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# An online study of L2 relative clause processing: Evidence from self-paced reading in Persian learners of English

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# Abstract

This study examines relative clause (RC) processing in Persian learners of English and native speakers of English to explore whether or how different task demands, referential context information with three potential RC antecedents along with the variables noun type (definite, indefinite), RC length (short, long) and RC type (extraposed, non-extraposed) affect their processing, using both an online non-cumulative self-paced reading task and an offline questionnaire. In the self-paced reading task, the online processing of RC attachment resolution was examined when participants read temporarily ambiguous sentences with RCs preceded by one clause or two clauses containing three NPs followed by comprehension questions to explore L2 RC attachment preferences. In the offline task, participants were asked to read ambiguous sentences and choose the antecedent which was most plausible to them for the RCs. Moreover, the Language History Questionnaire (LHQ) 3, the LexTALE test, a digit span task, and a reading span task were also administered to investigate whether measures from these tasks predicted the online processing outcome.

The results showed that Persian learners' and native speakers' online L2 RC processing was not significantly affected by the experimental conditions, but group effects were observable. There were significant differences between groups when reading sentences with extraposed RCs (region 4). The Persian learners read sentences with definite short non-extraposed RCs (region 2) faster than indefinite short non-extraposed RCs, and so did native speakers. Moreover, the Persian learners' overall reading times were longer than native speakers' reading times, whether with extraposed RCs or not. In contrast, in the offline task the Persian learners and the native speakers behaved differently in attachment preference. The Persian learners preferred high attachment and were sensitive to lexical-semantic dependencies in line with the predictions of the Competition model (CM) and Shallow Structure Account (SSA) which underline L1 influence. The native English speakers' RC ambiguity resolution, on the other hand, was affected by the recency principle, relying more on structural dependency and word order. However, the native speakers' tendency to high attachment was considerable. The results also revealed that for both groups, online L2 RC processing and observed attachment preferences are not robustly directly modulated by working memory, however, by a simple heuristic processing activated by semantic memory-based information in which earlier good-enough linguistic representations are mostly preferred to achieve a state of Cognitive Equilibrium (resolved or minimized ambiguity), such that language users are more likely to prefer high attachment than to prefer low attachment in RC attachment processing.

***Keywords****: relative clause, online L2 processing, second language comprehension, attachment preference, self-paced reading, heuristic processing, good-enough approach, working memory span.*

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# Abbreviations

| | |
|---|---|
| ANOVA | Analysis of variance |
| BNC | British National Corpus |
| CM | Competition model |
| COCA | Corpus of Contemporary American |
| EEG | Electroencephalography |
| ERP | Event-related potential |
| FMRI | Functional magnetic resonance imaging |
| L1 | First language |
| L2 | Second language |
| LHQ | Language History Questionnaire |
| LTM | Long-term memory |
| NP | Noun phrase |
| OCE | Online cognitive equilibrium |
| PS | Phonological |
| RC | Relative clause |
| RT | Reaction time |
| SD | Standard deviation |
| SOV | Subject object verb |
| SPR | Self-paced reading |
| SPSS | Statistical package of social science |
| SSA | Shallow structure account |
| STM | Short-term memory |
| WM | Working memory |

# 1 Introduction

Psycholinguistics has recently started studying second language receptive and productive processing, that is, the ways in which language users employ their acquired knowledge in online incremental sentence comprehension (Tily et al., 2010, p.3). The aim of the present study is to examine whether there are significant differences between Persian learners of English and English native speakers in sentence processing, and how working memory performance might affect the processing. This is done by looking meticulously at the time-course of sentence comprehension and critical places in online interpretation, where potential effects might appear. To this end, empirical data is collected from the processing of relative clauses (RC) in offline tasks, that is, tasks without time measures, as well as in online tasks, which measure the processing in real-time.

The investigated structures are RCs with syntactic and semantic ambiguities in which one element, the relative marker, can refer to three potential anteceding elements (NPs) in the sentence. These temporary ambiguities are widely employed to explore different processing strategies and the relationship between processing and memory performance (Rah, 2009). The investigated structure is the so-called RC attachment temporary ambiguity. An illustrative example is provided in (1).

(1) Someone shot the servant of the actress who was on the balcony.
a. Someone was on the balcony.
b. The servant was on the balcony.
c. The actress was on the balcony.

(Rah, 2009:2)

The key issue is what the antecedent of the relative pronoun *who* might be. In (1), the RC could be attached to the first noun *someone*, as in (1a), or to the second noun *the servant*, as in (1b) referred to as *N1 attachment, early closure, or high attachment*, and finally to the third noun *the actress*, as in (1c) referred to as *N2 attachment*, *late closure*, or *low attachment* when parsing the RC. Considering that RC attachment preferences have been reported to vary cross-linguistically, previous studies have found that native speakers of English prefer to attach the closest noun, low attachment, to the RC (Dussias, 2003; Frenck-Mestre 2002; Jacob, 2009; Rah, 2009) while Persian learners of English prefer the earlier noun, high attachment, (Arabmofrad & Marefat, 2008) or occasionally behave like native speakers of English (Marefat & Farzizadeh, 2018). Thus, native Persian speakers might behave differently from English speakers in processing RC attachment ambiguity. The present study therefore attempted to investigate how Persian learners of English process RCs in their L2, focusing on the reaction time of the processing which involves working memory performance. Drawing on predictions derived from two accounts in the literature, the present study aims to test effects of definite-indefinite first NPs, long/short-distance dependencies in extraposed/non-extraposed RCs conditions in Persian learners and English native speakers when processing L2 RC attachment ambiguity, taking working memory capacity (WMC) into account, to gain a better understanding of the mechanisms that underlie L2 processing when there is no agreement or pronoun cues in the sentences and three potential antecedents for RCs to attach to.

The present thesis is organized as follows. Chapter 2 gives an overview of the theoretical background, elaborating on the common processing theories and models that account for native speakers' syntactic ambiguity resolution, sentence processing in L2 learners, and finally the role of working memory in L2 processing. Chapter 3 outlines the research questions and the corresponding hypotheses which the present psycholinguistic study is going to address and test them. Chapter 4 explains the methodological details regarding the selection of participants, materials or tasks design, procedures and data analysis. Chapter 5 presents the results of the study, followed by the discussion of the results in Chapter 6. Chapter 7 finally summarizes the study in brief conclusions.

# 2 Theoretical background

Before going through the theoretical accounts and models, the first section of this chapter looks at the nature of the processing mechanism, L1/ L2 sentence processing, extraposition of relative clause, and the effect of working memory on sentence processing, here, on L2 RC attachment ambiguity. In this chapter I introduce the basic concepts that are important for the present study. Since the research questions are how native and non-native speakers behave in L2 processing, theories of processing in the first language (L1) as well as in the second language (L2) are considered. I therefore describe various general processing models and accounts that have been developed not only to support the predictions mentioned in section 3, but to account for empirical data on L2 RC attachment ambiguity resolution. In the following, four types of models are discussed: a Working Memory model, the Competition model (CM), the Shallow Structure Account (SSA), and Online Cognitive Equilibrium (OCE).

## 2.1 Language processing

### 2.1.1 Sentence processing

The language processing mechanism uses a set of algorithms to provide the meaning of the whole structure through retrieval of words from the lexicon and arrangement of them into a syntactic structure by using rules of grammar, which result in sentence comprehension (Ferreira, 2002). Current neuroimaging methods such as EEG[1], ERPs[2] and fMRI[3] have to some extent paved the way for an understanding of how the human brain functions (Kemmerer, 2015; Warren, 2014). However, behavioral data can also provide insights into the nature of language processing by the human parser when reading or listening to L2 sentences in real time, which is known as 'parsing' (Marinis, 2003**)**. When processing syntactic ambiguities, the parser often selects an initial analysis without regard to all existing information, which can result in misanalysis or the so-called "garden-path effects" (Rah, 2009, p.5). These can be experimentally measured by psycholinguistic methods such as self-paced reading (SPR), where a series of segments of a sentence appear in temporal

[1] Electroencephalography
[2] Event-Related Potentials
[3] Functional magnetic resonance imaging

sequence triggered by a participant pressing a button to reveal the appearance of the next segments until the entire sentence appears (Jegerski, 2014).

Furthermore, in language comprehension, the processing is believed to be incremental (Cole & Reitter, 2019). This means that the parser engages in a constant update of the interpretation through the left-to-right processing of a string (Sturt, 2004), meaning that new information is incorporated into the previous material as early as it appears (Hopp, 2016). However, it is still controversial if the parser analyzes serially or keeps in memory possible interpretations in parallel to predict processing (Niv, 1993). Slevc (2011) argues that working memory load can influence the incrementality of a sentence. More clearly, incrementality can be graded to the degree to which a sentence is understood/presented and may vary based on short-term memory, as proposed by Cole & Reitter (2019). Consequently, comprehension processes involve working memory, relying on computational capacity (Schewering & MacDonald, 2020).

### 2.1.2 The processing of relative clause resolution in a first language (L1)

The investigation of syntactic sentence processing has often drawn on studies of how relative clause (RC) attachment is processed, and especially the syntactic ambiguities it gives rise to. As it is described in the grammar books, RCs are part of subordinate clauses and function as adjectives in some occasions where writers call it restrictive RCs which is the focus of the present study as experimental stimuli. This structure has been of particular interest because more than one NP can be attributed to it, which might lead to processing cost. The scenario can be more complex when three possible NPs are considered antecedents for a RC. However, RCs with three potential antecedents to attach to, have not been investigated, Persian learners may therefore prefer RC antecedent among three available NPs to process RC attachment ambiguity. It is thus interesting to look at the parsing of such complex sentences and compare how they are processed in offline and online reading tasks. In the case of ambiguous relative clause attachments, the key issue is whether resolution of the relative clause antecedent is connected to the first or second, (or third) noun phrase, referred to as high vs. low attachment, respectively. Although attachment possibilities are, broadly speaking, ambiguous in such cases, it has been suggested that readers show preferences towards either high or low attachment in silent reading tasks (Baek, 2012; Rah, 2009;

Tan & Foltz, 2020). Furthermore, the direction of this preference can be partly predicted based on native language and typological differences (Jacob, 2009). In addition, addressing this issue in both first and second language provides information about the various parsing strategies speakers employ to process ambiguous sentences, indicating that the processing mechanism of ambiguity resolution among speakers in real time might be influenced by syntactic transfer as well as cross-linguistic differences (Malakooti et al., 2020). Attachment preferences concerning sentences with a RC preceded by complex NPs have been found to differ cross-linguistically. Therefore, a fully syntactic analysis of such sentences requires the disambiguation of the relative clause attachment.

Prior studies have explored the roles of different linguistic cues or other factors like RC length, number of preceding NPs, prosody, grammatical gender, genitives, etc., that could influence the way RC attachment ambiguity is resolved (Dussias, 2001; Fodor, 2002; Papadopoulou & Clahsen, 2003; Swets et al., 2007). In their study, with Dutch and English native speakers, Swets and colleagues (2007) found that readers of both languages preferred high attachment when the RC was read on a separate line, showing length effect in attachment processing. Moreover, a preference was found for high attachment in individuals with lower working memory. Findings from several studies show that adult native speakers of English prefer to attach the RC to the second NP, low attachment, in both offline and online reading processing tasks (Dussias, 2001; Fodor, 2002; Hillert & Nakano; Hopp 2015, 2016; Kempen, 1994; MacDonald & Christiansen, 2002; Rah, 2009;). A high attachment preference was also found in numerous other languages containing the same constructions with flexible word order, including Spanish (Dussias & Sagarra, 2007; Dussias & Scaltz , 2008; Hartsuiker et al., 2004; Jacob, 2009; Jegerski et al., 2014), Dutch (Hout et al., 2009; Jackson & Roberts, 2010; Swets et al., 2004), German (Felser et al., 2003; Jacob 2009; Loebell & Bock, 2003; Pan et al., 2014), French (Frenck-Mestre, 2002; Frenck-Mestre & Schuman, 2004), Greek (Papadopoulou & Clahsen, 2003; 2006). In contrast, the scarcity of evidence for low attachment preference is partly related to the fact that native speakers select a low attachment in many constructions, which makes it difficult to empirically distinguish native-like from a second-language specific processing.

2.1.2.1 Relative clause resolution in Persian

Non-configurational languages like Persian exhibit free word order variation compared to configurational languages in which verbs and their complements are not allowed to be non-adjacent, and that have a rigid word order (Malakooti et al., 2020). More clearly, "Persian is a null-subject verb final language with typologically SOV word order in declarative sentences and subordinate clauses" (Karimi, 2001, p.31). Like English, Persian RCs are post-nominal (2), and RCs are always initiated by an obligatory relativizer or complementizer *ke;* but unlike in English, there is no relative pronoun in Persian (Taleghani, 2008; Shabani, 2018) marking the animacy, grammatical gender, function or number of the noun modified by the RC (Rahmany et al., 2011; Taghvaipour, 2004), as seen in (3). In other words, the complementizer *ke* is invariant. That is, Persian RCs attachment ambiguity are thus more likely to be resolved with focus on semantic and structural dependencies.

(2) *an mærd pæræstar-e nozad [ke dašt ghædæm mizæd] ra did*

DEM-SBJ man.SG nurse-EZ infant-GEN.SG [REL[4] be-walk-PST-3SG] see-PST-3SG

'That man saw the nurse of the infant [who was walking].'

(Marefat et al., 2015:80)

(3) *dokhtar-e Ali ke diruz æz u: pul gereftid*

daughter-EZ Ali-GEN.SG REL yesterday from she money.SG take-PST-2PL

'Ali's daughter from whom you took money yesterday . . .'

(Shabani, 2018:12)

With regard to antecedents, a few studies of Persian have reported a preference for high attachment (NP1) both in offline and online tasks (Marefat & Meraji, 2005; Moghaddasian, 2008). A preference for the first NP, that is high attachment, seems to occur especially when the first NP is indefinite and is semantically dependent antecedent to attach to extraposed RC. According to Jun (2003) and Rasekh-Mahand et al. (2016), Persian is a head-final language like Japanese and

[4] The glossing has been standardized based on the Leipzig glossing rules to observe consistency for readers to better understand the examples. Moreover, the relative marker REL is used instead of the relative pronoun *who* because there is no relative pronoun in Persian but *ke* as a relativizer or complementizer.

Korean, but unlike in Japanese and Korean, Persian RCs come after head nouns, as in head-initial languages like English. So, although Persian is verb-final, it behaves like head-initial languages regarding the order of the head nouns and the RC (Jun, 2003). In addition, Persian is among the languages with complex and challenging preprocessing tasks, such as half space or no space between or within a word as in ('disappointed', ناامید/ نا امید/ نا امید) , diacritical marks ('slippery' سُر, 'head' سَر, 'secret' سِر), and uncommon characters (Sarabi et al., 2013).

Shabani (2018) indicated that when an ambiguity arises between two preceding nouns to act as potential antecedents for the upcoming RC in Persian, native speakers may rely on cues such as the enclitic marker -*i*[5] (in/definite markers), semantic congruity or in/animacy to resolve this ambiguity. The enclitic marker -*i* as a disambiguating cue is attached to the second NP to determine the relevant antecedent noun functioning as host for RC as in (4). Persian speakers show a clear NP1 attachment preference for the canonical RC but an ambiguous pattern for sentences with the enclitic marker -*i* attached to the second NP (Shabani, 2018).

(4) definite -*i*
*mardi ke kolah be sar dasht amad*
Man.SG-Encl REL who hat.SG wear-PST-3SG come-PST-3SG.
'The man who wore a hat came.'

(Shabani, 2018:14)

However, it is not clear whether Persian follows low or high attachment preferences when the enclitic marker -*i* is attached to the complex NP. In restrictive RCs, the enclitic marker -*i* is added to the noun to modify it and thus makes it specific as seen in (4). In contrast, in non-restrictive RCs, the RC without the noun with the enclitic marker -*i* provides extra information about the noun (Shabani, 2018). Therefore, one of the questions of the present study is whether the enclitic marker -*i* could have any effect on Persian learners' processing of RC attachment ambiguity in L2. Although, sometimes, the effect of the enclitic marker -*i* is neutralized due to the semantic content of the RC or verb categorization in sentences as in (5). The enclitic marker -*i* might also lead to processing cost since native Persian speakers mostly regard the enclitic marker –*i* attached to an

[5] In Persian, the enclitic marker -*i* is used for both indefinite nouns and definite nouns (followed by RC). Indefinite nouns are shown by the article (*yek* 'a/an') or by the enclitic -*i* (Aghaei, 2006).

indefinite noun which involves more lexical-semantic dependencies than definite noun in Persian processing. L2 Persian learners might thus transfer their L1 parsing strategy and indefiniteness might affect L2 processing specifically when reading ambiguous sentences.

(5) Monshi-e sherkat-i ke be tazegi kar-e khod ra aghaz karde bud ekhraj shod
Secretary-EZ company-Encl-GEN REL recently work-EZ self Obj-3SG start-PST-PTCP fire-PST- PTCP-3SG
The secretary of the company that has recently started his/her/its work got fired.

(Shabani, 2018:15)

Jun (2003) reported that three Persian learners of English preferred low attachment while one learner preferred high attachment. Moreover, despite the potential effect of the enclitic marker *-i* as a (in) definite, the subjects showed a relatively equal preference for NP1 and NP2, indicating no significant difference in RC attachment preference (Shabani, 2018). However, the results from the offline studies theoretically show subjects' high (non-local) attachment preference than low (local) attachment preference for Persian learners. In fact, this finding only emanated from offline interpretation tasks involving the subjects' conscious rather than online unconscious decision-making. Thus, further study is needed to test the RC attachment preference in a SPR task. In contrast, dominant preferences for NP1 provided in past studies are mainly observed in the languages with flexible word order which do not require adjacency between the verb and its complements, resulting in high attachment preference in languages such as Persian (Arabmofrad & Marefat, 2008; Jun, 2003; Marefat & Meraji, 2005; Shabani, 2018), Spanish, German, Greek and French (Rah, 2009; Jacob, 2009). Therefore, not surprisingly, for Persian learners the dominant preference is high attachment at least in offline tasks, which relies more on semantic dependencies regardless of learners' proficiency, immersion and exposure to target language.

