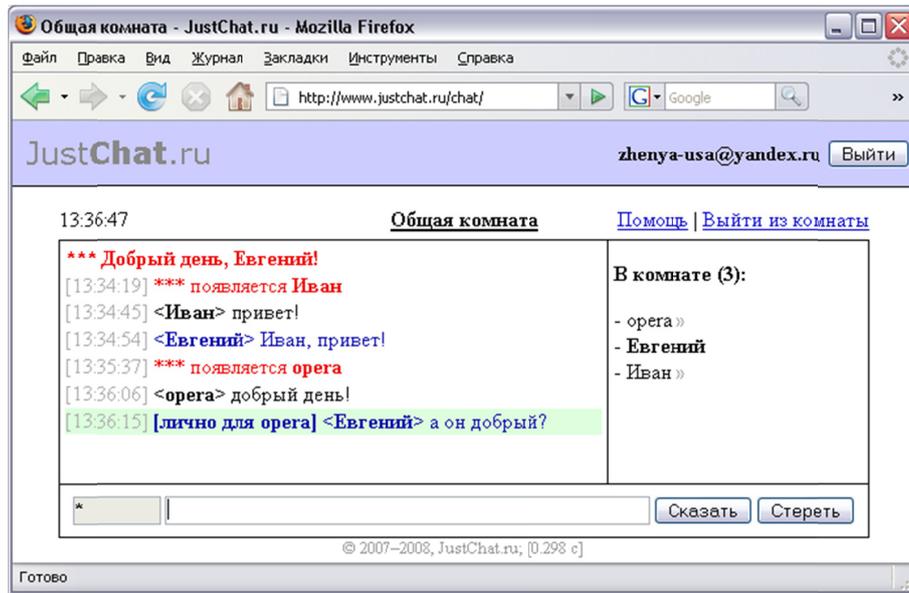


Figure 1: Web chat interface.

The chat application detected users' keystrokes while typing by establishing JavaScript handlers for the "keydown" and "keypress" events. The "keydown" event is triggered by the browser when the key is depressed, and "keypress" is triggered when an actual character is being inserted in a text string. When either of these events occurred, the event handler obtained a local timestamp calculated the IKI as the time that elapsed since the previous timestamp. To avoid double processing of events, and also for the sake of simplicity and cross-browser compatibility, the effect made by a keystroke on a message string was determined by performing a minimal-edit distance comparison of the strings before and after the keystroke occurred. This approach helped avoid tracking of caret position. The timings when the users released the depressed keys were not recorded, nor were mouse movements and clicks.

For the sake of illustration, let us consider message that was issued by a participant shortly on joining the chat room:

(CD-02:34) Вечер!
 V'ečer!
 Evening!

As it is evident from the keystroke log (see Table 1), the participant started with the letter *Д* (one could guess that the original intention may have been to type *Добрый вечер!* ‘Good Evening!’), then removed it, and typed the final message. Keystroke logs were sent to the server stored in the database along with the final message text.

Table 1. Key-Stroke Log Obtained While Typing Message CD-02:34.

IKI, ms	Event	Symbol	Resulting String (not sent to server)
—	symbol added	Д	Д
367	symbol removed	—	—
343	symbol added	В	В
253	symbol added	е	Ве
284	symbol added	ч	Веч
243	symbol added	е	Вече
54	symbol added	р	Вечер
473	symbol added	!	Вечер!

While JavaScript provides timestamps with a resolution of 1 ms, it is important to note that the precision of timing was not assessed in the present study. It has been shown that the temporal accuracy of keystroke logging depends on the programmatic approach used in the key-logging software (Frid, Wengelin, Johansson, & Johansson, 2012). Moreover, JavaScript code works within a single execution thread running an event loop, and time may pass between the moment when a keyboard event is generated and queued, and the moment when the event handler is invoked. In the general case of a complex JavaScript application, this time will depend on the performance of the user’s hardware, and, possibly, other factors, such as the operating system and the browser. To address this problem, one could employ the procedure introduced by Frid, Wengelin, Johansson and Johansson (2012), who recorded the clicking sounds of the keys as the gold standard for evaluating the precision and accuracy of timing in key-logging software. This procedure would have allowed accounting for the measurement error, but would have had to be carried out on each user’s computer, which was not practical in our setting.

