

Katarina Marjanovič, Christina Manouilidou
Univerza v Ljubljani

Processing of Centre-embedded and Right-branching Relative Clauses in Slovenian

1 Introduction*

The processing of relative clauses (RC) has been a reoccurring topic of interest in the last five decades of psycholinguistic research. Throughout this time, one of the most important issues of this line of research has been the difficulty of processing of centre-embedded relative clauses¹ (CE-RC; e.g., *The girl who is drinking the water hugged the mother.*), which is often addressed through the comparison to the processing of right-branching relative clauses (RB-RC; e.g., *The girl hugged the mother who is holding a flower.*). This issue is so well documented that it has led to several theories which aim towards explaining the difficulties in the processing complexity of CE-RC. However, most of the evidence these theories are based on comes from English. In the current paper we introduce a study that focuses on this aspect, and which provides evidence from Slovenian that was previously largely lacking.

1.1 Processing of centre-embedded and right-branching relative clauses

When it comes to the differences in the processing of CE-RC and RB-RC, the decades of research have led to a current consensus that CE-RC are much harder to understand than RB-RC, which typically results in longer reading times of such structures and/or accuracy of the participant's performance (in terms of, for example responses to comprehension questions, sentence recall).

So far, this finding has been confirmed both in auditory and visual modality, in a number of different paradigms, e.g., an auditory sentence comprehension task (Blauberger and Braine, 1974), free recall of auditorily presented sentences (Miller and Isard, 1964), phoneme monitoring task (Foss, 1969; Hakes and Cairns, 1970), written sentence comprehension task (Freedle and Craun, 1970; Blumenthal, 1966),

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1 Two other terms are also used to label this type of relative clause: (1) self-embedded and (2) nested relative clause.



combination of free reading of printed sentences and listening of auditorily presented sentences (Stolz, 1967), and self-paced reading paradigm (Gibson et al., 2005).

Importantly, this difference is also observed when the two structures contain the same words in the same thematic roles. This suggests that the observed complexity differences between the two cannot be assigned to the difference in the lexical or contextual information, but rather to the difference in the amount of computational resources needed to successfully process them (Gibson et al., 2005). While different proposals have been made as to what affects the processing complexity of embedded relative clauses (e.g., the interruption hypothesis² of Miller and Chomsky (1963), and see also Gibson et al. (2005) for a short overview of several proposals), one of the most influential ones is the so called dependency locality theory (DLT) (Gibson, 2000). According to DLT, the processing complexity of embedded structures depends on the distance or locality between the two dependents that are being integrated (Gibson, 1998; Gibson et al., 2005), where a larger distance introduces a heavier computational load. For example, compare the distance between the verb *hugged* and its dependent (D) in the following sentences, where 1a is an example of a CE-RC and 1b of an RB-RC:

- 1a. *The girl (D) who is drinking the water hugged the mother.*
- 1b. *The girl (D) hugged the mother who is holding a flower.*

More recently, the theory has been expanded to include two key components that contribute to the cost of the syntactic operations in humans: storage cost, quantified by the number of the incoming words or the number of predictions about the incoming words as the sentence is processed, and integration cost, representing the memory load as the incoming word is being integrated with the previously processed syntactic representation, which is sensitive to the distance between the dependent and its head (Gibson, 2000). Importantly, this theory is thought to be language-independent (Gibson, 1998, 2000), but most empirical evidence for it comes from English. However, in order to make proposals about any language processing factors, one needs to examine if the previously observed effects are in fact a result of language processing in general, or a result of characteristics of specific language (Reid and Marslen-Wilson, 2000; Frost, 2012). While some evidence is also emerging in other languages – see, for example, Gibson and Wu (2013) for Chinese, Babyonyshev and Gibson (1999) for Japanese, Grillo and Costa (2014) for Italian, Lovric (2003) for Croatian – Slovenian remains largely under-investigated in this regard.

2 Miller's interruption hypothesis (Miller and Chomsky, 1963) suggests that each nested structure (such as CE-RC) interrupts the sequential order of the clause in which it is embedded, in turn interrupting the processing of the main clause between the verb and its dependent – which is not the case in an RB-RC, where the clauses appear in a sequential order.