Persian differs from English because it belongs to the group of languages in which the dominant preference has been shown to be high attachment among complex genitive antecedents. As in head-final languages, in which the potential attachment sites come after the RC, in Persian, complex NP can also become available after the RC. This is in difference to head-initial languages such as English. However, as in English, complex NP can also precede the RC in Persian. Few studies have investigated RC attachment from this perspective in which the potential attachment sites can both precede or follow the RC in a head-final language like Persian.

### 2.1.2.2. Relative clause extraposition

Extraposition is traditionally described as a syntactic rightward movement in which "the nominal head of a relative clause becomes separated from the rest of the relative clause by intervening material" (Manninen, 2002:1). Such constructions, as exemplified by sentence (10), are called *relative clause extraposition* constructions. Put differently, relative clause extraposition occurs whenever a relative clause moves from its first position (the canonical position near the head) to the end position of the sentence (Baltin, 2007; Kuhbanani et al., 2016; Rasekhmahan et al., 2016).

(10) [A handsome man] walked into the room [who looked like Ewan McGregor].

(Manninen, 2002:1)

In English, Swedish, and most other Germanic languages, RCs follow the head nominals, while in Turkish and Hindi, they precede the nominal heads. The extraposed RCs are restrictive, functioning as complements of the heads as in (10), while in non-restrictive relative clauses, they are full DP as in (11) (Lindahl, 2017).

(11) Heath Robinson, who died in 1944, was a graphic artist and cartoonist.

Although extraposition is traditionally defined as a rightward movement, Kayne's antisymmetric theory (1994, as cited in Manninen, 2002) accounts for extraposition in terms of a leftward movement of the nominal head and RC stranding in situ, as exemplified in (10), called a normal structure or (non-extraposed). It is assumed, however, that there is no cogent reason to differentiate between DP (A handsome man who looked like Ewan McGregor) in (10) and (11) which functions as subject. Furthermore, RCs not only occur at the end of sentence (Manninen, 2002) but also near the head in its canonical position.

(12) [A handsome man who looked like Ewan McGregor] walked into the room.

(Manninen, 2002:4)

Satu (2002) believes that extraposition is usually allowed when the nominal head is indefinite as in (10), but definite heads seem to be separated from RC as in (13), meaning that heads might behave significantly differently in indefinite and definite conditions which might be reflected in reaction time in online incremental L2 RC attachment resolution.

(13) [The handsome man] walked into the room [who looked like Ewan McGregor].

(Manninen, 2002:7)

Extraposition often happens in subject position (Keenan & Cormier, 1997; Kuhbanani et al., 2016, Rasekh Mahand et al., 2016). There is evidence to suggest that it is easier to comprehend subject RC (6) than Object RC (7) (Rahmani et al., 2010).

(6) *Marde moseni vared shod [ ke yek gife bozorg be dastash bud]*.
Man old.SG enter-PST-3SG [REL a bag big.SG in 3POSS-hand-SG be- PST-3SG].
'An old man arrived who had a big bag in his hand' (Rasekh-Mahand et al., 2016:22)

(7) *Chandta az dostanam ra molaghat kardam [ke dar bazar maghazeh darand]*.
Some 1sPOSS-friend-PL-GEN meet-PST-1SG [REL in shop.SG have-PRS-3SG]
'I met some of my friends who have a shop in the bazaar.'

(Kuhbanani et al., 2016:46)

The sentence remains grammatically correct whether RC extraposition happens or not, suggesting that this movement may not have a syntactic motivation, but functional reasons such as information structure, relative clause length, repetition of the verb in the main and the relative clause, and the kind of verb used (Kuhbanani et al., 2016). It seems that among such functional reasons, RC length has the most effect in RC extraposition, which is supported by Hawkins' principle of domain minimization (Kuhbanani et al., 2016), which claims that heavy constituents tend to move to the end of the sentence after verbs in SOV languages. In this regard, Persian resembles East Asian languages in terms of being head-final and pro-drop with SOV word order. However, unlike in Korean, Japanese and Chinese, relative clauses in Persian are head-first with a tendency to behave similarly like European languages (Karimi, 2005, Taghvaeepour, 2005 as cited in Kuhbanani et al., 2016, p.49). RC extraposition, which exists in both historical texts and modern Persian (Kuhbanani et al., 2016), may therefore occur to decrease the processing difficulty by moving the heavy constituent to the end of the sentence (Hawkins, 2004, Dik 1997). Nonetheless, each syntactic movement which violates word order is considered to be costly (Fukui, 1993).

### 2.1.3 Sentence processing in second language (L2)

Regarding processing mechanisms employed by L2 learners when processing L2 input, it is worth discussing how L2 learners' two linguistic systems are represented and involved in L2 processing. It has been argued that, although learners' two lexical systems are simultaneously activated during comprehension, the non-target language does not affect the target language. For example, La Heij (2005) believes that a lexical or syntactic unit receives a higher activation level in the intended language than their equivalent translations in the unintended language. Apparently, proficient learners master two interrelated linguistic systems. They can also switch between them when communicating with others. Furthermore, learners can also keep one of their linguistic systems active if this is practically required and suppress one language when using or processing the other. However, more updated research takes views involving both L1 and L2 strategies when it comes to sentence processing (Jacob, 2009; Rah, 2009).

#### 2.1.3.1 The processing of relative clause resolution in a second language (L2)

Several studies have found that there are cross-linguistic differences in how native speakers resolve ambiguous RCs, as shown above. This means that cross-linguistic differences are important in the study of L2 RC processing, with studies asking whether L2 learners transfer L1 processing strategies to their L2 (Jacob, 2009) or whether they behave in a native-like fashion in online RC attachment ambiguity resolution. This is relevant since the ways in which RCs ambiguities are resolved seem to be cross-linguistically different, showing that some parsing strategies are language-specific not universal, and thus, can be learned through experience (Malakooti, 2010, as cited in Malakooti et al., 2020, p.223). Moreover, L2 learners may not exhibit L1-based preferences in L2 in online tasks, which indicates they are not directly influenced by attachment preferences from their L1 (Jacob, 2009). But transfer can have an effect in offline tasks as the L2 learners may resort to some metacognitive knowledge (Malakooti et al., 2020). It is also claimed that, in addition to L1 influence (Omaki, 2005; Jacob 2009; Rah, 2009), other factors such as long-distance dependency (Caplan, 2016; Baek, 2012), and working memory capacity (Caplan, 2016; Karimia & Ferreira, 2016) may affect the processing of L2 RC attachment ambiguity. Previous studies have reported that Persian learners prefer to attach the RC to the first NP, high attachment (Arabmofrad & Marefat, 2008; Jun, 2003; Marefat & Meraji, 2005; Marefat et al., 2015; Marefat & Farzizadeh, 2018; Moghadassian, 2008; Shabani, 2018).

Several interpretations have been suggested to explain why learners' L2 processing differs from their L1 processing. First, they may not have access enough to syntactic details or representations in online processing which is in line with the Shallow Structure Account (SSA) (Clahsen & Felser, 2006; Papadopoulou & Clahsen, 2003). This account predicts that specific syntactic phenomena, which influence processing among native speakers, are not activated among L2 learners, since such specific syntactic phenomena are not processed in L2 processing (Clahsen & Felser, 2006; Jacob, 2009).

Second, L2 learners might be satisfied with a quick overall representation of sentence information as a good-enough representation to tackle the task at hand, based on heuristic processing, consistent with the fundamental least effort principle, in the "Online Cognitive Equilibrium" hypothesis (Ferreira et al., 2002; Karimia & Ferreira, 2016). Although heuristic processing and algorithmic processing are simultaneously activated, heuristic processing is sometimes enough to solve the task in earlier stages of processing to achieve cognitive equilibrium faster, whereas algorithmic processing is activated for underspecified representations coming from the processing of garden-path sentences in later stages of processing only if necessary (Dwivedi, 2013). However, evidence provided by Christianson et al. (2001) & F. Ferreira et al. (2001) points out that correct interpretations may not always be computed even when the sentences are followed by comprehension questions and participants recall the sentences.

Third, L2 learners may have low processing capacity, either as a consequence of lower working memory during retrieval (Jacob, 2009; Caplan, 2016) or as a general effect of L2 processing such as age-related changes in syntactic representation, lower levels of lexical processing, the difference in reaction to hierarchical sentence structure, and semantic/syntactic dependencies (Hopp, 2015). Taken together, these accounts make different predictions (see section 3) for the strategies and patterns which may be observed in L2 processing. When L2 learners' knowledge of syntactic representation lacks details, it is assumed that they often rely more on semantic than syntactic cues to parse and process L2 RC attachments (Jacob, 2009), regardless of their choice of short-long dependencies.

Based on superficial views of L2 sentence processing, potential differences in sentence processing between L1/L2 could be either transitional or fundamental (Rah, 2009). Transitional differences which are often due to lack of exposure or automaticity, will disappear when language users arrive at "the level of ultimate attainment" (Marinis, 2003), while fundamental differences could possibly be related to various processing mechanisms and thus not disappear over time. Ambiguity resolution preferences, in particular RC attachment preferences, might be an overt example of fundamentally different processing in which transfer of L1 processing to L2 can be easily done and affect L2 processing. It is also believed that sentence processing among L2 learners do not follow L1/L2 syntactic parsing, but instead mainly relies on lexical and semantic interpretation (Caffarra et al., 2015; Clahsen and Felser, 2006). Therefore, they might avoid paying attention to long-dependencies and several possible information, which are simultaneously presented, indicating that preferences might be due to lack of grammatical representation (Clahsen & Felser, 2006), processing automaticity (Rah, 2009) or memory capacity (Omaki, 2005; Baddeley, 2012; Caplan, 2016). Therefore, it becomes interesting to investigate whether L2 learners employ L2 processing strategies different from those in their L1 or whether they transfer a high attachment preference from their L1 to the L2. This can shed more light on the effect of transfer, and the cross-linguistic study of this phenomenon.

## 2.2 Memory and language processing

### 2.2.1 Short-term memory- Working Memory (STM-WM)

While short-term memory (STM) refers to an immediate accessible storage of information, working memory (WM) developed from the study of short-term memory (STM) is something in which the information is manipulated, stored and processed (Baddeley, 2010, as cited in Mascio, 2015). Baddeley and Hitch's (1974) term WM serves as the limited memory capacity of human cognition, "an activated portion of long-term memory (LTM)" (Wen & Li, 2019) and "a dedicated system that underlies human thought processes (Baddeley, 2003), which helps us maintain a small amount of information in our buffer in the short term and to simultaneously manipulate this information for executing tasks involving cognitive functions in our daily life (Baddeley,1986; Omaki, 2005). The present thesis investigates the effect of WM performance on online L2 RC processing among native and non-native speakers of English. Importantly, the (verbal) WM which will be discussed here, is not necessarily the same as general working memory. Before delving into how WM might affect L2 processing, a functional and structural description of key components of the memory system (see Figure 1) and their functions are first presented.

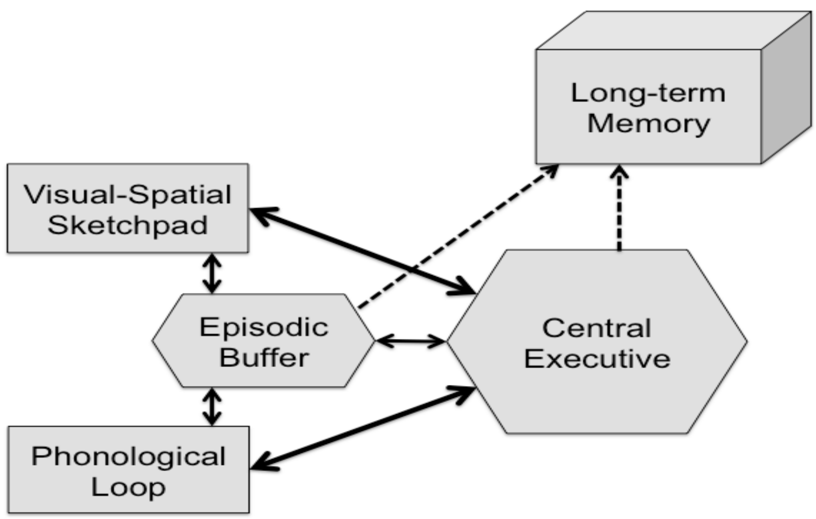


Figure 1. Components of working memory, their relationship with each other and long-term memory; based on Baddeley's (2012) model (adopted from Mascio, 2015)

As illustrated in Figure 1, Baddeley's (2012) model of WM includes four main components. The phonological loop "handles sound-based linguistic materials" (Wen & Li, 2019, p.368), which can be reinforced through subvocalized rehearsal, thus functioning as an "auditory short-term memory extending its use beyond auditory stimuli to written material, lip reading and signing" (Mascio, 2015, p.3). More clearly, the phonological loop plays a role as the verbal slave system of WM, including a phonological store (PS) which stores information in phonological form to rapid decay and an articulatory mechanism that reinforces linguistic materials in PS, and then converts the linguistic material from coded representation of written form into phonological form (Caplan, 2016). The second component is the visuo-spatial sketchpad which maintains visual-spatial stimuli but unlike for the phonological loop, it remains unclear how materials in this component are rehearsed.

The episodic buffer (Baddeley, 2000) preserves integrated visual, spatial, and verbal information distinctive for temporal occurrence (Caplan, 2016). The episodic buffer as a memory storage component in the STM-WM model holds multi-dimensional information (syntactic or semantic), interacting with other components as well as long-term memory (LTM) (Mascio, 2015). Moreover, this storing component incorporates new incoming information with the old one and adds up the time element, making sense of the information (Baddeley, 2012). Importantly, buffers by themselves are not sufficient to help retrieve the entire structure of longer sentences based on the current understanding of working memory in WM research, which stems from cognitive psychology (Cole & Reitter, 2019).

More pertinently for language, a considerable proportion of aspects of language acquisition and processing are related to this WM constraint (the decay of memory traces for later recall). For instance, WM is predicted not only to highlight phonological representations but also to shape grammatical phenomena such as the typology of word order and the domain minimization of syntactic/semantic dependencies (Hawkins, 2004). Language comprehension thus involves the ability to reconstruct the linguistic dependencies through retrieval of items that have already been processed in order to incorporate the new information into an evolved interpretation (Van Dyke, 2012).

Following the change of conception of WM, a growing body of studies has experienced a shift from focusing on functions of each component of WM into investigating the individual differences in WM and their effects on language processing (Wen & Li, 2019). For instance, according to Klaus & Schriefers (2016), WM capacity "as a source of individual differences" in the human cognitive system allows us to store and manipulate information in complex cognitive tasks. Consequently, these differences can forecast individuals' performance and behavior in cognitive activities such as L2 parsing and processing. These differences are seen in functional capacity, meaning that individuals differ in the processes in which they use the maximum amount of their limited capacities. They must, in fact, share their limited capacities between processing and storage demands of the task to which the WM system is being applied, as argued by Daneman and Carpenter (1980). In addition, it is also widely accepted that the effects of individual differences in WM on sentence processing can be a major complicating factor in investigations of L2 processing behavior among L2 learners, more likely suffering from resource limitations (Omaki, 2005). Taken together, WM plays a particularly vital role in the processes that integrate successively presented words, phrases, and sentences into a coherent representation.

### 2.2.2 Long-term Memory (LTM)

Unlike STM, Long-term memory (LTM) is considered to be an unlimited memory capacity which stores the information permanently. LTM consists of two components including declarative memory, that controls lexical knowledge, and procedural memory, that includes rule-based knowledge such as grammatical rules (Wen & Li, 2019).

### 2.2.3 The effect of Short-Term Memory -Working Memory (STM-WM) on L2 processing

This section first looks at how L2 learners prefer high and low attachment, then the effects of WM on L2 attachment processing are discussed in detail.

In addition to cross-linguistic differences and language-specific structural characteristics along with universal strategies, RC attachment preference among L2 learners is influenced by different factors depending on whether L2 learners' parsing strategies differ from the ones native speakers use when processing L2 ambiguous sentences and L2 learners prefer high or low attachment. In a study by Fernández (1999), L2 Spanish learners of English produced more high attachment answers than the native speakers of English in comprehending L2 ambiguous sentences, which was interpreted as a result of L1 influence. In Abdelghany and Fodor's (1999) study, the results showed that Arabic learners of English preferred low attachment influenced by the effect of prosody on ambiguity resolution or they preferred high attachment affected by predicate proximity account of RC attachment in a study by Bidaoui et al. (2016). Proficiency level is another factor the RC attachment preference can be affected by to consider. Karimi et al. (2021) showed that low-proficiency participants fully transferred their L1 (Persian) parsing strategies to their L2 processing, whereas high-proficiency participants processed sentences similarly to native English speakers even though there were still latent traces of their L1 attachment preferences consistent with Shallow Structure Hypothesis. More importantly, cognitive capacity is also evidenced as a factor that affects L2 sentence processing (Kim & Christianson, 2013; Traxler, 2007), suggesting that L2 learners with enough resources may behave native-like and those with insufficient capacity may not perform incremental processing while at the same time doing a memory-demanding task (Williams, 2006). The effects of WM therefore receive much attention to investigate.

The human syntactic parser performs computations in WM as short-term storage of lexical, syntactic and semantic information retrieved from LTM or created during linguistic processing. Working memory plays an important role in linguistic processing phenomena such as RC attachment resolution or filler-gap-dependencies in which the parser is required to store constituents in memory and retrieve them later for sentence comprehension (Jacob, 2009). Moreover, sentence processing and interpretation involve memory across time measures (Caplan, 2016). For instance, in (8), the subjects of *grabbed* and *lost*, and the antecedent of *his,* must be retrieved at the points where *grabbed, lost,* or *his* appear.