When signing up for an account on the chat website, each user was required to accept a user agreement that contained a provision granting an explicit permission to use any information gathered during their communication in the chat for the purposes of the present research. Therefore, all chat users were automatically enrolled in the data collection process.¹

2.2 Task

To facilitate naturalistic task-oriented conversations, the chat application was used to hold practice sessions of an intellectual game called “What? Where? When?”

There are two versions of this game. The original version is a popular show that has been on Russian television since 1975 (Andreeva, 2009). In the show, a team of six players called “experts” or “knowledgeable people” are posed questions sent in by viewers. The team is given one minute to discuss each question, and then the captain announces the team’s final answer. The person who sent in the question earns a prize if the team fails to answer the question correctly, while the team earns points if they manage to get the correct answer. The sports (or competitive) version of the game was invented by fans of the TV show so that more people could play the game without having to take part in the show. In the sports version, several teams compete in finding answers to the questions, which are posed to all teams at the same time.

To answer the questions correctly, no special knowledge is usually required, but rather common sense along with logical reasoning skills, insight, and intuition. Collaboration and teamwork are known to be the key success factors in this game (Potashev, 2005). For the sake of illustration, consider these sample questions translated from Knop (2010):

Margaret Thatcher believes that no one would remember the Good Samaritan if he’d only had good intentions. What else, according to the “Iron Lady,” did he have to have? (*Correct answer: The money, to give to the man in need.*)

What color is the longest line on the map of the London Underground? (*Correct answer: Blue. It is the River Thames.*)

The games held in the chat application were based on the sports version of “What? Where? When?,” but differed in that the team players’ communication was confined to the chat environment, the time limit was increased from one to four minutes per question, and the number of players on a team was unlimited. Questions for each game session were randomly drawn from Knop (2010).

The multi-room feature of the chat enabled several teams to play the game at the same time. Each of the teams occupied a separate chatroom, where they could discuss the questions in private. Questions were posed to the teams through chatbots, one per room, impersonating the show host. One player on each team was chosen to be the team captain. After a team had finished discussing a question, it was the captain’s responsibility to formulate the final answer and send it to the chatbot, which then announced both the correct answer and whether the team’s answer was accepted as correct. Since the answers could be worded in different ways, a human operator was employed to judge the answers behind the scenes in real time. Teams that succeeded in answering a question were awarded one point each, and the winning team was the one having earned the most points by the end of the game.

After the game was over, the team chatrooms were closed and all players were automatically transferred to a common chatroom where they could discuss the game or just enjoy casual chat.

2.3 Participants and Dataset

Participants were recruited through convenience sampling. Invitations to join the games were posted on “What? Where? When?” fan forums and sent to people via email. A total of 34 games were held. Forty-seven chat sessions in the team chatrooms and 39 sessions in the common chatroom (where all players met before or after the games) were recorded, resulting in an initial corpus of 22,501 chat messages (contributions) overall.

To reduce the size of the corpus while keeping it representative, the following procedure was followed.

Step 1. Participants who produced fewer than 10 messages were excluded from the study.

Step 2. For each participant who was retained after Step 1 and produced fewer than 100 messages, all sessions taken part in were flagged to be retained in the corpus.

Step 3. If deleting a session from the corpus would cause the number of remaining messages produced by at least one participant (retained after Steps 1 and 2) to fall below 100, the session flagged to be retained in the corpus.

Step 4. Chat sessions not flagged in Steps 2 and 3 were deleted from the corpus.

Following this procedure, the corpus shrank by 48.8%. Twenty-five team chatroom sessions and 18 common chatroom sessions were retained in the corpus, containing a total of 11,518 messages and over 68,000 tokens produced by 36 participants.

Demographic data were collected through a questionnaire administered at sign-up. Fourteen out of 36 participants (39%) were female. All participants were native Russian speakers, their mean age was 23.8 years ($SD = 3.9$, range 17–38), and their computer experience averaged at 3.4 years ($SD = 3.7$, range 1–18). Ten participants (28%) identified themselves as computer professionals, 12 (33%) were college students (including 5 students of computer science or computer engineering), 14 (39%) were home or office computer users. Based on the questionnaire, only 8 out of 36 participants (22%) touch typed, others were keyboard gazers. Twenty-two (61%) reported using chats or instant messengers on a daily basis. The typing rate averaged 110 keystrokes per minute ($SD = 52$) across participants.