1.2 Previous findings from the Slovenian language

While relative clauses in Slovenian are well-described in the field of linguistics (e.g., Cazinkić, 2000; Cvetko Orešnik and Orešnik, 2009; Gabrovšek, 2019; Gabrovšek and Žele, 2019; Sovrè, 1939; Toporišič, 2004), there is to the best of our knowledge only one study on this topic in the field of psycholinguistics (Pavlič and Stepanov, 2020). The latter very recently investigated the difference between processing of CE-RC and RB-CR in a self-paced reading experiment. As the authors themselves pointed out, their results revealed an unexpected pattern – in contrast to previous research in other languages, the observed reading times were longer in RB-RC than in CE-RC (see Table 1 for example sentences from Pavlič and Stepanov, 2020).

Table 1: Examples of a centre-embedded relative clause (CE-RC) and right-branching relative clause (RB-RC) as they appear in Pavlič and Stepanov (2020).

CE-RC	Policist, ki je oviral motorista na odstavnem pasu, je prezrl taksista. The policeman who was blocking the motorcyclist in the emergency lane overlooked the taxi driver.
RB-RC	Policist je prezrl taksista, ki je oviral motorist na odstavnem pasu. The policeman overlooked the taxi driver who was blocking the motorcyclist in the emergency lane.

The same pattern unexpectedly also emerged in the accuracy of the participant's responses to comprehension questions – the accuracy was lower in response to questions about sentences with RB-RC compared to the ones with CE-RC. The authors comment that this unexpected result could be due to the ambiguity which results from the availability of a competitive parse based on the pseudo-relative structure, a phenomenon that has previously been reported in Italian (Grillo and Costa, 2014). In other words, when both the subject and the object have an identical gender and number (see Table 1 and Table 2 a. for example as it appears in Pavlič and Stepanov (2020)), this leads to a temporary ambiguity which results in later resolution and consequently longer reading times when the relative clause is right-branching rather than an unambiguous centre-embedded structure (Pavlič and Stepanov, 2020).

Table 2: Examples of relative clauses in which subject (“policist”, in a., and “tisti policist”, in b.) and object (“taksista”, in both a. and b.) have different cases, but identical gender and number (i.e., masculine, singular), as they appear in Pavlič and Stepanov (2020). Note: text in italics denotes the relative clause, while text in boldm denotes the subject/object that can be interpreted as the agent of the relative clause.

a.	Policist je prezrl taksista , <i>ki je oviral motorista na odstavnem pasu.</i> The policeman overlooked the taxi driver <i>who was blocking the motorcyclist in the emergency lane.</i>
b.	Tisti policist je prezrl taksista, <i>ki je oviral motorista na odstavnem pasu.</i> That policeman overlooked the taxi driver <i>who was blocking the motorcyclist in the emergency lane.</i>

However, as Pavlič and Stepanov (2020) point out, it intuitively seems that this kind of pseudo-relative structure is not possible in Slovenian (i.e., in the given example – see Table 2 a. for example – a sentence interpretation where the policeman is the one blocking the motorcyclist in the emergency lane rather than the taxi driver) does not readily become available to a native Slovenian speaker. However, if the determiner *tisti*, “that” is added at the beginning of the main clause (see Table 2 b. for example), the alternative interpretation becomes possible. The authors thus conclude that the pseudo-relative structure in Slovenian might be possible, leading to a temporary ambiguity in their sentences – which is resolved by the principle of late closure (Frazier and Fodor, 1978), and leads to longer reading times of the RB-RC. While this interpretation is of course plausible, the authors themselves pointed out that more research in Slovenian is needed before any firmer conclusions could be made.

1.3 Self-paced reading task and its drawbacks

It should be noted that the evidence from Pavlič and Stepanov (2020) comes from a self-paced reading (SPR) task. While this is a well-established and commonly used paradigm, which was first introduced in the early 1980s (Just et al., 1982) and has been widely used ever since, it also differs from the natural reading experience of a skilled reader in a number of ways. In the SPR paradigm, the individual words of a given sentence are presented one by one in the middle of a screen, while the participants are allowed to control the presentation duration of each word by pressing a button when they are ready to move on from the currently read word to the next word of the sentence (thus, reading is seen as *self-paced*). The rationale behind this paradigm