(8) *The boy who the girl who fell down the stairs grabbed lost his balance.*

It is thus clear that words or clauses with long structural and semantic dependencies require more work to assign syntactic relations. The long dependency requires more processing resources to interpret and thus involves higher memory span across the time. For instance, in (9), the antecedents of *who studied in California* must be retrieved at the point where the relative clause occurs.

(9) *Someone* fell in love with *the daughter* of *the psychologist who studied in California*

In this case, the garden-path sentence makes the parser first retrieve three potential antecedents for the relative clause to attach to support the memory requirement of the initial assignment of the preferred structure and interpretation of a sentence ("first pass" parsing and interpretation) and finally select one antecedent after reanalysis. On the one hand, long-distance dependency between RC and the antecedents requires a high WM span/capacity over time scale; on the other, the difficulty of the RC attachment preference complicates processing, involving the use of further processing resources and information. Regarding the interpretation in (9), it seems that a large amount of information has to be stored in WM to retrieve later, so individuals with a high working-memory span might find it easier to parse, while the same task might be difficult for individuals with a low working-memory span. In this respect, Jacob (2009) hypothesized that participants might select low attachment even if their L1 prefers high attachment, showing that WM span can neutralize the L1 influence in L2 processing when participants with low working-memory span are unable to store the first noun long enough. Therefore, working-memory span has been a potential moderator variable in the language processing of several linguistic phenomena such as relative-clause attachment ambiguities (Jacob, 2009). For example, in (9), if *the daughter* has faded away from working memory, when the parser reaches the relative clause, there is no choice but to attach the relative clause to *the psychologist*, because that is the only possible candidate which is still available. If that is the case, an L2 speaker with a low working-memory span is unable to select high attachment, and should have to choose low attachment, even if his own native language prefers high attachment. In this case, L1 preference for high attachment cannot influence L2 processing. Thus, an effect of L1 influence could only occur for participants with a high working memory span, who are able to store a constituent such as *the daughter* until they get to the relative clause. Overall, depending on the tasks employed to measure WM capacity, the type of inputs, the nature of L2 processing task, and the learner's proficiency, empirical research is expected to provide inconsistent findings. For instance, for L2 learners with lower proficiency, executive WM (EWM) is assumed to influence processing and performance aspects, while for those with higher proficiency, it affects offline processing (Wen et al., 2015).

Short-term memory (STM), a historically appealing construct most connected to parsing and interpretation (Caplan, 2016: 633), operates similarly in terms of applying the temporal intervals or available capacities as parsing and interpretation do (Caplan, 2016; Caplan & Waters, 2013;

Jacob, 2009). Put differently, the memory system employs STM as a sentence memory to contribute to syntactic comprehension in parsing garden-path sentences with temporary ambiguity and accounting for processing difficulty of L2 sentences.

According to the STM-WM model, through matching a retrieval cue with other retrieved items in the memory, the parser places the focus of attention on one item which is assumed to be the recent item for low-span individuals (Lee & Federmeier, 2012; Payne et al., 2014). Items outside the focus of attention in long-term memory (LTM) are recalled through mechanism of content-addressable retrieval with chunking the memory with regard to semantic features (McElree 2006; Verhaeghen et al., 2007 cited in Caplan, 2016, p. 635).

Regarding sentence comprehension, two possibilities are derived from memory mechanisms in models of STM-WM. First, the information is retrieved through a content-addressable mechanism. Second, a limited number of highly accessible items (at most five) determines storage of limited capacity memory in parsing and interpretation (Caplan, 2016). While Lewis (1996 as cited in Caplan, 2016, p.638) argues that capacity limits occur when the buffer (memory storage) can contain two items of the same type, Lewis and Vasishth (2005) suggest that in a retrieval-based parsing model, a structure with three buffers, while having much in common with the conceptions of working memory and STM, refers to a limited capacity to focus on one item during the retrieval process, to bring retrieved items, and to focus when processing. Individual differences in working memory are partly due to interference of present items/information, as argued by Engelhardt et al. (2016). Thus, in retrieval-based parsing models, syntactic interference effects, as shown in Figure 2, are expected when retrieved items have syntactic features shared by the retrieval cue (Caplan, 2016, p. 366). Therefore, not surprisingly, individuals with lower vocabulary scores perform more poorly on comprehension questions, especially due to interference, suggesting a memory model that relies primarily on a cue-based retrieval mechanism, compatible with interference compared to capacity-based theories of working memory (Caplan, 2016). Consequently, this matching with retrieval cue interferes with retrieval of a target item if these features are part of the retrieval cue in online measures of parsing and interpretation, as illustrated in Figure 2.

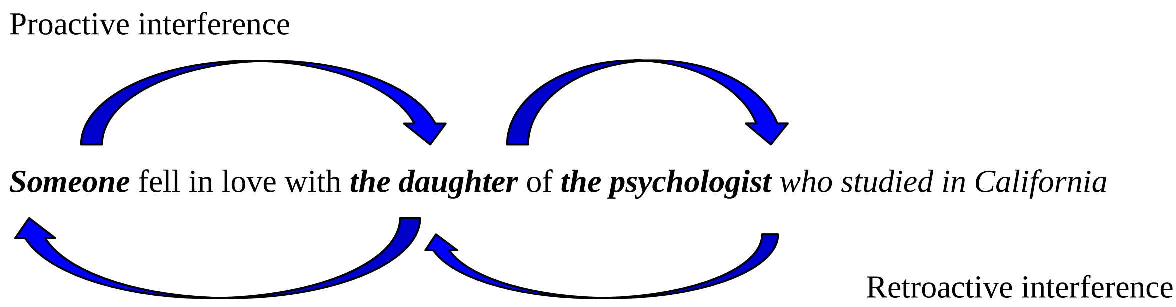


Figure 2. Proactive and Retroactive interferences in RC processing

As stated by Caplan (2016), LT-WM just supports skilled parsing and interpretation. In contrast, ST-WM receives much attention to support memory, especially when syntactic structures have to be revised and at points where incremental comprehension failure happens and the parser recalls the previously retrieved items held in memory, specifically in non-cumulative self-paced reading and externally paced reading. Therefore, the retrieval of items in such conditions employs mechanisms that support STM-WM tasks involving previously retrieved items in lists (Caplan and Waters 1999, 2013). Theoretically, retrieval in reanalysis occurs when the input is not semantically or syntactically completely well-structured, it has thus shared structural features with retrieved items, causing proactive and retroactive interference.

The factor assumed to play a role in RC attachment preferences of L2 learners in this study was WM. WM provides evidence in support of the ‘chunking’ hypothesis, suggested by Swets et al. (2007). Based on this hypothesis, low span participants within inadequate resources pause at the boundary between the complex DP and the RC and, in this way, chunk NP1 and NP2 into a single unit and prefer, as a result, a NP1 attachment. In the study by Swets et al. (2007), too, participants with high WM may have taken in longer chunks, without any break at the boundary between the complex DP and the RC and have thus preferred low attachment. The material in Swets et al. (2008) was presented chunk by chunk, thus, participants with different WMs could parse the sentences differently leading to different attachment preferences.

The results of a study by Jun (2003) also showed that L2 learners with low WM preferred high attachment supported by the Predicate Proximity principle. Similarly, Payne et al. (2014) provided evidence indicating that low-span adult learners had a stronger tendency to select high attachment, using online and offline measures. In contrast, L2 learners with high WM favored low attachment like that of the English native speakers (Karimia & Ferreira, 2016).

There is a lack of experimental research investigating whether and how WM affects L2 processing and reading comprehension using L2 knowledge along with the effect of the experimental conditions manipulated in the stimuli, which have not received attention. Although some L2 studies on RC attachment preferences have found no effect of WM, numerous studies have indicated that individuals with high WM process syntactically ambiguous sentences differently from those with low WM (Karimia & Ferreira, 2016; Kim & Christianson, 2013; Payne et al., 2014).

Experimental WM research explores whether WM plays different roles under different conditions. Multiple components of WM may have different effects on specific aspects of online L2 processing. In such studies, it is important to determine the predictor variables such as phonological short-term memory (PSTM) or executive WM. While phonological short-term memory has been found to be a predictor of length, executive WM has been found to be predictive of reaction/response time in studies where participants did not have complete information about the experiment (Wen & Li, 2019). While some studies have shown that the backward digit span task correlates more with STM than WM, just being as a storage of items (Mascio, 2015), others have highlighted associations between [6]Suppression of Interference (SoI) tasks and manipulation tasks but referring to reading span task as correlating with WM involving item storage and processing (Daneman & Carpenter, 1980; Klaus & Schriefers, 2016). In this regard, WM is argued to be the most widely studied executive function dealing with sentence comprehension (Engelhardt et al., 2016), which is commonly measured with reading span tasks (Baddeley, 1986; Daneman & Carpenter, 1980; Klaus & Schriefers, 2016).

[6] SoI tasks are those that interleave the memory task with some sort of distractor, either between each part of the Working Memory Assessments stimuli or at the end of each trial before the response. A manipulation task, however, is when the stimuli itself must be mentally manipulated (Mascio, 2015).

## 2.3 Processing models

While it is controversial whether properties of L2 can affect native language processing (Dussias, 2003), the influence from a reader's first language (L1) on L2 syntactic processing seems more likely. This section therefore discusses two frameworks of L2 processing, which are relevant to the issue of L1 influence in the sense that they make clear, and also directly opposing, predictions regarding a possible role of the L1 in L2 syntactic processing. However, results for effects of an L1 influence are contradictory. In addition, in comprehension, linguistic representations formed during language processing are sometimes good enough for the task at hand to satisfy online Cognitive Equilibrium where linguistic representations are sufficiently successfully integrated with existing knowledge structures. Put differently, the processing system is sensitive to online states of cognitive equilibrium when being presented with a sentence or a piece of discourse, in fact any cognitive challenge which disturbs Online Cognitive Equilibrium (Karimia & Ferreira, 2016). Hence, this section also discusses the Online Cognitive Equilibrium hypothesis, referring to the issue of working memory in L2 RC processing.

### 2.3.1 The Competition Model (CM)

One of the performance-oriented models is the Competition Model (CM) which accounts not only for linguistic representations but also language use for both first and second language acquisition (Bates & MacWhinney, 1989; Field, 2004). The CM holds that native speakers of different languages rely on language-specific cues when processing linguistic input (Jacob, 2009). More specifically, sentence parsing strategies involve two tasks: Firstly, a reader must identify the cue validity of each piece of information included in a sentence. In other words, it is important to determine which pieces of information in a sentence are more valuable for parsing. For instance, native speakers of English primarily rely on word order cues as a reliable cue to agent- or subject in English, whereas native speakers of German rely more on morphological cues, suggesting that native speakers generally prefer to rely most on processing cues with high validity in their respective native language. Considering flexible word order in Persian compared to English with a strict word order, Persian learners should be relatively more sensitive to semantic cues. Thus, such cues are of high validity, and relatively helpful for determining the syntactic structure of a Persian sentence and interpreting the RC attachment. Consequently, in Persian, while typologically word order is important, to some extent, lexical and structural dependency is of paramount importance in L1/L2 syntactic parsing.

Secondly, a reader should determine the *cue cost* of each piece of information contained in the sentence, that is, word order might be relatively easy to process (low *cue cost*), while the morphological cues or semantic/syntactic dependencies might be complex and might thus involve extra processing resources (high *cue cost*). In this regard, the competition model assumes that a reader shares his available processing resources to the different bits of information contained in the sentence, based on high/low cue validity and high/low cue cost. Hence, the more bits of information are useful and easy to process, the more processing resources it receives (Jacob, 2009). In this regard, a processing mechanism functioning as a dynamic system seems to re-estimate validity and cost of cues while processing new linguistic input.

Importantly, an assumption in CM is that the L1 grammar is the basis for the L2 syntactic processing, meaning that readers and listeners might use their knowledge of L1 as well as L2 knowledge to constrain their interpretations of sentences and mechanisms underpinning the L1, thus influence in the L2 processing (Hawkins, 2004; MacWhinney, 1997, 2005).

### 2.3.2 Shallow Structure Account (SSA)

While the CM predicts a strong syntactic influence of L1 mainly on the final interpretations of readers in offline measures (MacWhinney, 1997), the shallow-structure account mostly deals with effects of online measures on real-time sentence processing. As assumed by Clahsen & Felser's (2006) Shallow Structure Account (SSA), L2 readers build only a shallow representation of the syntactic structure of an L2 sentence compared to a native speaker during comprehension. This shallow representation, lacking in syntactic detail, is not enough for syntactic properties of the L1 to have an influence on processing. Therefore, syntactic properties of the L1 are not assumed to affect L2 sentence processing (Papadopoulou & Clahsen, 2003). The results provided by Smith (2016) were in consistent with the prediction of SSA in which it was shown that L2 Japanese speakers resolved RC attachment ambiguity like native speakers, and that the participants' L1 had no effect on their ambiguity resolution. Similarly, Marefat and Farzizadeh (2018) found that non-native speakers of English disambiguated RC attachment in native-like fashion, making reference to the same explanation. In contrast, other studies have found evidence against the predictions of SSA, emphasizing the L1-based preferences. In a study by Malakooti et al. (2020) results were in contradiction to the prediction of SSA in which L2 learners in an online task preferred high attachment compared to the native speakers of English, relying more on lexical-semantic cues, and less on phrase-structure rules and word order. Likewise, the findings by Jacob (2009) revealed that German learners of English successfully processed the syntactic structure of an L2 sentence, relying on deep representations of L2 structure with enough syntactic details. Despite investigating differences between L1 and L2 processing across the predictions of CM and SSA, it seems that these differences are not only related to effects of L1 influence, but to other unique properties of L2 processing.

### 2.3.3 Online Cognitive Equilibrium (OCE)

In addition to the above-mentioned processing models, the Online Cognitive Equilibrium (OCE) Hypothesis can contribute to our understanding of L2 processing (Karimia & Ferreira, 2016). The OCE holds that the comprehension system fundamentally strives to attain and maintain a state of Cognitive Equilibrium as early and for as long as possible. In Cognitive Equilibrium, linguistic representations are successfully integrated with available knowledge structures to form good-enough representations, and to reduce uncertainty, which result in processing difficulty. Based on this, the processing mechanism employs a set of algorithms to achieve the meaning of the whole structure by a retrieval process of words from the lexicon and organization of those words into a whole structure to present a meaningful and coherent representation of the linguistic material.

The OCE hypothesis is compatible with recent theories of language processing which maintain that linguistic representations are formed through a complex interaction between simple heuristic processing and deep syntactic algorithms (Figure 3), and also with theories which refer to shallow levels of linguistic representations, lacking in detail (see 2.5.2). Finally, the OCE is closely interrelated to memory models, thus contributing to explaining the processing mechanism when parsing L2 RC attachment, which will be discussed later.

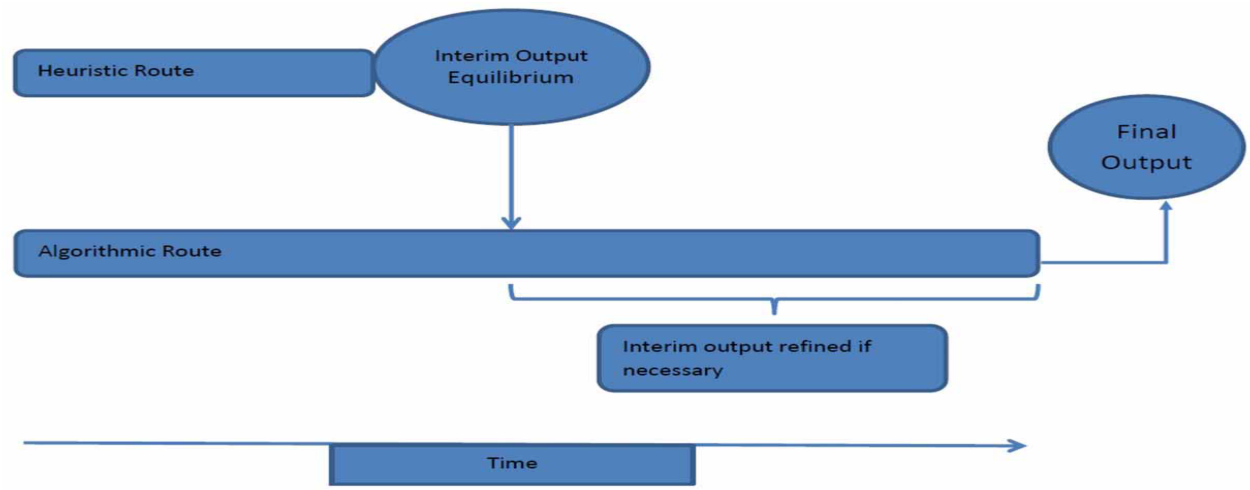


*Figure 3. The model of language processing according to the Online Equilibrium hypothesis (adapted from Karimia & Ferreira, 2016).*

As illustrated in Figure 3, while both heuristic and algorithmic routes are simultaneously triggered (Kuperberg, 2007; Lim & Christianson, 2013a; Karimia & Ferreira, 2016), the heuristic route, influenced by simple rules, usually delivers an initial interim output before the algorithmic route is used in order to achieve equilibrium faster. This process supports the first principle of the OCE based on which "the cognitive system attempts to maximize equilibrium at the earliest opportunity" (Karimia & Ferreira, 2016, p.6). When the cognitive system reaches a state of equilibrium (good-enough linguistic representations) it tends to remain in that state as long as possible, causing the system not to allocate more resources for algorithmic processing (Karimia & Ferreira, 2016). It is assumed that the initial heuristic route and the formation of the interim output may only satisfy degrees of equilibrium, not full equilibrium. The more certainty about accuracy of the interim output, the greater equilibrium is achieved, depending on the factors such as how relevant and convincing the retrieved information is. Alternatively, high task demand is an influential factor that requires deeper processing algorithms and the system may then rely more on the algorithmic route. Consequently, the interim output of the heuristic route (disequilibrium) will still be influenced by ongoing algorithmic processing to be refined through the allocation of more processing resources to achieve equilibrium, suggesting that language processing is incrementally sensitive to states of equilibrium in the relative timing of the heuristic and the algorithmic routes. It is more likely that heuristic processing depends more heavily on top-down information and is activated by semantic memory-based representations, while syntax-based algorithmic processing seems to rely more heavily on linguistic knowledge depending on bottom-up processing to derive meaning, by organizing complicated inputs using relevant linguistic rules (Lim & Christianson, 2013a).