2.4 Corpus Annotation

The corpus was automatically split into tokens (i.e., words, strings of punctuation characters, strings of digits, emoticons, and electronic addresses) using a tokenization program developed by the author and based on a set of regular expressions used to identify token boundaries. Spaces were treated as part of the immediately preceding

tokens. Punctuation characters were treated as separate tokens. Each token was assigned a label identifying the token sub-type (e.g., Cyrillic word, emoticon, etc.).

Manual annotation of PEs was performed on the corpus by four independent coders, who were familiar with the underlying theoretical framework (Hudjakov, 2000). For each chat message, the coders were asked to mark the boundaries of every segment which constituted a separate PE (i.e., denoted a single extra-linguistic situation, such as an event or a state of affairs). Within each PE, the coders further identified the vertex (or root) token, which, in their opinion, served as the surface-level linguistic expression of the notional predicate in the corresponding mental proposition. Krippendorff's α (Hayes & Krippendorff, 2007; Krippendorff, 2007) was used as a measure of inter-coder reliability. For the purposes of calculating α , the PE identification task was treated as nominal categorization of tokens, with a distinct category label assigned to every PE in a chat message; the vertex identification task was treated as a binary decision (vertex/non-vertex) that was made for every token. For these two tasks, respectively, $\alpha_{\text{nominal}} = .79$, $\alpha_{\text{binary}} = .84$. These values are interpreted as excellent reliability (Strijbos & Stahl, 2007).

2.5 Data Analysis

Because of variation in typing proficiency and keyboarding style between individuals (Wengelin, 2006), the IKIs could not be treated as independent observations; instead, they were nested within participants. The distribution of messages across participants was very uneven. The top five users of the chat produced as many as 58.1% of all messages, while the bottom nine produced fewer than 100 messages each. To make balanced judgments from the data, analyses were conducted either separately for each of the participants, or after two-stage resampling of the dataset.

All analyses were performed with programs in R and Perl written by the author (see also description on WritingPro.eu). Firstly, keystroke data were filtered to eliminate editing. Although the setting of a time-limited game with teams encouraged participants to minimize revisions in their messages, the chat interface did not eliminate the possibility of editing entered messages before sending them. The decision to exclude editing behavior from the present analysis was motivated by both the theoretical ambiguity of editing in chat in terms of the revisions/repairs dichotomy (see "Spontaneous Writing") and the practical intent of limiting the corpus annotation efforts: all annotation was performed on the final versions of user messages only, without regard to any editing that might have taken place prior to sending the message. Specifically, we excluded keystrokes made to insert characters into the middle of the string (rather than append them to the end of the string), "Backspace" and "Delete" keys used to remove portions of the string, and keys pressed immediately after "Backspace" or "Delete." Also discarded from the data were utterance-initial IKIs and those occurring after the input textbox had lost and regained keyboard focus (participant switching to another window).

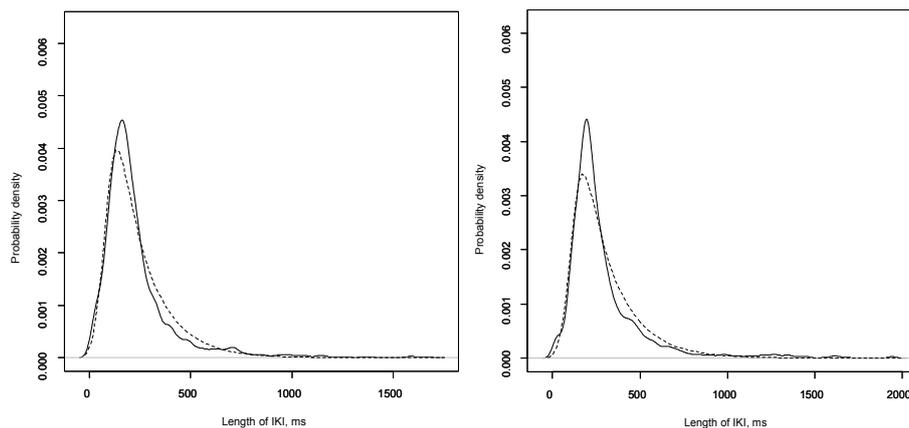
Secondly, the observed IKI distributions were described in terms of parametric statistics and fitted with relevant theoretical distribution laws, and an interpretation of the distribution parameters was attempted to provide for a statistically-grounded definition of “pause” in spontaneous writing (Research Question 1).