is that the latencies of the button presses, which serve as a proxy to reading times of a given word, depend on the properties of that word and correlate with the online processing during reading (Just et al., 1982). However, this kind of experimental setup presents an unnatural reading experience, which could potentially have uncontrolled effects on the observed effects. The most important difference between SPR and natural reading is that in the SPR paradigms the reader has no other choice but to read each word, from the first word of the sentence to the last one, in their sequential order. This differs importantly from the normal reading process, during which the reader freely determines not only how long each word will be read, but also which word will be given the attention next. This is important, as we now know that we typically do not read in a strictly serial manner (Marjanovič et al., 2022): we tend to focus our attention on some words more than once, while others do not receive our immediate attention at all (i.e., are skipped), we frequently return back to previously read words in a sentence, and, to a certain extent, we prepossess upcoming words in our parafoveal vision (see e.g., Dimigen et al., 2011; Metzner et al., 2017; Degno et al., 2019; Rayner and Reichle, 2010; Snell et al., 2018). All this is of course not possible in an SPR task, and could have uncontrolled effects on the reading process observed in such paradigms. Moreover, button presses are much slower than the natural eye movements that occur when reading (Just et al., 1982), which is particularly important when dealing with reaction times.

This has very recently also been established in direct relation to the processing of relative clauses. Roland et al. (2021) investigated the difference in processing times of full NP (e.g., *The artist that avoided the painter exhibited statues in the art gallery.*) and pronominal relative clauses (e.g., *The artist that avoided me exhibited statues in the art gallery.*) in a typical SPR paradigm, compared to a natural reading paradigm, where the same sentences were displayed in their full length while the reading processes and times were tracked via an eye tracker. Their study confirmed that the results obtained with an SPR task cannot be directly compared to those obtained in a task that allows natural reading. The main issue with self-paced reading is the fact that the difficulties the reader experiences at a given point (at a given word) in the sentence inevitably affect the reading times of the following words in the sentence, which is known as a spillover effect (e.g., Mitchell, 2018; Rayner, 1998; Reichle and Drieghe, 2015; Roland et al., 2021). The reading times of the individual words of the sentence are thus less informative than it might seem, since it is impossible to disentangle all the effects that are contributing to the times of the button presses. As the authors suggest, more attention should be given to this fact when interpreting the results of self-paced reading times and more caution is in order before any firm conclusions can be made based on such data (Roland et al., 2021).

This could be particularly important in light of the above described DLT theory (Gibson, 1998, 2000), since the theory's key component, which is thought to be sensitive to the distance between the dependent and its head, is represented by the memory load of the integration of the incoming word. And compared to the memory load during natural reading, this is surely affected differently when the reader is forced to focus their attention on each individual word in a serial manner, without the option of returning to the previously read parts of the text, or – in short – when the reader is not allowed to read naturally.

Given the lack of evidence from Slovenian, our study thus offers a much needed addition to the only previous related study in this language, which provided evidence from the SPR paradigm. Here, we complement this insofar largely unaddressed line of research in Slovenian by presenting a more natural reading task – a sentence-picture matching task (see section 2.3 – *Design and Procedure* below for more details).

2 Methods

2.1 Participants

Ninety-seven native Slovenian speakers ($F=78$) took part in the study. They were all either first year undergraduate ($N=82$) or first year master's degree students ($N=15$). Their mean age was 20.66 (range=18-44). They all grew up in a monolingual environment and had normal or corrected-to-normal vision. They all provided online informed consent to take part in the study, and received course credit in exchange for their time.

2.2 Materials

The stimulus set was based on 120 unique sentences in Slovenian, where $N=60$ were CE-RC and $N=60$ RB-RC. Three examples of both types of sentences are provided in Table 3 below.

Table 3: Three examples of centre-embedded relative clauses (CE-RC) and right-branching relative clauses (RB-RC), as they appear in the experiment.

CE-RC	1.	Deklica, ki drži rožo, je objela mamo. The girl who is holding a flower hugged the mother.
	2.	Deček, ki drži lopar, je poljubil očeta. The boy who is holding a racket kissed the father.
	3.	Policist, ki nosi torbo, je pozdravil gasilca. The policeman who is carrying a bag said hello to the fireman.
RB-RC	1.	Deklica je objela mamo, ki drži rožo. The girl hugged the mother who is holding a flower.
	2.	Deček je poljubil očeta, ki drži lopar. The boy kissed the father who is holding a racket.
	3.	Gasilec je pozdravil policista, ki nosi torbo. The fireman said hello to the policeman who is carrying a bag.

As fillers, the same number of sentences with different sentence structures were used, such as simple subject-verb-object sentences (Deklica je objela mamo./*The girl hugged the mother.*), object-verb-subject sentences (Mamo je objela deklica./*The mother (O) hugged the girl (S).*), and wh-sentences (“ko-sentences”; Deklica je držala rožo, ko je objela mamo./*The girl was holding a flower when she hugged the mother.*). As can be observed in the given examples, the same words in the same thematic roles were used across all sentence categories, in order to avoid the possibility that any potentially observed differences could be assigned to differences in lexical or contextual information.