As mentioned earlier, the OCE is connected with memory models in how and when linguistic input is represented, processed and retrieved to help the parser achieve equilibrium and meaning to be fully understood. The heuristic processing in earlier stages results in quick or good-enough representations of the information, whereas in later stages of processing, costly computational algorithmic processing causes the processor to involve more resources to achieve Online Equilibrium (Dwivedi, 2013). In contrast, in the earlier stage of the retrieval process in working memory, focus of attention is on one item through matching a retrieval cue with other retrieved items in the memory, then items outside the focus of attention in long term memory (LTM) are recalled. While in later stages, the retrieval difficulty will increase when non-target items also have the features of the retrieval cue as well as more items with similar features semantically and syntactically, causing interference effects in online measures of parsing (Caplan, 2016). Lim and Christianson (2013a) proposed that L2 learners try to process L2 sentences with a combination of semantic-based heuristics and L2 grammar-based algorithmic processing, but since L2 grammar is different from the L1 grammar, the syntactic processing in an L2 context may be relatively more superficial and thus more susceptible to the influence of heuristic processing.

It has been argued that while individuals with low WM span prefer high attachment in L2 RC ambiguity resolution, individuals with high WM span select low attachment (Jacob, 2009; Karimia & Ferreira, 2016; Swets et al., 2007). Swets et al. (2007) claims that these attachment preferences may be related to the different chunking strategies among people with different working memory capacities. Moreover, it is more likely that low-span individuals attempt to arrive at equilibrium at the earliest opportunity which is in line with the first principle of the OCE hypothesis. It has been also documented in the working memory literature that maintaining structured information in memory is easier than maintaining unstructured information (Szmalec, & Vandierendonck, 2009), which is incompatible with theories of language processing that maintain that partially processed but incomplete syntactic dependencies impose more workload on working memory, and thus, increase parsing difficulty (Gibson, 2000). Because people with low working memory spans are unable to keep much information in their memory, their need to arrive at equilibrium faster makes them attach RC to a NP faster compared to people with high working memory spans. In contrast, it is also argued that people with high working memory spans are more tolerant to disequilibrium regarding RC ambiguity. There should thus be significant differences between individuals with high/low span in how long they defer the resolution of RC attachment (Stewart et al., 2007).

## 2.4 Summary

To sum up, the literature on RC attachment preferences has mainly examined cases with only two NPs as the potential antecedents for RCs, simple natural stimuli, and also the effect of working memory without using any other independent predictors for the time course of attachment processing. (In) definiteness, length of stimuli, and (non) extraposed RC could all significantly influence speakers' attachment preferences and reaction time of processing, but these have not been examined when there are three NPs as potential antecedents to the RC, and no morphological or syntactic cues exist to guide the parser in attachment processing. The correlation between these independent predictors in Persian compared to English in individuals with different working memory spans have not been investigated. The present study will thus employ multiple tasks to explore how the above-mentioned variables interact with each other and the time course in real-time processing of L2 RC attachment ambiguity resolution while also taking working memory capacity into account.

# 3 The current study

The purpose of the study is to explore how Persian learners of English behave in online incremental sentence processing with a focus on RC resolution. Variables such as (in)definiteness, length of stimuli, and (non) extraposed RC will be examined, along with working memory capacity. The study pays special attention to relative reaction times and the learners' scores obtained from the experiments.

## 3.1 Research questions and hypotheses

This thesis aims to address the following research questions:

1. Do L2 learners read L2 sentences more slowly than native speakers when processing L2 RC ambiguity?
2. Do (in)definiteness, RC length, and RC extraposition affect L2 RC processing in Persian learners of English?
3. Do Persian L2 learners of English transfer parsing strategies from their L1 to L2 RC attachment processing?
4. Does working memory (capacity) affect L2 RC attachment processing?

To answer the research questions, the following hypotheses were formulated:

**H1** Persian learners are assumed to read L2 sentences more slowly than native speakers. It might depend on the conditions and be affected by L2 proficiency, L2 exposure and WM performance among Persian learners when processing ambiguous sentences online.

**H2** Definite nouns, RC length, and non-extraposed RCs are expected to lead to faster reading times for Persian learners of English than indefinite nouns, long chunks of the experimental stimuli, and extraposed RCs.

This hypothesis is derived from the findings by Kuhbanani (2016), Shabani (2018) and Rasekh-Mahand et al. (2016), which indicated that definite nouns, short RC
s, and RCs extraposed to the end of the sentences were easier to read, thus resulting in easier L2 RC processing.

**H3** It is more likely L2 learners use their L1 parsing strategies when processing L2 RC attachment ambiguity. Persian learners of English may resort to lexical-semantic cues (Arabmofrad & Marefat, 2008; Marefat & Farzizadeh, 2018; Marefat & Meraji, 2005; Marefat et al., 2015; Moghadassian, 2008) while native speakers of English may rely on word order and syntactic structure (Caffarra et al., 2015; Clahsen and Felser, 2006).

**H4** It is assumed that Persian learners' parsing strategies may be modulated by WM performance (Jacob, 2009). L2 learners with high WM capacity are assumed to prefer low attachment and process L2 sentences in a shorter time, meaning their RC L2 attachment preference is like that of native speakers. Put differently, people with different working memory span may present different preferences (Caplan, 2016; Jacob, 2009). WM effects also might neutralize the L1 influence in L2 processing for Persian learners and cause high attachment preference for native speakers by neutralizing the recency principle, as Jacob (2009) suggests.

Furthermore, to satisfy Online Cognitive Equilibrium, L2 learners are predicted to employ both heuristic and costly algorithmic processing when garden-path sentences appear with extraposed RCs followed by comprehension questions, resulting in longer reaction times in online RC processing. Although extraposed RC is intended to reduce processing cost in Persian, it might increase processing difficulty in L2 processing. In case L2 processing is constrained by lower levels of working memory, L2 learners are predicted to employ native-like default strategies, showing longer reaction time in real-time processing. In case L2 learners have reduced processing capacities as compared to native speakers, L2 learners would be predicted to show longer processing and difficulties in recovering from initial reanalysis to parse L2 RC attachment. Considering these predictions from the above models and accounts, it is more likely that L2 learners transfer their L1 processing strategies to L2 processing as seen in most L2 processing studies. It is argued that shorter RTs suggest that learners employ heuristic processing to achieve equilibrium faster, and longer RTs suggest that costly algorithmic processing can tolerate disequilibrium to arrive at full equilibrium after allocating more processing sources to interim output (Karimia & Ferreira, 2016).

# 4 Methodology

In chapter 2, I discussed how native and non-native speakers of English may process RC attachment, and that there are multiple potential factors that might affect their attachment preference in online incremental language processing. Although extraposition and RC attachment processing has been documented in a large number of L2 processing studies, studies in which there are three potential nouns to which RCs can attach are rare. To address this, the present chapter introduces a study of online RC attachment processing among adult Persian learners of English and English native speakers, which is based on the experimental design of a previous L2 processing study of RC attachment.

## 4.1 Participants

Eighteen Persian learners (6 females, 12 males; mean age = 31.44; range: 21-37; *SD* = 5.49) and 15 native speakers of English (13 females, 2 males; mean age = 30.67; range: 22-40; *SD* = 4.67) participated in the experiment. They were recruited with the help of friends and acquaintances by sharing experiment information on social media such as Facebook and Instagram. The Persian learners were all university students of English who had completed or had been exposed to English in an instructional context from approximately the age of twelve years at high school. They were all living or studying in Iran at the time of participating in the study. Native speakers of English included British or American English speakers. Although some of them were living in countries other than their homelands at the time of testing, they reported that English was still their dominant language which they used on a regular basis. 5 Persian learners and 3 native speakers filled out the consent form but did not complete the experiment or ceased their participation in the experiment.

## 4.2 Materials and tasks design

### 4.2.1 LHQ3

The language history questionnaire (LHQ3) is a web-based tool for evaluating the linguistic background and language proficiency of multilinguals or bilinguals, developed by Li et al. (2019). This questionnaire consists of demographic questions about age, education, and a number of questions asking for information about L2 proficiency in reading, writing, comprehension, speaking, other language knowledge, length of stay abroad, and so on (see Appendix B).

### 4.2.2 LexTALE

LexTALE is a quick online lexical test for advanced learners of English (Lemhöfer & Broersma, 2012). It is a reliable predictor of English vocabulary knowledge which is fundamentally correlated with a measure of general English proficiency, frequently used by L2 researchers. It is a lexical decision task which consists of 60 trials. In each trial a string of letters is presented on the screen and participants' task is to judge whether the string is an existing English word by pressing buttons for yes or no. LexTALE can be downloaded from www.lextale.com and be run online.

### 4.2.3 Reading span task

The reading span task adopted from Klaus & Schriefers (2016) consisted of a processing component in which participants judged the semantic correctness of a sentence (e.g. *During winter you can get a room at the beach for a very low rate*) and a storage component in which participants memorized nouns (e.g. *carrot, sleeve and light*) to recall later. This sentence-noun combination constituted a trial. Such trials with two to six set sizes of sentences built individual blocks, which were presented in randomized order for participants to judge the sentences and recall as many words as possible after each sentence[7].

[7] The scripts to run the task are available here: https://github.com/janakl4us/workingmemory.

### 4.2.4 Backward digit span task

Measures of backward digit span (BDS) as the most widely used tests of short-term verbal memory (Richardson, 2007) are presented to show participants' memory span capacity derived from reverse-order (backward) recall of digit sequences. According to Woods et al. (2011), testing ceases when the subject fails to accurately recall when the maximum digit length is reached (7 or 8 backward). Hence, the longest digit span participants could recall without a mistake can be taken as their memory span capacity (Indrarathne & Kormos, 2017). Traditional memory span refers to the maximum length of a sequence of items that can be reproduced from memory following a single presentation and treat short-term memory as a passive storage buffer (Daneman & Carpenter, 1980). The memory tests often measure the maximum number of items that an individual can store in a task that simply requires that the individual attend to some input, encode it, store it, and retrieve it. It is also assumed that maximum length (ML) and digit span (DS) metrics, obtained over all 14 trials, were reliable predictors of BDS performance over all trials that were obtained from recalling digits by groups (Woods et al., 2010). These metrics make it possible to provide a better representation of reduced variance. The backward digit span task was adopted from Luthra & Todd (2019). Initially, the task was to measure forward digit span, but to achieve the purpose of the present study focusing on participants' STM (storage) and WM performance (processing), it was redesigned to measure backward digit span (Stimuli 2 3 4 8, response 8 4 3 2) since the parser needs to store constituents and remember them later to process sentences through integrating information. Moreover, the BDS is assumed to involve the additional manipulation of information within temporary storage (Hester et al., 2003). The BDS task, which is often employed as a measure to assess STM and WM, can thus better measure memory performance when processing sentences in real-time. Redesigning was done by changing some Javascript coding (*return selection* into *return selection.reverse()*, changing *minSetSize*), and setting instructions to correctly reflect the task, and to test backward recall (see Appendix C). It was coded and run on the Cognition.run server as a database to access data.

### 4.2.5 Self-Paced Reading (SPR)

SPR is a computerized technique employed in psycholinguistic research to measure processing of linguistic units on-line (i.e., real-time) (Jegerski, 2014) in which participants read sentences broken into words or segments at a pace they control (Marsden et al., 2017). The materials for the SPR task were initially adopted from previous studies of the processing of relative clause attachment, namely Felser et al. (2003), Hopp (2014), and Rah (2009). However, when piloting the stimuli, some changes were made to sentences to adjust them for length, naturalness, plausibility, and experimental conditions. Some words were added or removed from the sentences to organize them to be of the same length. NPs were changed to adjust the length. RCs elements were modified in terms of tense, verb form, predicate type and order of elements (Appendix D for the complete list).

For this experiment, all experimental items consisted of three critical noun phrases (the segments to which RCs can attach). All English words used in the sentences were of a high frequency to reduce the possibility of lexical processing cost for all the L2 learners. The frequency of words was checked both in the British National Corpus (BNC) and the Corpus of Contemporary American English (COCA). The minimum normalized frequency of the words was 19.9 in BNC and 9.18 in COCA (per 100,000). The maximum normalized frequency was 1.540 in BNC and 11.282.5 in COCA (per 100,000) with the frequency ratio between 1.02 and 1.15. Nevertheless, it was difficult to perfectly match all words in all experimental sentences for frequency. Moreover, it has to be considered that corpora yield different frequency counts for frequency as a relative factor.

Sixty-four sentences were used as part of this experiment, 32 experimental sentences, and 32 fillers. Some of sentences were segmented into four segments such as *Someone shot/the servant/ of the actress/ who was on the balcony,* and some into five segments like in *The man /who wrote to /the manager /of the assistant /was late*. The sentences with extraposed RC were composed of 4 segments and those with non-extraposed RC were composed of 5 segments. This difference in segmentation of the sentences was created after clear separation of the critical regions to satisfy the purpose of the study focusing on L2 RC processing. For the SPR task, it is especially important that the sentences are not only matched for total length but also for the length of the critical words and regions (NPs and RCs). Experimental sentences were designed, crossing the variables noun type (definite vs. indefinite), RC length (short vs. long), and RC type (extraposed vs. non-extraposed), following a 2*2*2 factorial design (see Appendix D). The variable indefiniteness was only manipulated in the conditions for the NP1s to test whether they cause processing cost to occur in region 1, whereas NP2 and NP3 are always definite. Eight lists were constructed, each comprising four items from each condition, with each list containing exactly one of the four versions of each item. The SPR task was designed in Psychopy builder, with some additional code components and routines then uploaded on the Pavlovia.org server to run the experiment online and access data.

The present study tries to test the effect of the experimental conditions on L2 RC processing by using a word-by-word SPR paradigm and by carefully analysing all the critical words and regions separately. Thus, the NPs and RCs are considered as critical regions in order to better track the possible processing cost of the conditions the learners might face when reading sentences. In this study, the relative RTs were collected and analyzed since the experiment was run online due to the pandemic and research limitations regarding the participants.

### 4.2.6 Offline questionnaire

The offline questionnaire was adopted from Rah (2009) to measure the offline judgement of L2 RC attachment. It included eight questions with three options to assess the plausibility of options for RC attachment. Here, one example is provided (5). The whole questionnaire is given in Appendix E.

(5) The housemaid saw the driver of the lady who was waiting in front of the garage.

- the housemaid was waiting.
- the lady was waiting.
- the driver was waiting.

## 4.3 Procedure

All tasks were run online. The URLs of the web-based tests and questionnaires were emailed to participants. The order of the tests was the same for all participants.*

The LHQ questions were customized according to what was intended for the present study. To fill out the LHQ3 questionnaire, participants were asked to click on the following link, enter the questionnaire using their special temporary code, and complete it.

(lhq3.herokuapp.com/student/student_signin/?questionnaire_ID=vvz27qcx).

In the LexTale test, participants entered the task by clicking on the link, clicked on Start LexTale, and then selected English, and started the test. The URL of the task was copied from the browser tab and was then sent to participants via email.

In the reading span task, sentences were displayed at the center of the screen for a maximum of 10 seconds. Participants were requested to read the sentences and press the right arrow button corresponding to the response “no” if it did not make sense, or the left arrow button corresponded to the response “yes” if it made sense. After a blank screen of 500 ms, the word appeared for 1,200 ms, and participants were instructed to read and remember this word. Following two to six sentence-word combinations, six empty fields appeared on the left side of the screen, prompting the participant to recall all words they could remember, and type a word in each empty field regardless of the order in which they were presented. The next trial was then initiated by the participant by pressing the continue key.

In the digit span task, a sequence of words was presented on the screen and participants were required to recall them in reverse order. The test started with sequences of 3-digit sets going up to 13-digits sets randomly presented after 1 second. Each time the feedback for each response was displayed ( https://1plpk9wavy.cognition.run).

In the SPR task, a fixation point (+) was displayed in the middle of the screen before trials. Sentences were presented phrase by phrase in the middle of the screen. Each time participants pressed the button, the phrase disappeared, and the next phrase of the sentence appeared instead in a non-cumulative mode of stimuli presentation (Marinis 2003, as cited in Rah, 2009). Each new sentence was preceded by an asterisk (*) to alert participants that a new sentence was about to begin. After some of the sentences, a comprehension question appeared without delay, followed by a screen prompting participants to answer the comprehension question by pressing one of two buttons (y) for yes and (n) for no. The questions were included to reduce the possibility of continuous motor behavior by participants. This technique might also yield different reading time patterns resulting from misinterpreted sentences relative to target-like interpreted sentences. The comprehension questions therefore also distinguish this possibility. The experimental session started with a practice session so that participants could get used to the phrase-by-phrase presentation of the sentences. Participants were given a break screen after the practice session to be ready for the rest of the experiment. The experiment lasted approximately 15 minutes.

Finally, an offline questionnaire was presented to participants and they were asked to show their preferences to which noun phrases RCs can attach by selecting one of the three alternative interpretations of the sentence most plausible to them.

All participants did the tasks in their own time without being monitored by the researcher. They were allowed to ask about any issue about running or doing the tasks through email or social media.

## 4.4 Data Analysis and coding

### 4.4.1. LHQ3

The descriptive measures from the LHQ3 was self-estimated L2 proficiency and exposure. In scoring system in LHQ3, L2 proficiency were counted based on the sum of a participant's self-rating of his proficiency levels on different components of English language.