Thirdly, the locations of pauses were analyzed in relation to discourse structure constituents. Since the model of sentential semiosis (Hudyakov, 2000) stipulates that discourse structure reflects the psycholinguistic processes of utterance production, we made inferences about the mental processes that occurred during the pauses on the basis of the location of such pauses in the local discourse structure (Research Question 2).

3. Results and Discussion

3.1 Distribution of Individual IKIs

Typical distributions of individual IKIs are shown in Figure 2 (solid lines).



- a) Solid line – empirical distribution of IKIs produced by Participant #7 (N = 37,002); dashed line – ex-Gaussian distribution ($\mu = 92$; $\sigma = 45$; $\tau = 249$)²
- b) Solid line – empirical distribution of IKIs produced by Participant #14 (N = 1,824); dashed line – ex-Gaussian distribution ($\mu = 72$; $\sigma = 41$; $\tau = 192$)

Figure 2: Probability density functions for empirical and theoretical distributions of IKIs.

Notably, this shape is very similar to that of reaction-time distributions (Dawson, 1988; Palmer, Horowitz, Torralba, & Wolfe, 2011; Van Zandt, 2002). Reaction time (RT) has a long history in psychology as a common dependent measures in experimental studies of cognition and perception (Hohle, 1965; Luce, 1986). Typically, RTs are obtained in

speeded binary or multiple-choice tasks, where participants need to make decisions about each of the presented stimuli. An example relevant to linguistics is the Lexical Decision Task (e.g., Katz et al., 2012).

RTs have been shown to consist of two independent components, or stages: the time taken to decide upon a response (decision component) and the time to perceive the stimulus and physically make the response (transduction component) (Dawson, 1988). It has been argued that the duration of the transduction component is distributed normally, since it summarizes a large number of different sub-stages; the decision stage, in contrast, follows the shape of the exponential distribution law (Botwinick & Thompson, 1966; Hohle, 1965).

A sum of two independent random variables $Z = X + Y$, where X is distributed normally with the mean of μ and standard deviation of σ , and Y is distributed exponentially with the scale of τ , is described by an exponentially modified Gaussian distribution, also known as an ex-Gaussian distribution (Matzke & Wagenmakers, 2009). An ex-Gaussian equation was found to fit empirical RT distributions very well (Dawson, 1988; Van Zandt, 2000). The probability density function of the ex-Gaussian distribution is given by

$$f(x | \mu, \sigma, \tau) = \frac{1}{\tau\sqrt{2\pi}} \exp\left(\frac{\sigma^2}{2\tau^2} - \frac{x - \mu}{\tau}\right) \cdot \int_{-\infty}^{\frac{x - \mu - \sigma}{\tau}} \exp\left(\frac{-y^2}{2}\right) dy \quad (1)$$

and its mean and variance are

$$E(x) = \mu + \tau \quad (2)$$

and

$$\text{Var}(x) = \sigma^2 + \tau^2. \quad (3)$$

Roughly, μ and σ reflect the leading edge of the distribution (the Gaussian component), while τ describes the right asymmetric tail (the exponential component).

One way to explain the apparent similarities between the distribution shapes of RTs and IKIs is by assuming that there are two components contributing to IKI durations, namely, motor execution time (which is similar to the transduction stage of RT in that it is determined by perceptual and motor performance) and linguistic hesitation latency (which constitutes the decision stage of a pause). This assumption is in line with Rumelhart and Norman's (1982) model of skilled typing, which has been successfully applied to a number of studies (e. g. Logan, 2003). According to this model, a complex mechanism of motor schemata coordinating simultaneous movements of several fingers is employed to shorten IKIs in fluent typists. Hesitation terminates this mechanism, and when typing is resumed, additional time is required to prepare and begin executing a new motor program. This time, together with the duration of the pause per se (when the writer makes a linguistic choice), constitutes the observed interval between consecutive keystrokes.