2.3 Design and Procedure

The participants were presented with a sentence-picture matching task, in which they were instructed to press one of three buttons as quickly as possible, denoting which one of the three pictures best described the sentence presented to them. The three

pictures were presented horizontally on the upper half of the screen, while the sentence was presented underneath the pictures in the middle of the bottom half of the screen (see Figure 1 for a screenshot of one trial in the experiment).



Figure 1: Screenshot of a trial in the experiment.

A keyboard was used to collect the participant's responses. The experiment was run online, using the OSWeb extension for OpenSesame (Mathôt et al., 2012) to create the experiment, which was uploaded on the server and distributed to participants via JATOS (Lange et al., 2015), a system for managing online experiments. The experiment would only run on a computer (and not on tablet or smartphone), and all participants were instructed to access the experiment using the Google Chrome browser.

At the beginning of the experiment, the participants underwent a short practice session with four trials so they could familiarize themselves with the task before the start of the actual experiment. During the practice session they received feedback on the correctness of their responses (i.e., a green circle appeared on the screen after the trial if their response was correct, and a red one if their response was wrong). This feedback was not given to them during the main part of the experiment. The trial timeline was as follows. A fixation cross appeared in the middle of the screen for 250ms, followed by a presentation of the three pictures and a sentence. The participants had up to 12,000ms to provide their response before the new trial began. Every 20 trials the participants were allowed to take a break. The total testing time was approximately 1h.

2.4 Data analysis

Each participant's individual performance was checked to make sure their overall accuracy exceeded 50%, indicating they performed the task properly and did not just respond by chance without actually reading the displayed sentences. Further, individual response times were checked – trials with extreme reaction times (below 1s and above 7.5s) were removed from the further analysis (this corresponds to 4% of the data). We additionally removed from the further analysis four participants who performed the task more than once.

Accuracy and response times (RT) in correct trials were analysed through generalized linear mixed-effects modelling, using the R (R Development Core Team, 2008), RStudio (RStudio Team, 2020), and its package lme4 (Bates et al., 2015). Response times and error data were modelled as a function of relative clause position (centre-embedded vs. right-branching), with subjects and items as crossed random intercepts. Significant effects were checked for their dependence on outliers following Baayen (2008): models were re-run after excluding data points whose standardized residuals were larger than 2.5 in absolute value (1.88% of outliers were removed). Only those effects that remained significant after the removal of outliers are reported as significant.

2.5 Results

All participants responded correctly to at least 85% of the trials (overall mean=95%, SD=.21), which suggests that they performed the task appropriately and understood the sentences very well.

The overall descriptive statistics for the variables that we considered in the analysis are reported in Table 4.

Table 4: Means (and standard deviations) across conditions. Statistics are reported in % (accuracy) and ms (response times), and are based on aggregated data. Note: Response times are reported for correct trials only.

Condition	Accuracy	Response time
Centre-embedded relative clause (CE-RC)	94 (.23)	4,523.13 (1,290.03)
Right-branching relative clause (RB-RC)	96 (.18)	3,920.14 (1,144.79)

We observe a significant effect of relative clause position in the reaction times of the correct trials ($\chi^2 = 41.82$, $t = -6.52$, $p < .001$), indicating that the participants were

slower when dealing with CE-RC ($\Delta RT=693ms$). Similarly, we also observe a significant effect of the relative clause position in the error data ($\chi^2=8.15$, $z=2.85$, $p=.004$), indicating that the participants were more accurate when dealing with RB-RC. The model predictions are illustrated in Figure 2.

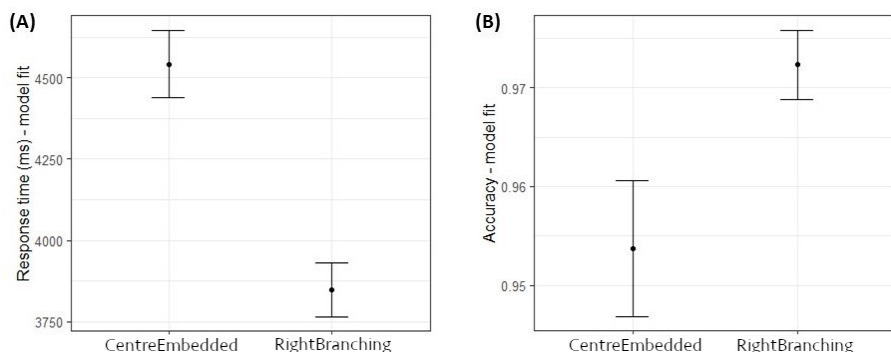


Figure 2: LMM estimates for (A) response time of correct responses and (B) accuracy. Error bars represent 95% CIs. Note: CentreEmbedded - Centre-embedded relative clause, RightBranching - Right-branching relative clause.