### 4.4.2. LexTALE

The means and standard deviations of proportion of correct responses in the LexTALE were counted to assess the participants' general English knowledge. To present a comprehensive picture of the measured proficiency by two tasks, LHQ3 and LexTALE, a Pearson correlation test was performed to determine whether there was a relationship between these two measures and whether they were a reliable predictor affecting the participants' online processing performance. Moreover, their relationship was also tested by a linear regression model for more clarification.

### 4.4.3. Reading span task

For scoring the WM reading span task, the results from the processing component of the task and from the storage component were considered. The descriptive statistics of the storage component was retained. More precisely, the mean of correctly recalled items of each set appeared sequentially between sentences on the screen to be stored and recalled later in each block during task was first counted to make up the final WM scores. Standard deviations for the data distribution, skewness and kurtosis values for normal distribution of data and error rates were also measured to give a better picture of the participants' performance in the reading span task (see Table 12). Additionally, Cronbach's α was computed as an index of internal consistency at the level of the 15 individual blocks (see Table 7). For the processing performance, mean RT and error rates were computed.

### 4.4.4. Digit span task

In digit span measurement, the longest span participants could remember without mistake was taken as their digit span. The means, the standard deviations and coefficients of variance of the backward digit span were calculated for both groups. In addition, a correlation test was performed to explore the relationship between the two metrics of digit span task, (Maximum Length) ML and (Digit Span) DS. With regard to high standard deviations from the means of backward digit span (BDS) metrics and coefficients of variance values, the relationship between independent age predictor and dependent digit span was measured by a simple regression model to illustrate the distribution of data points which seemed to be far away from the mean due to individual differences.

### 4.4.5 SPR task

Online L2 processing was investigated by using a segment-by-segment SPR paradigm and by carefully analyzing all the critical regions separately in order to better understand the possible processing difficulties Persian learners and native speakers might face when reading ambiguous sentences. The sentences were designed with 8 conditions based on the noun type (definite/indefinite), RC length (short/long), (non)extraposed RC, with four sentences for each condition. The accumulated RTs of the comprehension questions and experimental sentences were analyzed per region by condition to compare the RTs between Persian learners and native speakers to identify where the processing costs occurred.

The mean comprehension accuracy was calculated for each experimental condition between participant groups. Mean reaction times for trials with correctly answered comprehension questions were computed. Specifically, means and standard deviations of reading times for each segment of each experimental sentence were calculated. ANOVAs were performed to measure the mean difference of RTs by experimental condition as the within-subject variables and Group as the between-subjects variable. In addition to mean differences measured by ANOVAS, a post hoc test (Bonferroni) was also run to identify the source of any significant effects. Pearson correlation tests were also employed to probe any relationship between variables. All statistical analyses were run using the R programming package (1.4.1717, 2009-2021 RStudio) and SPSS, version 26.

### 4.4.6. Offline task

The mean and standard deviations of attachment frequency distribution were computed, and the frequency distribution in percent of the attachment choices (NP1, NP2 or NP3). In this task, N1 and NP2 are considered to be high attachments and NP 3 to be low attachment since no written literature or research were found to discuss and name the first nouns appearing at the beginning of the sentences as the third possible antecedent for the RC. In order to explore whether proficiency had an influence on the Persian learner's low attachment choices, a correlation test was run to determine whether proficiency was a reliable predictor for low attachment choices. In addition, a mixed two-factor ANOVA test was performed with attachment (High vs. Low) as a within-subjects variable and Group as a between-subjects variable.

# 5 Results

The present chapter first presents the data extracted from the tasks separately, but some metrics of the tasks such as proficiency, age and memory span are compared to measure the correlation between them. Then, the SPR task is analyzed as the main task of the thesis to better examine the effect of other variables on the online processing performance among the participants.

## 5.1. LHQ3

Following previous experimental studies on L2 processing, the results from the LHQ3 were used to predict the potential effect of the Persian participants' linguistic background, and language proficiency through measuring their correlation with participants' online performance derived from the experiment in this study. Although 6 participants reported that they had one parent who spoke a language other than Persian (Kurdish, Turkish), their main language was still Persian. All participants started learning or learned English in classroom settings and some of them continued to learn in a self-study mode. Table 1 shows descriptive information of the data derived from the LHQ3 regarding the Persian learners' proficiency in English. The mean and standard deviation of overall self-reported proficiency level (rated on a 7-point Likert scale and automatically combined from four components of L2 to a composite score ranging from 0 to 1) and their age of exposure to L2 are summarised in Table 1.

*Table 1. Self-rated proficiency for Persian learners of English*

| LHQ3 metrics | Mean | SD |
|---|---|---|
| L2 Proficiency | 0.71 | 0.14 |
| L2 Exposure (year)<br>Range (10-35) | 20.44 | 6.67 |

## 5.2. LexTALE

Table 2 shows the means and standard deviations of the native English speakers' and the Persian learners' LexTALE scores, displayed as % correct responses. As was expected, native English speakers scored higher on the LexTALE ($M$ = 91.40) than the Persian learners ($M$ = 74.09).

*Table 2. Descriptive statistics of LexTALE % correct test for two participant groups*

| | N | Mean | SD |
|---|---|---|---|
| Native speaker | 15 | 91.40 | 7.76 |
| Persian learners | 18 | 74.09 | 15.83 |

The Persian learners' proficiency scores measured by LexTALE was compared with their self-rated proficiency by LHQ3 using a Pearson's correlation test. The test results showed a significant correlation between the proficiency measures ($r$ (18) = 0.503, $p$ = 0.033). In addition to the Pearson's correlation test, a simple regression model was also run to show how much LexTALE and self-rated proficiency scores were correlated. The correlation coefficient was positive since y increases as the x increases (see Appendix F).

## 5.3. Backward digit span

The total correct scores on the backward digit span task reported by Persian learners and native speakers as well as descriptive statistics are provided in Table 3.

*Table 3. Mean, standard deviation, and coefficient of variation for metrics obtained from the backward digit span test*

| | Persian learners | | Native speakers | |
|---|---|---|---|---|
| | ML | DS | ML | DS |
| Mean | 9.39 | 8.17 | 8.33 | 7.53 |
| SD | 1.75 | 1.58 | 2.22 | 1.95 |
| C.V | 18.63% | 19.33% | 26.65% | 25.8 % |

ML = Maximum length over all trials, DS = Digit Span over all trials and C.V = Coefficient of Variance

The Persian learners showed a higher mean maximum length over trials than native English speakers (9.39 digits vs 8.33 digits), but there was no difference between the groups on the BDS task. A simple regression model was also employed to examine the relationship between participants' age and their digit span. Thus, the model estimates how much change in *y* standard units results from a corresponding change in *x* standard units. The resulting slope functions like a Pearson's *r*, the 'correlation coefficient' (Winter, 2020). As seen in Table 6, the intercepts of the outcome variable (2.2437, 11.80746), slopes (0.1725, -0.11578) and *p* values (0.507, 3.87e-05), respectively for native speaker and Persian learners, show age and DS scores not to be correlated in the native speakers, whereas a significant negative relationship was found for the Persian learners such that the younger learners outperformed older ones in recalling digits backwards (see Appendix F).

In the case of the age effect, the slope of the line is negative for Persian learners, but positive for native English speakers, meaning that for Persian learners as the age increase, the digit span decreases. In contrast, for native speakers of English as age increases, the digit span increases as well. This odd finding might be in consistent with a study by Winter (2020:72), who says that "regression models may produce odd results when predicting beyond the range of the attested data, what is called 'extrapolating'". Therefore, it can be concluded that the increase of age might not always result in weaker performance when doing cognitive tasks involving memory capacity.

## 5.4. Reading span

Table 4 presents the scores on the WM component of the reading span task. As can be seen, native English speakers on average outperformed Persian learners (*M* = 54.33 vs. 48.72). However, the error rate for native English speakers is somewhat higher than that for Persian learners. In addition, Cronbach's α (Table 5) was measured as an index of internal consistency at the level of the 15 individual blocks, with the scores being counted as the correct proportion of the respective set. Internal consistency for the reading span task was exceptionally high, meaning that all blocks contributed the same amount to the individual scores over trials (α = 0.97).

*Table 4. Descriptive statistics for WM performance (storage capacity) in the reading span task*

| | Mean | SD | Recalled (range) | Skew | kurtosis | Error rate |
|---|---|---|---|---|---|---|
| Native speakers | 54.33 | 9.34 | 40-65 | -.545 | -1.352 | 4.84 |
| Persian learners | 48.72 | 9.20 | 28-66 | -.223 | .780 | 4.23 |

*Table 5. Reliability statistics*

| Cronbach's Alpha | No of Items |
|---|---|
| 0.97 | 15 |

Table 6 displays the descriptive statistics for mean RTs and error rates for the reading span task. As can be seen, native English speakers outperformed Persian learners, as evidenced by shorter RTs *(M* = 2.295 vs. 5.643). Standard deviations were high for Persian learners (*SD* = 2182), revealing individual differences. It can, moreover, be assumed that the lower error rate for native speakers may be associated with higher WM scores. The overall analysis of the reading task demonstrates that native speakers tried to do equally well on both recalling and processing tasks, whereas Persian speakers were assumed to sacrifice the accuracy of the processing task to focus more on the recall task.

*Table 6. Descriptive statistics of processing performance in the reading span task*

| | Mean | SD | RT (range) | Skew | kurtosis | Error rate |
|---|---|---|---|---|---|---|
| Native speakers | 2.295 | 1,698 | 1.031-6750 | 2.267 | .536 | 7.85 |
| Persian learners | 5.643 | 2,182 | 1.087-9877 | -.412 | .686 | 11.05 |

## 5.5. Offline questionnaire and attachment preferences

The descriptive statistics of attachment choices in the offline judgement task are shown in Table 7. The results revealed that the two groups performed differently. Although the native English speakers' low attachment preference was relatively consistent (i.e. 60 %), a considerable tendency to high attachment preference was also observed (i.e. 40 %). Persian learners clearly preferred high attachment (i.e. 83.3%) and showed a much lower tendency towards low attachment (i.e. 16.7 %). These results suggest that most of the Persian learners showed a high attachment preference as in similar studies of Persian speakers, whereas the native English speakers' decisions were more heterogeneous. Proficiency does not seem to be a reliable predictor for the Persian learners' low attachment choices (see Appendix F).

*Table 7. Mean percentage of attachment preferences for Persian learners and English native speakers*

| | response | Frequency | Percent | mean | SD |
|---|---|---|---|---|---|
| Native speakers | High | 6 | 40 | 4.27 | 1.33 |
| | Low | 9 | 60 | 4.00 | 1.73 |
| Persian learners | High | 15 | 83.3 | 6.61 | 1.65 |
| | Low | 3 | 16.7 | 1.33 | 1.53 |

An independent samples *t*-test was run to identify any significant differences for high or low attachment in native speakers and Persian learners. The one-way ANOVA showed a statistically significant difference between groups in high attachment ($F$ (1, 31) = 1.346, $p < 0.001$). As shown in Table 9, the Persian learners showed a clearer and more dominant high attachment preference than native speakers' low attachment preference in the offline task, which is supported by the significant difference of attachment preferences in both groups.

## 5.6. Online SPR (Self-Paced Reading)

The SPR task provided three measures: (a) RTs means for critical regions across the experimental conditions, (b) the accuracy rates for the comprehension questions, and (c) RTs to the comprehension questions. The results of these three measures are presented in turn in the following.

### 5.6.1 RC processing

The mean RTs from the two groups are presented across five sentence regions (*NP1, NP2, NP3, extraposed RC and non-extraposed RC*) in four pairwise comparisons across conditions *definite-long-extraposed RC (1)* vs. *indefinite-long-extraposed RC (2);* then *definite-short-extraposed RC (3)* vs. *indefinite-short-extraposed RC (4); definite-long-non-extraposed RC (5)* vs. *indefinite-long-non-extraposed RC (6); and definite-short-non-extraposed RC (7)* vs. *indefinite-short-non-extraposed RC (8)*. The statistical analyses will focus on critical regions only, namely regions 2 and 4 where the RCs appear. Therefore, to examine whether the experimental conditions had an effect on participants' online processing, the results were submitted to a two-way ANOVA with Condition as the within-subject variable and Group as the between-subjects variable.

#### 5.6.1.1 Definite/indefinite long-extraposed RCs

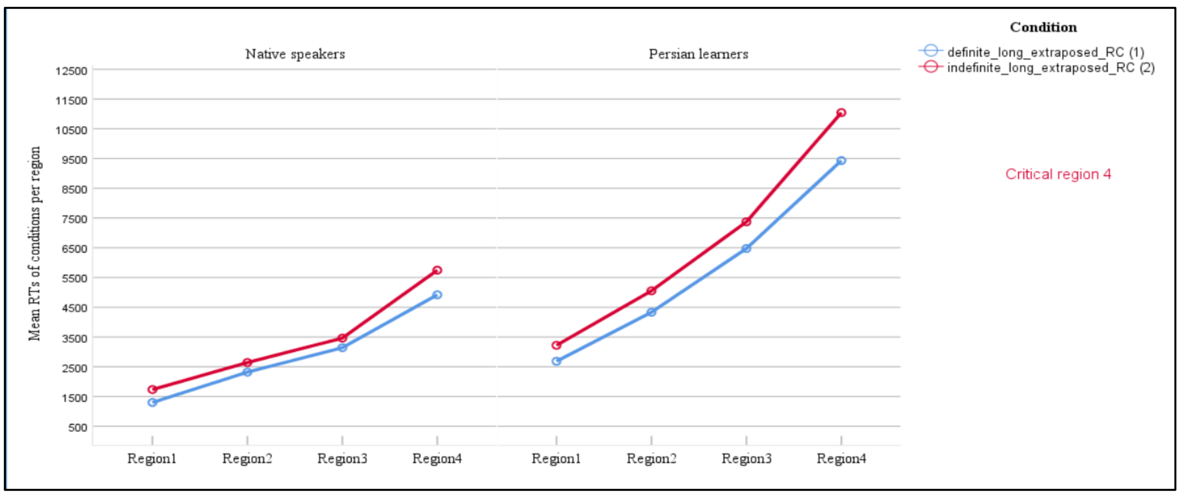


*Figure 4. RTs mean of conditions (1) (2) (definite vs. indefinite long-extraposed RCs) in both groups*

As seen in figure 4, the Persian learners' RTs are overall slower than those of native speakers. More importantly, for both groups, the mean RTs in condition (2) are overall higher than in condition (1), meaning that indefinite NPs might affect online processing causing processing cost in both groups and across all regions. Testing for effects of condition and group in region 4 (See appendix F) we find no significant main effect of condition ($F$ (1, 31) = 2.517, $p$ = 0.118), but a significant main effect of group ($F$ (1, 31) = 13.337, $p$ = 0.001), indicating that there was a difference in reading times between the groups. There was no interaction effect ($F$ (1, 31) = 1.719, $p$ = 0.195).

5.6.1.2 Definite/indefinite short-extraposed RCs

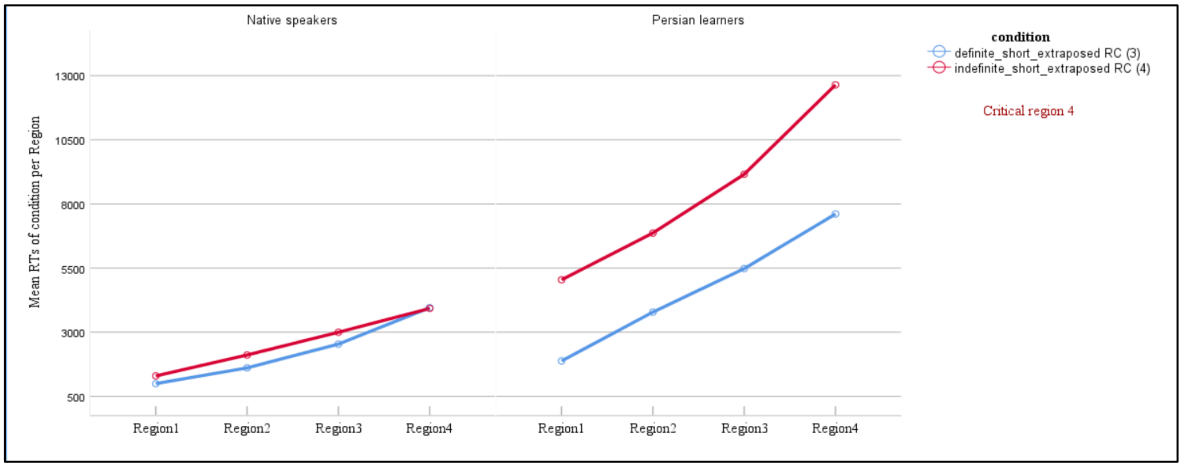


*Figure 5. RTs mean of conditions (3) (4) (definite vs. indefinite short-extraposed RCs) in both groups*

Figure 5 shows RTs for conditions 3 and 4 with much longer RTs in condition 4 in the Persian learners compared to native speakers. A two-way ANOVA with the factors conditions and group was calculated for region 4. This analysis found no significant main effect for condition ($F$ (1, 31) = 0.744, $p$ = 0.392), but a significant main effect for group ($F$ (1, 31) = 31.953, $p$ < 0.001). The interaction effect was also not significant ($F$ (1, 31) = 0.012, $p$ = 0.913). Moreover, unsurprisingly, the general pattern of the RTs indicates overall faster reading by native speakers.