Because the observed IKIs were nested within participants, the complete dataset was split into $N = 36$ subsets, one for each of the participants, which were treated separately for the purposes of fitting the data with the ex-Gaussian equation. A separate vector of ex-Gaussian parameters was obtained for each of the subsets (i.e., for each of the participants individually). The parameters (μ , σ , and τ) were estimated by the method of maximum likelihood with Nelder-Mead optimization, using Massidda's (2013) package for R. Ex-Gaussian distributions fit to empirical data for two participants are presented in Figure 2.

After all parameter vectors (each describing the within-subject ex-Gaussian distribution of IKIs for a particular participant) were obtained, they were summarized across all participants with descriptive statistics. No assumptions were made about the distribution of the ex-Gaussian parameter values between participants. The results are presented in Table 2.

Table 2. Ex-Gaussian Distribution Parameters for IKIs (in ms).

Parameter (within-participant)	Distribution of parameter across participants			
	min	max	mean	SD
Mean of the Gaussian component (μ)	46.09	189.30	99.35	36.22
SD of the Gaussian component (σ)	23.62	103.96	41.58	15.59
Scale of the exponential component (τ)	156.12	549.17	267.71	81.50
Estimated pause threshold (t_{pause})	357.51	810.28	491.79	119.36

A long-standing debate in the RT literature focuses on the psychological interpretation of the ex-Gaussian distribution parameters μ , σ , and τ . Some researchers have argued that changes in the parameters correspond to changes in specific cognitive processes (Balota & Spieler, 1999; Hohle, 1965; Kieffaber et al., 2006). Other studies have shown that the parameters may not map onto the properties of underlying hypothetical models of cognition (Heathcote, Popiel, & Mewhort, 1991; Matzke & Wagenmakers, 2009). One particularly strong point against any psychological interpretation of the ex-Gaussian distribution is that “the Gaussian component necessarily assigns positive probability to negative RTs” (Matzke & Wagenmakers, 2009, p. 800), which poses a problem because RTs, by definition, cannot be negative. IKI distributions, however, may allow for sensible interpretation of “negative IKIs” as “metathesis typos,” i.e. instances when two sequential letters are mistakenly swapped due to an error in motor execution (cf. Gentner, 1983), resulting in a “negative” interval between them. Based

on the ex-Gaussian distribution parameters presented in Table 1, such “negative” intervals would constitute a proportion of .84% (Z-score = 2.39, one-tailed).

Manual correction of orthographic errors on the token level was undertaken by two independent coders ($\alpha_{\text{nominal}} = .84$, “excellent reliability”). On average across participants, 6.5% (SD = 4.0) of tokens were found to be misspelled. Two kinds of “metathesis typos” were identified: in 9.0% (SD = 5.7) of all misspelled tokens, the “Space” key was pressed at the wrong moment, resulting in incorrect token boundaries; in 5.1% (SD = 4.3) cases, two consecutive letters were typed in the wrong order. Thus, .91% of all tokens (weighed by participant contributions) were marked as “metathesis typos.” At the average of 4.62 letters per token, this translates into an estimated .20% of “negative” IKIs. This estimate is lower than the .84% predicted with the ex-Gaussian distribution parameters; however, it has the same order of magnitude, so it does not invalidate the proposed psycholinguistic interpretation of the ex-Gaussian distribution parameters.

Under the assumptions discussed above, if motor execution time is distributed normally with the parameters μ and σ , then pausing reflects the exponential component of the distribution. Under the “three-sigma” rule of thumb, an event is considered “practically impossible” ($p < .003$) if it lies in the region of values of the normal distribution more than three standard deviations from its mathematical expectation. In our case, it is practically impossible to explain IKIs greater than $\mu + \tau + 3\sigma$ by the variance of the Gaussian component, and so they must be attributed to the variance of the exponential component. Therefore, we propose to use the value of

$$t_{\text{pause}} = \mu + \tau + 3\sigma \quad (4)$$

as the threshold for observable pause. For practical purposes, it seems convenient to assume $t_{\text{pause}} = 500$ ms. This is not to say that IKIs *shorter* than t_{pause} are *not* associated with linguistic processing. However, if a particular observed IKI was *longer* than t_{pause} , one could assume that an amount of linguistic processing significantly exceeding the mathematical expectation took place at the particular point in writing. We notice that this threshold is lower than the cutoff of 1–2 s used in composition studies (cf. Alves et al., 2007). Also, we notice that the value of t_{pause} considerably varies across participants, in line with previous research that emphasized the effect of typing skill on the selection of the pause criteria (Grabowski, 2008; Wengelin, 2006).