3 Discussion

Our results are in line with the current consensus that CE-RC are harder to process than RB-RC. While this is not too surprising, we believe it adds important evidence to the study of a so far largely under-investigated language. This is particularly important in light of the DLT theory described above (Gibson, 2000), which has been claimed to be language independent, but empirical work supporting this claim across the world's many languages, including Slovenian, is still lacking.

Interestingly, our results are not in line with the findings reported in Pavlič and Stepanov (2020), where the opposite pattern was recorded, i.e., longer reading times and lower accuracy were observed with RB-RC, compared to CE-RC. While the authors themselves pointed out this pattern was not expected, they suggest the possible reason for it might be a temporary ambiguity which results from the availability of a competitive parse. This phenomenon could potentially emerge when both the subject and the object have an identical gender and number, leading to a later resolution when the relative clause is right branching, while, on the other hand, this kind of ambiguity does not emerge with centre-embedded structures. While this explanation is of course

plausible, the authors themselves point out that it intuitively seems that this alternative parse does not readily become available to a native Slovenian reader (i.e., most native speakers of this language would reject the alternative as a plausible option), indicating a need for further research before any conclusions can be made.

While the present study was not designed with the aim of comparing the results with those of Pavlič and Stepanov (2020), the two experiments do share an important aspect – in both, the stimuli sentences include the subject and object of identical gender and number. Thus, the above-described temporary ambiguity could also emerge in the stimuli set used in the present study, if the alternative parse does in fact get activated. While determining whether this is actually possible in Slovenian is beyond the scope of this paper, the present results nevertheless indicate that even if the temporary ambiguity does emerge it does not necessarily make RB-RC more difficult to process than CE-RC.

The difference in the observed results between the two studies may perhaps be due to the different paradigms that were used. While Pavlič and Stepanov (2020) introduced an SPR task, the present study made use of a sentence-picture matching task, which enabled the participants to read naturally during the experiment, while the observed results reflect their judgment after the reading process. Importantly, a very recent study (Roland et al., 2021) investigated exactly this issue in relation to the processing of RC and reported that introducing an SPR task does indeed affect the observed results, which should thus be considered with caution. In short, not allowing the participants to read naturally has an effect on the results that we might not be able to predict or account for.

4 Conclusion

The aim of the present study was to provide evidence from Slovenian with regard to the processing differences between CE-RC and RB-RC, something that is so far mostly lacking in the literature. These differences have been one of the main topics in the last few decades of psycholinguistic research, and the results of numerous studies have led to the consensus that CE-RC are harder to process than RB-RC. This typically results in longer reading times and/or lower accuracy of the participant's performance when dealing with CE-RC compared to dealing with RB-RC. While this evidence is so consistent across different paradigms and languages that it has led to the development of several theories, evidence from Slovenian is still scarce at this point – there is, to the best of our knowledge, only one other study that very recently investigated this issue (Pavlič and Stepanov, 2020). While this study added important evidence to the topic, it yielded unexpected results which are not in line with the above described consensus, indicating a pressing need for further research in Slovenian.

In the present study, we introduced a sentence-picture matching reading task in which the participants read sentences that were displayed on the screen in their entirety, enabling natural reading. Our results reveal longer reading times and lower accuracy when the participants were dealing with CE-RC compared to RB-RC, indicating that the former were harder for the participants to process. Importantly, these results are in line with the current consensus that CE-RC are harder to process than RB-RC, which has up to now not been reported for Slovenian.

We thus believe the current study provides an important piece of evidence about the processing of centre-embedded and right-branching relative clauses in Slovenian, a language that to date still largely lacks empirical work on the processing of relative clauses.