5.6.1.3 Definite/indefinite long non-extraposed RCs

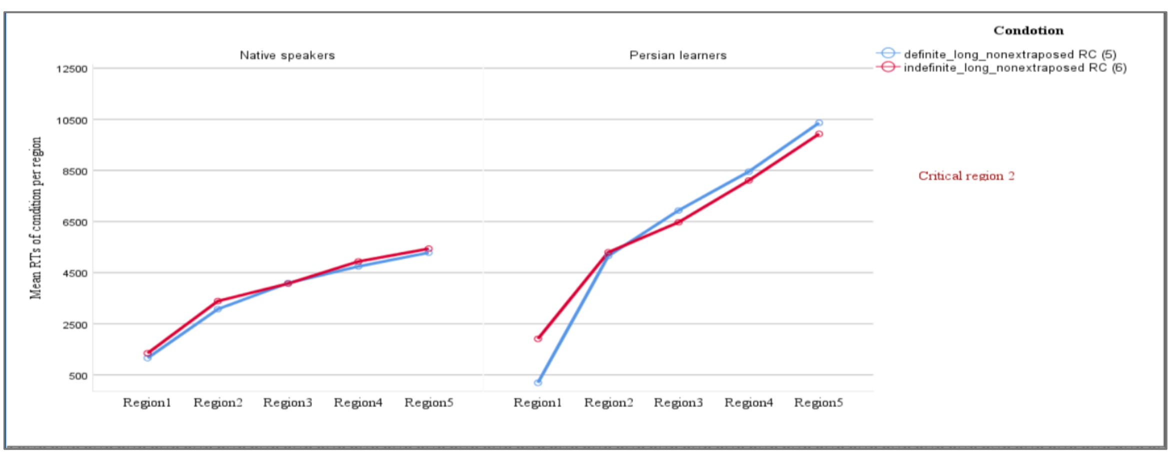


*Figure 6. RTs mean of conditions (5) (6) (definite vs. indefinite long-non-extraposed RCs) in both groups*

The mean RTs of condition (5) and (6) are illustrated in Figure 6. There is virtually no difference in the online processing and both groups read the sentences with long non-extraposed RCs similarly as shown in the parallel forms from region 1 to region 5. At region 2 (See appendix F), an ANOVA with Condition as the within-subjects variable and Group as the between-subjects variable yielded no significant effect for condition ($F$ (1, 31) = 0.043, $p$ = 0.837), or for group ($F$ (1, 31) = 3.308, $p$ = 0.074). There was also no significant interaction ($F$ (1, 31) = 0.025, $p$ = 0.874). The analysis for condition (5) and (6) at region 4 yielded similar results as for conditions (1) and (2).

5.6.1.4 Definite/indefinite short-non-extraposed RCs

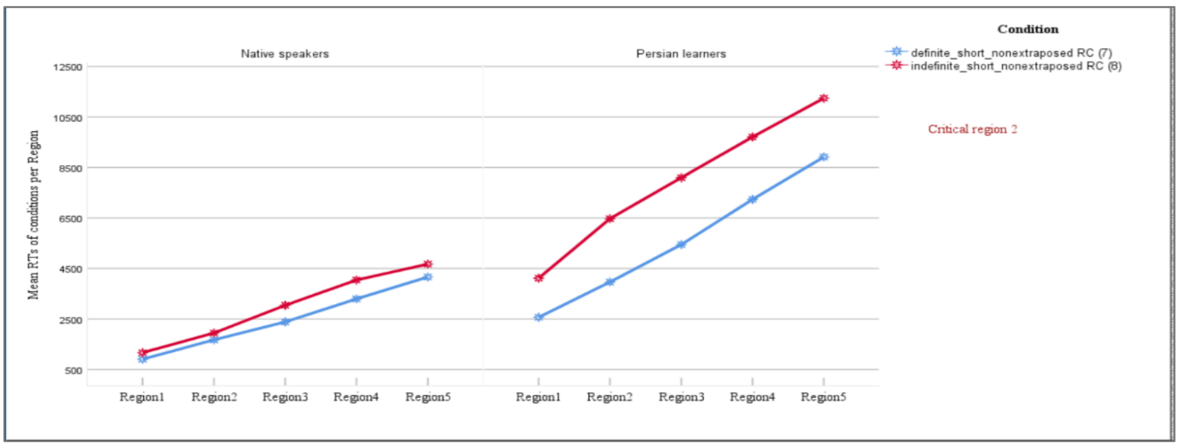


*Figure 7. RTs mean of conditions (7), (8) (definite vs. indefinite short-non-extraposed RCs) in both groups*

Figure 7 illustrates the RTs for conditions 7 and 8. As shown in figure 7, both groups read the sentences in condition 8 more slowly than sentences in condition 7. Unsurprisingly, for the RT comparison at region 2 with short non-extraposed RCs, the analysis yielded a significant effect of condition ($F$ (1, 31) = 4.368, $p$ = 0.041), but not for group ($F$ (1, 31) = 3.102, $p$ = 0.083). There was no significant interaction ($F$ (1, 31) = 0.183, $p$ = 0.670).

## 5.6.2 Attachment processing

As noted by (Rah, 2009), preferred attachments are processed in shorter reaction times than unpreferred ones. According to the general pattern of RTs across regions, as shown in Figures 4 and 5, both native speakers and Persian learners processed the referents of RCs in high positions (region 2) faster than those in low positions (region 3) close to the RCs in sentences with extraposed RCs in conditions (1) – (4). In contrast, this comparison does not seem to be made in sentences with non-extraposed RCs. For Persian learners, the high attachment preference is in consistent with the dominant preference in the offline task, with significant effect of attachment within subjects and between subjects. It seems easier especially for the Persian learners to process the sentences faster in high attachment conditions. For the native speakers, the result is unexpected, considering that in previous studies the low attachment was more prominent and preferable for them and thus might be easier to process faster, as seen relatively in the offline task and by looking at the significant effect of attachment ($F$ (1,14) = 113.449, $p < 0.001$) in the ANOVA analysis.

Similar to the results measured with ANOVAs, the *t*-test yielded significant differences of reaction time means for attachment preference between the native speakers and Persian learners (High attachment $p$ =0.003, Low attachment $p$ =0.007). Furthermore, the direction of the lower and upper bounds towards positive values showed that the mean for the Persian learners is higher and the mean difference for the high attachment is higher than that for the low attachment (see Table 8).

*Table 8. Mean difference of reaction times of attachment between native speakers and Persian learners*

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% CI of the Difference Lower | Upper |
| High attachment | Equal variances assumed | 4.716 | .038 | 3.207 | 31 | .003 | .98 | .30 | .35 | 1.61 |
| | Equal variances not assumed | | | 3.281 | 30.894 | .003 | .98 | .30 | .37 | 1.59 |
| Low attachment | Equal variances assumed | .222 | .641 | 2.906 | 31 | .007 | .79 | .27 | .23 | 1.34 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Equal variances not assumed | 2.819 | 24.775 | .009 | .79 | .28 | .21 | 1.37 |

### 5.6.3 RTs to comprehension questions

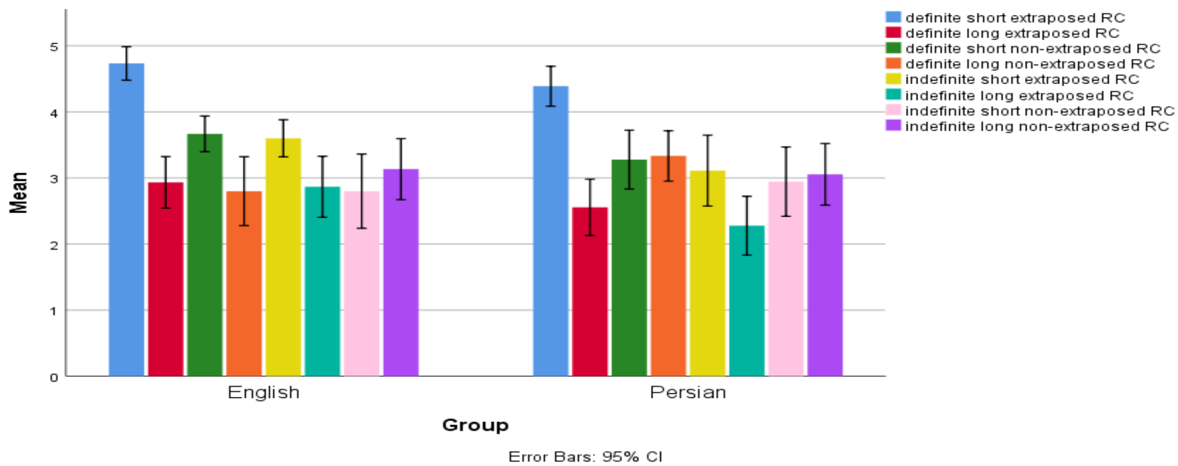


*Figure 8. Mean accuracy for the comprehension questions across experimental conditions and groups*

Figure 8 presents the mean accuracy rates for the correctly answered comprehension questions by groups and conditions. As can be seen in Figure 8, the mean accuracy of the answered comprehension questions is highest for definite short extraposed RCs in both groups, but also for definite short non-extraposed RC, and indefinite short extraposed RC, indicating that the participants often processed and answered more comprehension questions along experimental conditions with the length short and the RC type extraposed. Overall, the native speakers were numerically more accurate and processed the comprehension questions faster than the Persian learners, but the groups did not differ statistically.

In general terms, the results show that all participants were not remarkably sensitive to the experimental manipulations because their online RC attachment processing were not significantly influenced by (in)definiteness, RC length and extraposition of RC, which was observed both in their sentence comprehension and in their reading times. This result is especially important because of the disambiguation via referential information and semantic-structural dependencies. Further to this, two participant groups behaved similarly in most cases in online task with high comprehension accuracy and short response time when reading the sentences.

### 5.6.4 Correlation analyses with working memory measures

To explore whether WM affects online processing, a Pearson correlation test was conducted to explore whether WM performance is correlated with comprehension questions RTs. Hence, digit span scores and reading span scores were taken to run the test.

*Table 9. Correlation between digit span and comprehension question RTs*

| | | Digit span | RT |
|---|---|---|---|
| Digit span | Pearson Correlation | 1 | -.418* |
| | Sig. (2-tailed) | | .015 |
| | N | 33 | 33 |
| Comprehension Qs RTs | Pearson Correlation | -.418* | 1 |
| | Sig. (2-tailed) | .015 | |
| | N | 33 | 33 |

*. Correlation is significant at the 0.05 level (2-tailed).

As seen in Table 9, digit span is significantly correlated negatively with comprehension question RTs (-.418), meaning that the participants with high digit span read and comprehend the comprehension questions faster than those with low digit span.

*Table 10. Correlation between digit span and high attachment RTs*

| | | Digit span | RT |
|---|---|---|---|
| Digit span | Pearson Correlation | 1 | .089 |
| | Sig. (2-tailed) | | .623 |
| | N | 33 | 33 |
| High attachment | Pearson Correlation | .089 | 1 |
| | Sig. (2-tailed) | .623 | |
| | N | 33 | 33 |

*. Correlation is significant at the 0.05 level (2-tailed).

Table 10 indicates no correlation between digit span and high attachment RTs. The same scenario is also true, as seen in Table 11, for the relationship between digit span and low attachment RTs with no correlation.

*Table 11. Correlation between digit span and low attachment RTs*

| | | Digit span | RT |
|---|---|---|---|
| Digit span | Pearson Correlation | 1 | .193 |
| | Sig. (2-tailed) | | .283 |
| | N | 33 | 33 |
| Low attachment | Pearson Correlation | .193 | 1 |
| | Sig. (2-tailed) | .283 | |
| | N | 33 | 33 |

*. Correlation is significant at the 0.05 level (2-tailed).

A multiple regression model was also employed to explore whether proficiency, memory digit span and age predicted participants' online performance when processing L2 RC attachment ambiguity resolution. Because adding more variables into a regression model might result in overfitting, the best independent variables were picked up for the model to explain variation in the outcome variable. Furthermore, sometimes the independent variables are not only related to the outcome variable but potentially might be associated with each other which results in multicollinearity. In order to avoid the potential problems by adding more independent variables to model(overfitting) and the multicollinearity, the proficiency, the memory digit span and age were, therefore, selected as predictors to predict participants' online processing reflected in reaction times. The regression analysis indicated that when proficiency decreases, the reaction time increases by – 0.003, however, variations of reaction times are not explained by the proficiency. The reaction time is also expected to change by 0.104 for each change in span. Moreover, an increase in each value of age will increase the reaction times by 0.042. Multiple R-squared is 0.3887 and adjusted R-squared is 0.3014, which is not a huge drop off from the adjusted R-squared. Although the model fit seemed good, no outcome was statistically significant, which may be due to multicollinearity or small sample size. Despite this, the overall regression *p*-value (0.006) and *F*-statistic (4.452) indicated that the model as a whole is statistically significant, meaning that there is a relationship between the predictors and the reaction time. However, such models in general might not be a good model for predicting the outcome variables (see Appendix F).

# 6 Discussion

The findings of this study can be generally summarized as follows: (a) factors such as indefiniteness, RC length, and RC extraposition did not affect L2 RC attachment processing; (b) the Persian learners of English can employ their L1 parsing strategies in L2 RC attachment processing in both offline and online tasks; (c) working memory capacity is not correlated with L2 RC attachment preference and online processing performance, but with RTs to comprehension accuracy; (d) the attachment preferences, high attachment for the Persian learners and low attachment for the native speakers were significantly different in both offline and online tasks. e) it is speculated that the high attachment preferred online by both Persian learners and native speakers seems to involve initial heuristic processing while low attachment seems to ask for algorithmic processing to satisfy the Online Cognitive Equilibrium through involving more processing resources and working memory.

## 6.1 Research questions reviewed

The research questions are repeated from chapter 3 with tentative answers.

1- Do L2 learners read the sentence more slowly than native speakers when processing L2 RC ambiguity?

The overall results from the RT comparisons of online processing (Figures 4-7) indicated that the Persian learners read L2 sentences more slowly than native speakers across all conditions, as revealed by main effects of group for conditions *(1), (2) (definite vs. indefinite long-extraposed RCs)* and *(3), (4) (definite vs. indefinite short-extraposed RCs)* in the critical region 4, suggesting that both the Persian learners and the native speakers differed significantly in reaction times in regions 4 across all extraposed conditions.

2-Do (in)definiteness, RC length, and RC extraposition affect L2 RC processing in Persian learners of English?

ANOVA analyses did show a main effect of conditions (7) and (8), such that everybody had longer reaction times in the critical region 2 in the indefinite than the definite condition. Moreover, there were significant effects of group in conditions (1), (2), (3) and (4), meaning that the Persian learners experience more processing difficulty than the native speakers when processing sentences with *definite vs. indefinite long/short extraposed RCs* (region 4).

Furthermore, the experimental manipulations did not play a significant role in either comprehension accuracy or response time, there were however numerically high comprehension accuracy and shorter response time to comprehension questions in particular when reading sentences with definite short extraposed or non-extraposed RCs in both Persian learners and native English speakers, as shown in Figure 10 . In contrast, sentences with indefinite NPs and long RCs are, rather unsurprisingly, more likely to be read and processed with longer reaction time. Additionally, Persian learners' reading times were overall longer than native speakers' reading times, meaning that the Persian learners faced more processing difficulty which increased gradually from region 1 to critical regions 2 or 4 where the RCs appeared. Apart from this difference, it seems that the two groups' L2 RC processing showed similar patterns in most regions, suggesting that the processing involved incrementally updating interpretation of the string left-to-right (Sturt, 2004) which could not nonetheless be influenced by L2 learners' proficiency or short-term memory, which is not inconsistent with Cole and Reitter (2019). Moreover, longer reading times in regions 2 and 4 might reflect L2 learners' uncertainty about the grammaticality of the sentences disambiguated towards long movement with extraposed RCs.

The ANOVA results and general patterns illustrated that the reaction times of the experimental conditions with the noun type (definite), RC length (short) and RC type (non-extraposed) are numerically overall shorter than that of the experimental conditions with the noun type (indefinite), length (long) and RC type (extraposed) for both native speakers and Persian learners. The statistical analyses explored that participants' online processing was affected by the experimental conditions within subjects and between groups. It did, thus, display significant effects of group in conditions (1), (2), (3) and (4). Consequently, the analysis from the SPR is in compatible with the participants' performance in answering comprehension questions correctly. So the Persian learners might have more difficulties with some of the experimental conditions than native speakers with definite/indefinite short non-extraposed RCs, as supported by ANOVA's significant effect of conditions (7) and (8).

3. Do Persian L2 learners of English transfer parsing strategies from their L1 to L2 RC attachment processing?

In the offline task, Persian learners' dominant high attachment preference (NP2), and their greater sensitivity to semantic dependencies than to syntactic structure could, at least theoretically, associate a L1 influence in their L2 processing. Although this sensitivity is predicted by the SSH, it could also be transferred from the learners' L1. Further to this, this observation was confirmed by ANOVA, which yielded significant difference for high and low attachment preferences between the Persian learners and native speakers. None of the Persian learners preferred NP1 as referents for RCs, but all preferred only NP2 as high attachment in the offline task. The results are thus in line with the findings from previous empirical studies for the Persian learners of English in which participants showed a clear preference for high attachment. In contrast, the results are in compatible with the results of prior studies for natives speakers in which participants did show a relatively dominant preference for low attachment, with a remarkable tendency to high attachment however. Following previous studies on L2 RC attachment preferences, the Persian learners in the present study were expected to show a high attachment preference, and the predictions were less clear for the native speakers. Since a high attachment preference is expected in the case of L1 transfer and the Persian learners show a significant high attachment preference in the present study ($F$ (1, 31) = 1.346, $p < 0.001$), it is conceivable that their RC attachment preference is influenced by L1 parsing strategy.