3.2 Association Between IKIs and Token Boundaries

Prior research has demonstrated the effect of within-word position of the character on the preceding IKI in traditional prepared writing (Spelman Miller, 2006). One would expect to observe a similar effect in spontaneous CMC. This hypothesis was tested using the following procedure, separately for the subsets of data obtained from each participant. In this procedure, no filtering based on the pause threshold (see previous section) was implemented; instead, all IKIs were included in the analysis.

IKIs that occurred while typing each token were combined into a numerical vector X_i . Aggregate functions yielding scalar values were applied to all such vectors X_i . This way, the mean, the minimum, and the maximum IKI that occurred while typing each token were obtained. After that, all messages produced by the participant in question were randomly split into strings of consecutive characters we termed “pseudo-tokens.” We ensured that the lengths of pseudo-tokens were distributed precisely as the lengths of actual tokens in the sub-corpus of messages produced by the participant in question, but the boundaries of pseudo-tokens were established at random. The same aggregate functions were computed for pseudo-tokens and compared to those for real tokens. For each of the aggregate functions and for each of the participants, the within-participant means were obtained for tokens and pseudo-tokens. Because the values of the aggregate functions were not normally distributed (in fact, they followed ex-Gaussian distribution), we used bootstrapping as an alternative to inference based on parametric assumptions (Mooney, Duval, & Duval, 1993). Monte Carlo simulations (a technique that relies on repeated random sampling to obtain the distribution of an unknown probabilistic entity) from the empirical distributions were performed. Differences between the means were found statistically significant ($p < .001$) for all participants and for all aggregate functions. The within-participant means of the aggregate-function values are summarized across participants in Table 3.

Table 3. Aggregate-Function Values for Tokens and Pseudo-Tokens (in ms).

Aggregate Function	Distribution of aggregate-function values across participants			
	Tokens		Pseudo-Tokens	
	mean	SD	mean	SD
mean(X)	346	128	303	105
max(X)	624	245	600	233
min(X)	197	88	153	62

This finding supports the claim that the relationship between IKIs and token boundaries is not random (i.e., the position of the character within the word has a significant effect on the preceding IKI). However, at this time, we are unable to explain the fact that the values of all three aggregate functions were significantly *higher* for tokens than for pseudo-tokens, that is, the respective distributions for tokens appeared to be shifted to the right from the ones that would be expected by chance.

3.3 Association Between IKIs and PEs

The model of sentence semiosis (see “Interpretation of Pause Locations” above) suggests that the production of the vertex of a PE is likely to require more cognitive effort compared to other words in the PE. We hypothesize that increased cognitive effort will be reflected in an increased incidence of pauses associated with PE vertices.

If this hypothesis is confirmed, it would reinforce the validity of the model and contribute to answering our second research question.

As noted above (see “Corpus Annotation”), vertices were manually annotated in the dataset by four independent coders. A dataset of tokens produced by all participants was created. Every token was marked as “vertex” or “non-vertex” based on the manual annotation. For every token in the dataset, the value of the aggregate function $\max(X)$ was computed to reflect the longest IKI that occurred while typing the token. The dataset was resampled with replacement following a two-stage sampling procedure, so that data from all participants were equally represented in the resulting sample. A limitation of such resampling is that it does not allow for quantification of inter-participant variance of the variable in question.

Using values $t = 200, 300, \dots, 1,400$ as thresholds, we calculated the proportion of vertex tokens marked with IKIs exceeding the given threshold t , and the proportion on non-vertex tokens marked with IKIs exceeding the same threshold t . Two-proportion z-test was used to assess the significance of the differences between the proportions. The results are summarized in Table 4.

Table 4. Differences in Proportions of Vertex and Non-Vertex Tokens, Marked by IKIs Above a Sliding Threshold.