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Keywords: processing of relative clauses, centre-embedded relative clauses, right-branching relative clauses, sentence-picture matching task

The current consensus in the literature of processing of relative clauses states that centre-embedded relative clauses introduce a heavy computational load. While this is well-established, most evidence for it comes from English, while the empirical

evidence from many other languages is still lacking. Here, we try to fill this gap by researching the differences in the processing times of centre-embedded and right-branching relative clauses in Slovenian. We report results from a sentence-picture matching task, in which we observe longer reaction times and lower accuracy when the participants are dealing with centre-embedded relative clauses, compared to right-branching ones. This result provides important evidence in a so far largely under-investigated language, contributing to the theoretical claim that the difficulties observed in the processing of centre-embedded relative clauses are language-independent.

Procesiranje oziralnih odvisnikov s sredinsko in desno vstavljenimi strukturami v slovenščini

Ključne besede: procesiranje oziralnih odvisnikov, oziralni odvisniki s sredinsko vstavljeno strukturo, oziralni odvisniki z desno vstavljeno strukturo, naloga povezovanja stavka in slike

V literaturi o procesiranju oziralnih odvisnikov trenutno obstaja soglasje, da procesiranje sredinsko vstavljenih oziralnih odvisnikov predstavlja veliko kognitivno obremenitev. Čeprav je to mnenje uveljavljeno, večina dokazov prihaja iz angleščine, medtem ko empiričnih dokazov iz številnih drugih jezikov še vedno nimamo. V pričujoči študiji skušamo to vrzel zapolniti z raziskavo razlik v času procesiranja sredinsko in desno vstavljenih oziralnih odvisnikov v slovenščini. Navajamo rezultate iz naloge povezovanja stavka in slike. Pri njej smo zabeležili daljši reakcijski čas in nižjo natančnost udeležencev pri procesiranju sredinsko vstavljenih oziralnih odvisnikov v primerjavi s tistimi, vstavljenimi desno. Raziskava prinaša pomembne podatke za doslej skoraj neraziskan jezik in tako prispeva k teoretični predpostavki, da je težavnost obdelave sredinsko vstavljenih oziralnih odvisnikov neodvisna od jezika.

About the authors

Katarina Marjanovič, PhD is a postdoctoral researcher who received her PhD in Cognitive Neuroscience from International School for Advanced Studies, Italy. In her research she uses behavioural and neuroimaging methods for investigation of reading and language processing, morphological processing, linguistic impairments in patients with dementia and language intervention.

Email: katarina.marjanovich@gmail.com

Christina Manouilidou, PhD is an Associate Professor of Psycho-/Neurolinguistics at the Faculty of Arts, University of Ljubljana. She received her PhD in Linguistics from the University of Ottawa, Canada. She is the principal investigator of the ARRS-funded project CogLiTreat and the Co-investigator of the ESRC-funded project SAVaNT. She participates in numerous international schemes and consortia related to various topics such as reading, discourse analysis, creation and adaptation of language assessment tools for pathological populations. Her research interests include the processing of complex words, linguistic impairments in dementia, and language intervention in acquired language disorders by employing behavioural methods as well as transcranial magnetic stimulation.

Email: Christina.Manouilidou@ff.uni-lj.si

O avtoricah

Dr. **Katarina Marjanovič** je podoktorska raziskovalka, ki je na mednarodnem inštitutu International School for Advanced Studies v Italiji doktorirala iz kognitivne nevroznanosti. V svojih raziskavah uporablja vedenjske in slikovne metode za preučevanje možganov in kognicije. Njeni raziskovalni interesi vključujejo bralno in jezikovno procesiranje, morfološko procesiranje, jezikovne motnje pri bolnikih z demenco in jezikovne intervencije.

E-naslov: katarina.marjanovich@gmail.com

Dr. **Christina Manouilidou** je izredna profesorica za psiholingvistiko in nevrolingvistiko na Filozofski fakulteti Univerze v Ljubljani. Na Univerzi v Ottawi v Kanadi je doktorirala iz jezikoslovja. Trenutno je vodja projekta CogLiTreat, ki ga financira ARRS, in sovodja projekta SAVaNT, ki ga financira ESRC. Sodeluje v številnih mednarodnih programih in konzorcijih, povezanih z različnimi temami, kot so branje, analiza diskurza, ustvarjanje in prilagajanje orodij za ocenjevanje jezika za patološko populacijo. Njeni raziskovalni interesi vključujejo procesiranje kompleksnih besed, jezikovne motnje pri demenci in jezikovne intervencije pri pridobljenih jezikovnih motnjah z uporabo vedenjskih metod ter transkranialne magnetne stimulacije.

E-naslov: Christina.Manouilidou@ff.uni-lj.si