With regard to the question of L1 influence, the Persian learners might be more strongly influenced by their L1 in online processing. Moreover, if participants have any attachment preferences, these are expected to show in shorter reading times for the preferred than for the dispreferred disambiguation (Rah, 2009). Unlike in the offline task, the predictions were less clear for the Persian learners in the online task, meaning that it is also possible that they either adopt English low attachment preference or that they employ an L2-specific strategy. Since none of the Persian learners selected NP1 in the offline task to attribute to RCs, NP1 was not taken into consideration for attachment processing and the focus was only on NP2 and NP3 to find the participants' attachment preference in real-time. As shown in Table 17 (See Appendix G), the reading times in region 2 (NP2) are higher than that in region 3 (NP3) in the Persian learners and native speakers across all conditions with extraposed RCs, indicating that, as in the offline task, a clear high preference attachment is observable among the Persian learners. The analyses found a significant effect of group. Additionally, as in RCs processing, conditions (4), (7) and (8) showed a significant effect in attachment preferences in the Persian learners and native speakers and condition 6, indefinite long non-extraposed RC. The SSA does provide a plausible explanation for the findings. Since the Persian learners did show a significant preference, this finding does necessarily constitute evidence for the SSH. Accordingly, it is more likely that the Persian learners employ a shallow processing strategy. Since high attachment is expected to impose higher processing load, this finding is not in line with an L2-specific recency strategy. Hence, L1 transfer is the most likely explanation for the Persian learners' attachment preferences in the present study. Accordingly, the Persian learners' pattern in reading times of conditions with overall significant effect but individual preferences either for high attachment or low attachment, indicates that the Persian learners transfer the attachment preference from their L1 to L2. In conclusion, the correlation analysis of low attachment choices with the Persian learners' reported proficiency measures revealed that this relationship is not straightforwardly a robust predictor (Persian learners: $r = 0.089$, $p = 0\ .725$).

4. Do working memory (capacity) affect L2 RC attachment processing?

The results obtained from the correlation analyses revealed that digit span is significantly correlated with RTs to the comprehension questions, suggesting that the higher digit span the participants have, the shorter time they need to comprehend comprehension questions. Therefore, I explored the relationship between high comprehension accuracy and response times for condition 3, definite short extraposed RC and for condition 8, indefinite short non-extraposed RC to assess the role of WM in L2 RC processing. The correlation analyses indicated that there was no significant relationship between digit span and high attachment mean RTs ($r = 0.089$, $p = 0\ .623$) or low attachment RTs ($r = 0.193$, $p = 0\ .283$). Moreover, the attachment preferences and the reaction times for the experimental sentences rather provided evidence that the Persian learners prefer high over low attachment. Further research with adult L2 learners with a closer analysis of

WM is thus needed to provide new insights into the processing mechanism to adjust L2 parsing strategies. Considering the analysis for mean ML (Maximum Length) for two groups, the results suggest that low standard deviations might be related to participants' age in addition to their individual differences in recalling digits backward. What is more, the coefficient of variance for the BDS (Backward digit span) metrics showed that relative variations of data distribution are higher for native speakers than for Persian learners, indicating that the greater dispersion around the mean might also be due to age or other individual differences in WM performance, which appear as data points far away from the mean, outliers. These analyses from the BDS metrics also might suggest that, apart from age, high or low digit span can influence online L2 processing.

Although the reaction time results are in compatible with the accuracy results of comprehension questions, it must be noted that longer reaction times do not necessarily result from processing difficulties but might be influenced by other factors such as a temporary lapse of concentration and functional online lag. This would explain the relatively high standard deviations, to some extend why the some expected effects were not found and that why all the results were not statistically significant. Furthermore, the effects reached statistical significance more often in the analyses by subjects, which is indicative of interpersonal variation. The high attachment preference by both Persian learners and native speakers is more likely to involve initial heuristic processing to select the earlier available elements to reach Online Cognitive Equilibrium at the earliest opportunity, while low attachment seems to ask for algorithmic processing to satisfy the Cognitive Equilibrium through involving more processing resources and high working memory. The situation underlines the importance of WM in processing psycholinguistic phenomena such as RC attachment resolution in which the parser is required to store constituents in memory and retrieve them later for sentence comprehension, as discussed by Jacob (2009). Based on the Short-Term Memory-Working Memory (STM-WM) model and L2 processing models as discussed in chapter 2, the thesis discusses L2 processing with regard to the employment of L1 syntactic knowledge (Competition Model), shallow syntactic processing (Shallow Structure Account) and reliance on an initial heuristic processing which causes L2 learners to prefer to use available information in earlier stages to satisfy the Online Equilibrium or costly computational algorithmic processing, which causes processors to involve more processing resources to reach the Online Cognitive Equilibrium, depending on the acceptable retrieved items and working memory capacity. Unlike much previous research, the results from the current study suggest that native speakers showed a main pattern of low attachment, but an unexpected 40 % tendency to high attachment preference, which might highlight the influential role of WM in processing temporarily ambiguous sentences and the role of initial heuristic processing and costly algorithmic processing which are closely interrelated with WM performance, as stated by Karimia & Ferreira (2016). Moreover, this preference is in consistent with what Ferreira (2003) argued, in that while learners use a deep representation computed fully, namely algorithmic processing, for comprehending language, at the same time, in many cases, native speakers might prefer quick heuristics for sentence comprehension.

## 6.2 Hypotheses reviewed

H1 stated that the Persian learners would be predicted to have overall slower reading times than native speakers, employ heuristic processing intended to decrease processing cost, and select earlier information in order to achieve Online Cognitive Equilibrium faster when processing. The results showed that the Persian learners did indeed have longer reading times, preferred high attachment and therefore presumably used the initial heuristic processing, selecting the earlier available elements to reach the Online Cognitive Equilibrium at the earliest time, while a low attachment preference could be assumed to involve algorithmic processing to satisfy the Online Cognitive Equilibrium by involving more processing resources. Based on these results, H1 is supported.

H2 stated that (in)definiteness, length and extraposed RC might cause processing difficulty. The findings of the study revealed that the experimental conditions which manipulated noun indefiniteness, RC length, and RC extraposition significantly affected the online processing of L2 RC ambiguity significantly only in conditions (7) (*definite short non-extraposed RCs*), (8) (*indefinite short non-extraposed RCs*). Although high accuracy of comprehension questions for definite short non-extraposed RC was observed and both groups were affected by the conditions, longer reaction times for indefinite NPs in short (non)extraposed conditions and other conditions showed observable effect of conditions on the graphs only in the Persian learners. H2 can therefore neither be confirmed nor refuted.

H3 stated that the Persian learners would theoretically employ their L1 parsing strategy rather than being native-like when processing L2 RC attachment. In line with this hypothesis, the results indicated that the Persian learners preferred high attachment for resolving RCs as reflected in shorter reaction time in the online task as well as in their choices in the offline task (high attachment 83.3%, low attachment 16.7%), meaning that they relied more on lexical-semantic dependencies due to cross-linguistic differences than on structural dependencies. However, native English speakers also showed a dominant low attachment preference (60%) with a considerable tendency to high attachment preference in the offline task (40%) but behaved similarly like the Persian learners' with a high attachment preference in real-time processing. This unexpected result might be due to confounding factors such as functional online lag, lack of concentration or age. More importantly, regardless of lexical-semantic dependencies, the Persian learners' high attachment preference can be supported by ANOVA results, showing that while the Persian learners significantly preferred to select high attachment, sticking to L1 parsing strategies, rather than being native-like in both offline and online tasks, the native speakers significantly preferred to select low attachment in offline task but high attachment in online task. It is therefore difficult to refute H3. No robust evidence however exists because of lack of significant results in online processing for conditions, both groups behaved similarly in online attachment processing with significant high attachment preference as well as in the offline task, which underlie L1 transfer in L2 processing in the Persian learners of English and might highlight the effect of WM in native speakers to employ heuristic processing in sentence comprehension.

H4 stated that working memory capacity may have an influence in L2 RC attachment processing. The correlation analysis showed that WM performance was significantly correlated with RTs to comprehension questions in Persian learners and native speakers but not significantly correlated with RTs of high and low attachment. Although working memory capacity was not statistically significant in the multiple regression model, probably due to multicollinearity or small sample size, the overall model fit indicated that the model was statistically significant, implying that there could still be some kind of real effect of working memory still going on in predicting the L2 RC attachment processing. Overall, H4 was also arguably supported.

## 6.3 Theoretical implications of the present study

In case of Persian learners' performance on comprehension questions with short length and non-extraposed RC, it may be the effect of WM reflected not only in the frequency of comprehension accuracy but also in shorter reading times of processing. This effect is evidenced by the fact that high WM is correlated with comprehension reaction times regardless of syntactic complexity and semantic dependency in online reading. Furthermore, the results suggest that the ability to process comprehension questions through incorporating syntactic or semantic information may be modulated by individual differences in WM performance, as shown by the ANOVA results with significant main effects of experimental conditions as within-subjects variable. The results also confirm that the Persian learners and native speakers often show longer reading times when processing the sentences with indefinite NPs than when reading the sentences with definite NPs, suggesting that the indefinite nouns may therefore cause processing cost in RC attachment processing. In the case of the Persian learners, this effect of indefiniteness is in line with the implication that Persian learners of English theoretically rely more on semantic information to answer and process the items than syntactic structure (Shabani, 2018), which is not accessible in initial processing (Karimia & Ferreira, 2016). This may reflect the role of the processing mechanism which functions as a dynamic system to re-estimate validity and cost of cues such as word order and semantic dependency while processing new linguistic input (Jacob, 2009).

In addition to the two possibilities discussed above, it is also assumed that the processing difficulty may result from multiple sources, as suggested by Staub (2010), both the position of the RC and the difficulty of reanalysis with shallow knowledge responsible for the comprehension and the reaction times influenced by WM effects as shown in the experiment. It seems that the RCs extraposed to the end of the sentence are easier for everybody to comprehend in their L1 but may be difficult for the Persian learners to comprehend when processing L2 in different conditions, for example, when encountering the ambiguous sentences with three NPs as potential referents attributable to RC extraposed. Although this underlines the importance of the Principle of

Minimalization Domain proposed by Hawkins (2004) based on which complex interrelated structures can be moved to the end of the sentence for the processor to process faster and reduce processing difficulty. The reader needs to keep more words in the buffer to reach the end of the sentences. The results reflect that comprehension question processing and interpretation involve WM across time measures, as Caplan (2016) pointed out. Therefore, not surprisingly, WM appears not only to predict the overall comprehension but also to modulate readers' ability to incorporate different types of syntactic and semantic information during the time course of online sentence processing, especially when the different types of information conflict with each other, leading to structural and semantic ambiguities.

The results of the online sentence processing in the SPR task seem to show a pattern relatively similar to the accuracy data in terms of groups' online behavior when reading sentences with indefinite and non-extraposed RCs or extraposed RCs. The above-discussed sources for processing difficulty, such as the effects of shallow syntactic representation (SSA) and WMC, also have their own influence on online processing of RC attachment. The online reading time results for attachment preference, however, appear to suggest a rather different story with more sources for the processing difficulty. This means that the RC attachment is readily processed through the reanalysis of a definite antecedent for RC but may not be easily explained by the facilitation of reanalysis of two or three definite antecedents for RC. This may be due to lexical properties of the RC verbs or plausibility differences across conditions. The stronger possibility may be the interference of the similar constituents the parser is required to keep in the buffer and retrieve simultaneously at the critical region before the RCs in order to comprehend the sentences, as stated by Jacob (2009).

Furthermore, extraposed RCs may involve processing cost and thus cause higher memory load for Persian learners to interpret the sentences. For example, it seems that the learners may face difficulty in storing definite antecedents (*the director, the instructor, the schoolboy),* to retrieve them at the point where the RC appears *(*who was writing interesting reports*).* The results indicate that Persian learners prefer to attach the antecedent in the high position to the RC. This finding may reflect that the readers with a high working-memory span find RC attachment easier to process, and the readers with a low working-memory span unable to store the first noun long enough to attach to the RC, as noted by Payne et al. (2014) and Lee and Federmeier (2012). Unlike in previous studies showing a dominant low attachment preference (Dussias, 2001; Fodor, 2002; Hillert & Nakano, 2016; Hopp 2015; Kempen, 1994; MacDonald & Christiansen, 2002; Rah, 2009) in both offline and online tasks, native English speakers showed a remarkable tendency to prefer high attachment.

Returning to the interference, this possibility may be also affected by the individual differences in working memory, which is partly related to the syntactic interference effects, as Engelhardt et al. (2016) argues. In this respect, it can be inferred that longer reaction times for low attachment might be due to algorithmic processing and the retrieval process in the reanalysis when the retrieved items with shared structural features cause interference, and thus leading to increased processing difficulty, as pointed out by Caplan (2016). Therefore, we can conclude that a definite antecedent may indeed facilitate the processing, resulting in faster processing of RC, but two or more definite RC antecedents as intervening elements increase the processing cost, and readers have no choice but to attach the only possible antecedents which are still highly active available in the buffer of short-term memory specifically in non-cumulative self-paced reading experiments as the most appropriate for tapping syntactic processing in real-time, in which the participants are unable to go back and reread words that have been presented previously in the sentence.

Finally, in addition to the above-mentioned processing accounts, the high attachment preference by both groups may be better explained by the Online Cognitive Equilibrium hypothesis proposed by Karimia & Ferreira (2016). It seems that the participants prefer the antecedents at the high position to achieve Cognitive Equilibrium (good-enough linguistic representations) at the earliest opportunity. The high attachment preference in both groups could therefore be modulated not only by WM performance but also by simple heuristic processing, in particular, in the non-cumulative SPR, which may affect the results. Although the initial heuristic processing may only satisfy degrees of equilibrium, the participants achieve the greater equilibrium by retrieving the relevant and convincing antecedents to attach to the RCs. For both L2 learners and native English speakers, the high attachment preference is achieved through semantic-heuristic processing than grammar-based algorithmic processing, which relies more on top-down information activated by semantic memory-based representations, as assumed by Lim and Christianson (2013a). In contrast, the participants' longer response times for dispreferred low attachment may be due to the ongoing algorithmic processing which relies more on linguistic knowledge and involves more processing resources to achieve equilibrium, depending on bottom-up processing to derive meaning, as Lim & Christianson (2013) stated. This emphasizes that initial heuristic processing may result in fast and good-enough representation of the information with the high attachment preference, while later costly computational algorithmic processing may cause processors to satisfy Cognitive Equilibrium with the low attachment preference through the involvement of more processing resources and WMC (Dwivedi, 2013). In other words, the Cognitive Equilibrium may not be immediately satisfied, so successful comprehension is more difficult for individual with low span to achieve, resulting in longer response times for the low attachment preference.

In summary, the findings suggest that online processing of L2 RC attachment ambiguity is more likely influenced by the L1 parsing strategies, and heuristic processing to meet OCE based on significant effects of high attachment preference, which may affect L2 processing, leading to high attachment preference. Previous empirical research has investigated the effect of these factors for native speakers of English and less for Persian learners of English (e.g., Arabmofrad & Marefat, 2008: 2020; Clahsen & Felser, 2006; Dussias, 2001; Jacob, 2009 Marefat & Meraji, 2005; Moghaddasian, 2008; Jun, 2003; Papadopoulou & Clahsen, 2003; Rah, 2009; Shabani, 2018) but no empirical study has tested the influence of L1, experimental conditions or WMC on online processing among Persian learners of English compared to native speakers of English.

## 6.4 Considerations for future studies

The overall results of the study indicated that the experimental conditions did not provide a serious problem for the Persian learners. This may be explained by some factors. Although, the proficiency was not found to be a reliable predictor in the present study, the proficiency levels of the participants are assumed to affect their L2 processing (Jacob, 2009). The experimental conditions might have impacted differently on processing pf L2 RC in the Persian learners with a grouping in terms of their proficiency levels. Moreover, this can be explained by L2 exposure (Rah, 2009). Since the Persian learners showed a significant difference in attachment preference, results may thus have differed if the present study had examined the experimental conditions in Persian-English bilinguals.

The current study has only explained the overall effect of the Online Cognitive Equilibrium in L2 online processing, while methodologically, a separation of participants into groups with high-low working memory could have more clearly clarified how the participants with different memory capacities behave when processing underspecified representations in garden-path sentences to present more precisely the role of the Online Cognitive Equilibrium along with memory performance in online incremental processing of RC attachment ambiguity. Since it is assumed that individuals with high working memory spans are more resistant against tolerating disequilibrium when processing RC ambiguity, there may thus be significant differences between high-low span individuals in how long they defer the resolution of RC attachment ( Stewart et al., 2007).

The results from the offline and online studies on RC attachment ambiguity occasionally provide insights into the mechanisms that pilot L2 processing and attachment preferences. The native speakers' preferences were found to differ in offline and online processing recovering from misanalysis, meaning that even native speakers may not resort to a recency preference and show a slight tendency to non-local preferences. It may not be merely due to the complexity or ambiguity of the sentences which cause the effect but rather more likely the word-by-word presentation in the SPR task. Therefore, it would be necessary to conduct the study with an eye-tracking paradigm in which the participants process a sentence as a whole to cope with garden-path ambiguity by trying successive analyses of the problematic structure until one is found which the context allows.

# 7 Conclusion

This study investigated how L2 RC ambiguity is processed in real-time using a self-paced reading task in Persian L2 learners of English compared to native speakers of English. The present study is the first to take different factors into consideration together and to examine their effects on online sentence processing where the role of Online Cognitive Equilibrium closely interrelated with the memory models is examined during online incremental processing of RC attachment ambiguity, thus contributing to a less explored area of online L2 RC processing using SPR.

The key finding is that L2 learners are slower processors than native speakers online but that their comprehension accuracy offline is equal to native speakers. This study has investigated a range of factors that are likely to play a role for processing and comprehension of RCs. It can serve as a useful starting point for a bigger study where a bigger sample may strengthen findings that were only numerical trends in the current study.

In terms of L2 processing, the study has contributed by exploring key factors influencing online incremental processing of RC attachment ambiguity. In terms of depth of processing in L2 learning, it could help educators and EFL instructors to measure and test the factors positively affect L2 RC learning and promote pedagogical strategies and cognitive skills in classroom setting. This study provides the learners with potential methods of processing ambiguous sentences so that they can more efficiently use appropriate processing strategies and gain automaticity and fluency in English RC comprehension.