Threshold	Proportion of vertex tokens marked with IKI > t	Proportion of non-vertex tokens marked with IKI > t	$p_1 - p_2$	Significance
t	p_1	p_2		
200	0.967	0.938	0.029	< .01
300	0.773	0.682	0.091	< .01
400	0.612	0.527	0.085	< .01
500	0.486	0.397	0.088	< .01
600	0.379	0.309	0.070	< .01
700	0.284	0.237	0.047	< .01
800	0.207	0.185	0.022	< .01
900	0.161	0.146	0.015	< .01
1000	0.132	0.109	0.023	< .01
1100	0.113	0.097	0.015	< .01
1200	0.097	0.083	0.014	< .01
1300	0.080	0.072	0.008	ns
1400	0.062	0.063	-0.002	ns

As seen, statistically significant differences in proportions of vertex and non-vertex tokens that were marked by IKIs above a set threshold were found for thresholds up to $t = 1,200$ ms. Vertex tokens were more likely to be marked with longer IKIs, compared to non-vertex tokens, which is consistent with the theoretical assumption that vertex

tokens would require more processing. However, from $t = 1,300$ ms and up, the difference in proportions is no longer significant. This could suggest that pauses over 1.2 seconds may correspond to higher-level processing, not accounted for by the model of sentence semiosis, such as global discourse planning, conscious reasoning, or information retrieval.

4. Conclusion

In the present study, we looked at the process of spontaneous writing in light of two research questions suggested by Wengelin's (2006) overview of pausological studies: (1) What constitutes a pause in spontaneous CMC-based writing? (2) How are pauses in spontaneous CMC associated with linguistically relevant units, such as tokens and PEs, and what does this association tell us about mental processes that occur while the typing is paused?

We addressed the first question by examining statistical properties of IKI distributions, and we believe that there is evidence in favor of establishing a threshold of approximately 500 ms, so that any IKI exceeding this threshold may be treated as a marker of linguistic hesitation. Such IKIs would be rather frequent, and not every delay of 500 ms would even be consciously detected by the writer. However, since such delays cannot be explained by the variation of the Gaussian component of the IKI distribution, they are likely to manifest linguistic processing of some kind. Moreover, one can account for variation in typing skills by fitting the distribution equation to each person's individual set of IKIs and finding a personalized cut-off value for pauses.

Psycholinguistically, the question of what the writer is doing during the pause is, of course, the most interesting one. Unfortunately, this question is nearly impossible to answer by looking at key-stroke data alone. While external evidence from eye-tracking, ERP measurements, or think-aloud protocols (Wengelin, 2006) may shed some light on this question, it would entail giving up the naturalistic conditions of the present study and shifting to a laboratory setting, which we find a very exciting and promising direction for our future work. Nevertheless, based on our data, we can make a cautious claim that the duration of a pause could predict the type of mental processing that may be going on while the execution of typing is suspended. Specifically, if a pause exceeds 1.2 seconds, it may involve planning on a level beyond the scope of a single PE.

In the present paper, we have not specifically addressed one of Wengelin's (2006) items on the research agenda for pausological studies: how pause behavior is affected by the genre of the writing task. We have looked at spontaneous writing in an uncontrolled naturalistic environment, which is an important, yet understudied genre of written communication. Prior research on the linguistic properties of this genre (e.g., Beißwenger, 2003; Blyth, 2013; Hård af Segerstad, 2002; Litnevskaja & Baklanova, 2005) unveils its unique properties on all levels of the linguistic system, which render traditional approaches to the identification of text constituents less feasible. However, we have demonstrated that functional units of the local discourse structure, such as PEs

and discourse operators, can be reliably identified in chat logs by human annotators. We have also found that, consistent with Hudyakov's (2000) model of sentence semiosis, pauses are associated with such discourse units and, more specifically, PE vertices. Comparing these findings to those obtained in written composition studies constitutes a promising avenue for future research.

Another important direction for future study constitutes the analysis of editing behavior that occurs in quasi-synchronous CMC. Editing is a fundamental property of writing, and the exclusion of editing behavior is a limitation of the present study. Further research is indicated to determine the function of editing actions in chat in terms of the revision/repair dichotomy. Unlike pausing, editing is more likely to be consciously registered by the writer, and it may be possible to collect qualitative data (e.g., through stimulated recalls) about the reasons for editing.

Notes

1. As we discovered later by interviewing our participants, most had not actually read the agreement before clicking "I Agree" and thus were unaware that their communication and keystroke timings had been recorded. Those interviewed were given the option to retrospectively withdraw their data from our dataset, which they all declined.
2. Parameters μ , σ , and τ are estimated from the empirical data (solid line) by the method of maximum likelihood.

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