Finally, this study underlines how syntactic processing of L2 complex clauses, here RCs involving more than one NPs as potential hosts, are affected by factors leading to a decrease or increase in processing cost, and highlights the trace of working memory in L2 RC attachment preference through selecting earlier linguistic inputs to satisfy Online Cognitive Equilibrium. It can inform future studies to examine the conditions in which Online Cognitive Equilibrium is achieved employing heuristic or costly algorithmic processing to solve L2 RC attachment ambiguity.

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# Appendices

## Appendix A

Consent form

### Informed consent form

Consent form

Email *

Valid email

This form is collecting emails. Change settings

Master's thesis project

1. Background and purpose

The study is related to the master's thesis in program General Linguistics, at the Department of Language and Linguistics, at Lund University, under the supervision of Marianne Gullberg. The purpose of the study is to investigate how non-native learners process and comprehend L2 sentences compared to native speakers of English

3. Handling and storing the data

All data will be anonymized in the report. Observe that supervisor/teacher will also have access to the data. Until the paper/thesis graded, all data will be stored on my computer. Thereafter I will delete it.

4. Voluntary participation

Participation is voluntary, and as a participant you have the right to cease participation at any time.

5. Responsible persons

Abdolnoor Khaleghi
Email address: ab6026kh-s@student.lu.se
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Supervisor: Marianne Gullberg
Email of supervisor: marianne.gullberg@ling.lu.se

Education

Short answer text

Age

Short answer text

Gender

- Female
- Male

Date

Month, day, year

I have read the information about the study, and that I consent to participate.

- [ ] I accept terms and conditions

# Appendix B

Language History Questionnaire LHQ3

1. Participant ID number

2. Age

3. Gender

Select an option

4. Education

Select an option

5. Parents' Education

Father: Select an option    Mother: Select an option

6. Handedness

Select an option

7. Indicate your native language(s) and any other languages you have studied or learned, the age at which you started using each language in terms of listening, speaking, reading, and writing, and the total number of years you have spent using each language.

| Language | Listening | Speaking | Reading | Writing | Years of use* |
| --- | --- | --- | --- | --- | --- |
| Select an option | | | | | |
| Select an option | | | | | |
| Select an option | | | | | |
| Select an option | | | | | |

*Notes For "Years of use", you may have learned a language, stopped using it, and then started using it again. Please give the total number of years.

8. Country of origin

Select an option

9. Country of residence

Select an option

10. If you have lived or traveled in countries other than your country of residence for three months or more, then indicate the name of the country, your length of stay (in Months), the language you used, and the frequency of your use of the language for each country.

| Country | Length of stay (in Months)* | Language | Frequency of use |
|---|---|---|---|
| Select an option | | Select an option | Select an option |
| Select an option | | Select an option | Select an option |
| Select an option | | Select an option | Select an option |
| Select an option | | Select an option | Select an option |

* You may have been to the country on multiple occasions, each for a different length of time. Add all the trips together

11. Indicate the way you learned or acquired your non-native language(s). Check one or more boxes that apply.

| Non-native Language | Immersion* | Classroom instruction | Self-learning |
|---|---|---|---|
| Select an option | ☐ | ☐ | ☐ |
| Select an option | ☐ | ☐ | ☐ |
| Select an option | ☐ | ☐ | ☐ |
| Select an option | ☐ | ☐ | ☐ |

* e.g., Immigrating to another country where the dominant language is different from your native language so you learn this language through immersion in the language environment.

12. Indicate the age at which you started using each of the languages you have studied or learned in the following environments (Including native language).

| Language | At home | With friends | At school | At work | Language software | Online games |
|---|---|---|---|---|---|---|
| Select an option | | | | | | |
| Select an option | | | | | | |
| Select an option | | | | | | |
| Select an option | | | | | | |

13. Rate your language learning skill. In other words, how good do you feel you are at learning new languages, relative to your friends or other people you know?

Select an option

14. Rate your current ability in terms of listening, speaking, reading, and writing in each of the languages you have studied or learned (including the native language).

| Language | Listening | Speaking | Reading | Writing |
|---|---|---|---|---|
| Select an option | Select an option | Select an option | Select an option | Select an option |
| Select an option | Select an option | Select an option | Select an option | Select an option |
| Select an option | Select an option | Select an option | Select an option | Select an option |
| Select an option | Select an option | Select an option | Select an option | Select an option |

15. If you have taken any standardized language proficiency tests (e.g., TOEFL, IELTS, TOEIC, etc.), then indicate the name of the test, the language assessed, and the score you received for each. If you do not remember the exact score, then indicate an "Approximate score" instead.

| Test | Year taken | Language | Score | Approximate score |
|---|---|---|---|---|
| | | Select an option | | |
| | | Select an option | | |
| | | Select an option | | |
| | | Select an option | | |

16. Estimate how many hours per day you spend speaking with the following groups of people in each of the languages you have studied or learned (including the native language).

| Language | Family members | Friends* | Classmates | Others (co-workers**, roommates, etc.) |
|---|---|---|---|---|
| Select an option | | | | |
| Select an option | | | | |
| Select an option | | | | |
| Select an option | | | | |

Note *Include significant others in this category if you did not include them as family members (e.g., married partners)

**Include anyone in the work environment in this category (e.g., if you are a teacher, include students as co-workers).

17. In which language do you communicate best or feel most comfortable in terms of listening, speaking, reading, and writing in each of the following environments? You may be selecting the same language for all or some of the fields below.

| | Listening | Speaking | Reading | Writing |
|---|---|---|---|---|
| At Home | Select an option | Select an option | Select an option | Select an option |
| At school | Select an option | Select an option | Select an option | Select an option |
| At work | Select an option | Select an option | Select an option | Select an option |
| With friends | Select an option | Select an option | Select an option | Select an option |

18. Use the comment box below to indicate any additional answers to any of the questions above that you feel better describe your language background or usage.

19. Use the comment box below to provide any other information about your language background or usage.

20. Do you also speak/use any dialects of the languages you know? Please indicate the name(s) of the dialect and the degree you use them.

# Appendix C

Backward digit span

Test results from a single backward span test for one subject. Fourteen trials were presented, with list length (column 2) increasing after each trial. The lists presented are shown in column 3 and the response in column 4. The correctness of the response is shown in column 5 (1 = correct, 0 = incorrect). Errors are shown in bold and underlined.

| Digit span scoring | | | | |
|---|---|---|---|---|
| Trial | Length | Presented | Response | Outcome |
| 1 | 3 | ["9","4","3"] | ["3","4","9"] | 1 |
| 2 | 4 | ["3","1","4","5"] | ["5","4","1","3"] | 1 |
| 3 | 5 | ["0","4","5","2","8"] | ["8","2","5","4","0"] | 1 |
| 4 | 3 | ["4","0","8"] | ["8","0","4"] | 1 |
| 5 | 4 | ["4","1","2","8"] | ["8","2","1","4"] | 1 |
| 6 | 5 | ["1","0","5","2","6"] | ["6","2","5","0","1"] | 1 |
| 7 | 6 | ["0","9","1","2","3","4"] | ["4","3","1","1","0","9"] | 0 |
| 8 | 6 | ["4","3","5","7","6","1"] | ["1","6","4"] | 0 |
| 9 | 5 | ["8","6","0","7","3"] | ["3","7","0","9","8"] | 0 |
| 10 | 4 | ["0","1","4","7"] | ["7","4","1"] | 0 |
| 11 | 3 | ["5","3","0"] | [] | 0 |
| 12 | 3 | ["9","2","8"] | ["8","2","9"] | 1 |
| 13 | 4 | ["3","1","7","4"] | ["4","7","1","3"] | 1 |
| 14 | 5 | ["3","4","0","8","1"] | ["1","8","0","4","3"] | 1 |
| 15 | 6 | ["4","6","5","7","9","2"] | ["2","9","7","5","4","4"] | 1 |
| 16 | 7 | ["7","8","1","2","5","4","9"] | ["9","4","5","2","1","8","7"] | 1 |
| 17 | 8 | ["5","7","8","0","4","2","3","6"] | ["6","3","2","4","0","8","7","5"] | 0 |

# Appendix D

## Experimental stimuli and fillers (SPR)

| | | |
|---|---|---|
| 1 | target sentences | stimuli type |
| 2 | *The lecturer fell in love with/ the daughter/ of the psychologist/ who studied chemistry in California./Did the daughter fall in love? | definite-long-extraposedRC |
| 3 | *The director congratulated /the instructor/ of the schoolboy/ who was writing interesting reports./Was the instuctor recording the reports? | definite-long-extraposedRC |
| 4 | *The student had liked/ the secretary /of the professor / who was killed in the robbery event./Was he killed in the accident event? | definite-long-extraposedRC |
| 5 | *The father was talking to /the girl /of the young woman /who was standing in the garden./Was the young man talking to the girl? | definite-long-extraposedRC |
| 6 | *A policeman noticed /the bodyguard /of the actor/ who was talking on the phone in the salon. /Did a policeman notice the bodyguard of the actor? | indefinite-long-extraposedRC |
| 7 | *A journalist had dinner with/ the secretary/of the boss/ who liked working in the company./Did a man eat with the boss? | indefinite-long-extraposedRC |
| 8 | *A secretary met /the driver/ of the manager/ who was dreaming of holidays in the countryside. /Did a woman meet the driver of the manager? | indefinite-long-extraposedRC |
| 9 | *A researcher knew /the photographer /of the singer /who was reading a book in the library. /Was a book read in the library? | indefinite-long-extraposedRC |
| 10 | *The lecturer/who studied chemistry in California/ fell in love with/ the daughter/ of the psychologist./Did the lecturer study in Florida? | definite-long-non_extraposedRC |
| 11 | *The director /who was writing interesting reports/ congratulated /the instructor /of the schoolboy./Did the schoolboy congratulate the instructor? | definite-long-non_extraposedRC |
| 12 | *The student/ who was killed in the robbery event/ had liked /the secretary /of the professor./Was the professor killed in the robbery event? | definite-long-non_extraposedRC |
| 13 | *The father /who was standing in the garden /was talking to /the girl /of the young woman./Was the father standing in the garden? | definite-long-non_extraposedRC |
| 14 | *A policeman /who was talking on the phone in the salon/ noticed/ the bodyguard/ of the actor./Was the actor talking on the phone? | indefinite-long-non_extraposedRC |
| 15 | *A journalist/who liked working in the company/ had dinner with/the secretary/of the boss./Did a journalist liked working in the office? | indefinite-long-non_extraposedRC |
| 16 | *A secretary/ who was dreaming of holidays in the countryside/ met /the driver/ of the manager./Did the manager have the driver? | indefinite-long-non_extraposedRC |
| 17 | *A researcher /who was reading a book in the library/ knew /the photographer /of the singer./Did the reasearcher knew the photographer of the singer? | indefinite-long-non_extraposedRC |
| 18 | *The man wrote to /the manager /of the assistant /who was late./Did the man write to the manager? | definite-short-extraposedRC |
| 19 | *The doctor recognised/ the nurse/ of the pupil/ who was tired./Did the doctor recognise the nurse of the pupil? | definite-short-extraposedRC |
| 20 | *The girl talked to/ the coach /of the gymnast /who was sick./Was the girl sick? | definite-short-extraposedRC |
| 21 | *The dean liked /the secretary /of the boss/ who was late./Did the dean like the secretary? | definite-short-extraposedRC |
| 22 | *A nurse ignored/ the stepfather/ of the girl /who was upset./Did the girl ignore the stepfather? | indefinite-short-extraposedRC |
| 23 | *A woman ate with/ the cousin /of the dentist/ who was divorced./Did a woman eat with the cousin of the dentist? | indefinite-short-extraposedRC |
| 24 | *A passenger criticized/the waitress/of the pilot / who was angry./Did the pilot criticized the waitress? | indefinite-short-extraposedRC |
| 25 | *A reporter interviewed with/the doctor/ of the lady/ who was clever./Did a reporter interview with the doctor? | indefinite-short-extraposedRC |
| 26 | *The man /who wrote to /the manager /of the assistant /was late./Was the man late? | definite-short-non_extraposedRC |
| 27 | *The doctor /who recognised/ the nurse /of the pupil /was tired./Was the nurse tired? | definite-short-non_extraposedRC |
| 28 | *The girl /who talked to /the coach /of the gymnast/ was sick./Did the girl talk to coach? | definite-short-non_extraposedRC |
| 29 | *The dean /who liked/ the secretary/ of the boss/ was late./Did the dean like the secretary? | definite-short-non_extraposedRC |
| 30 | *A nurse /who was upset/ ignored/ the stepfather/ of the girl./Was the nurse upset? | indefinite-short-non_extraposedRC |
| 31 | *A woman/ who was divorced/ ate with/ the cousin /of the dentist./Was the man divorced? | indefinite-short-non_extraposedRC |
| 32 | *A passenger/ who was angry /criticized/the waitress/of the pilot./Was the passenger angry? | indefinite-short-non_extraposedRC |
| 33 | *A reporter/ who was clever/ interviewed with/the doctor/ of the lady./was the doctor clever? | indefinite-short-non_extraposedRC |
| 34 | *The guard concealed /the weapon /from the criminal yesterday. | filler |
| 35 | *The guard concealed /the weapon/ of his new colleague/ yesterday. | filler |
| 36 | *The author mailed /the story /to the editor /once again. | filler |
| 37 | *The author mailed/ the story /with the improvements/ once again. | filler |
| 38 | *The police informed /the guards /about the danger/ this morning. | filler |
| 39 | *The police informed /the guards /of the old castle/ this morning. | filler |
| 40 | *The journalist sent/ the report /to the magazine/ right away. | filler |
| 41 | *The journalist sent/ the report/ about the murder/ right away. | filler |
| 42 | *The robber hid /the jewels/ from the policemen/ yesterday. | filler |
| 43 | *The robber hid /the jewels/ of the millionaire/ yesterday. | filler |
| 44 | *The lady showed/ the necklace/ to her new neighbour/ once again. | filler |
| 45 | *The lady showed/the necklace/ with the diamond/ once again. | filler |
| 46 | *The salesman offered/ the apples/ to the little girl/ this morning. | filler |
| 47 | *The salesman offered/ the apples/ with the red patches/ this morning. | filler |
| 48 | *The soldier handed/ the weapon/ to his new comrade/ right away. | filler |
| 49 | *The soldier handed/ the weapon/ of his new comrade/ right away. | filler |
| 50 | *The guard fired/ the weapon/ on the training ground/ yesterday. | filler |
| 51 | *The guard fired /the weapon/ of his new colleague/ yesterday. | filler |
| 52 | *The author wrote/ the story/ within two weeks/ once again. | filler |
| 53 | *The author wrote/ the story/ with the happy end/ once again. | filler |
| 54 | *The police interviewed/ the guards/ during the morning/ once again. | filler |
| 55 | *The police interviewed/ the guards/ of the old castle/ this morning. | filler |
| 56 | *The journalist read/ the report /in the evening/ once again. | filler |
| 57 | *The journalist read/ the report/ about the murder/ right away. | filler |
| 58 | *The robber sold/ the jewels/ on the black market/ yesterday. | filler |
| 59 | *The robber sold/ the jewels/ of the millionaire/ yesterday. | filler |
| 60 | *The lady lost/ the necklace/ in the afternoon/ once again. | filler |
| 61 | *The lady lost/ the necklace/ with the diamond/ once again. | filler |
| 62 | *The salesman ate/ the apple/ with great appetite/ this morning. | filler |
| 63 | *The salesman ate/ the apple/ with the red patches/ right away. | filler |
| 64 | *The soldier destroyed/ the weapon/ in the fierce battle/ yesterday. | filler |
| 65 | *The soldier destroyed/ the weapon/ of his new comrade/ yesterday. | filler |

# Appendix E

Offline questionnaire

## Off-line Questionnaire

Instruction:
Please read the following sentences and decide which of the alternative answers seems most plausible to you.

Participant ID or Email

Short answer text

1. a. The student had liked the secretary of the professor who was killed in the robbery.

- ◯ the student was killed.
- ◯ the secretary was killed.
- ◯ the professor was killed.

2. a. The doctor examined the mother of the small boy who was badly injured in the accident.

- ◯ the doctor was injured.
- ◯ the mother was injured.
- ◯ the boy was injured.

3. a. The photographer ignored the daughter of the manager who was very impolite and arrogant.

- ◯ the photographer was arrogant.
- ◯ the daughter was arrogant.
- ◯ the manager was arrogant.

4. a. The secretary found the mistress of the baron who had left the party very early.

- ◯ the secretary had left the party.
- ◯ the mistress had left the party.
- ◯ the baron had left the party.

5. a. The housemaid saw the driver of the lady who was waiting in front of the garage.

- ◯ the housemaid was waiting.
- ◯ the lady was waiting.
- ◯ the driver was waiting.

6. a. The pilot smiled at the nephew of the stewardess who was writing a postcard in the cockpit.

- ◯ the pilot was writing a postcard
- ◯ the stewardess was writing a postcard.
- ◯ the nephew was writing a postcard.

7. a. The judge knew the solicitor of the baroness who had lost an important trial recently.

- ◯ the judge had lost a trial.
- ◯ the baroness had lost a trial.
- ◯ the solicitor had lost a trial.

8. a. The little girl envied the lover of the princess who was looking at the wonderful castle.

- ◯ the little girl was looking at the castle.
- ◯ the princess was looking at the castle.
- ◯ the lover was looking at the castle.

# Appendix F

*Table 12. Correlations of Proficiency measures for Persian learners*

| | | Proficiency | LexTALE |
|---|---|---|---|
| Proficiency | Pearson Correlation | 1 | .503* |
| | Sig. (2-tailed) | | .033 |
| | N | 18 | 18 |
| LexTALE | Pearson Correlation | .503* | 1 |
| | Sig. (2-tailed) | .033 | |
| | N | 18 | 18 |

*. Correlation is significant at the 0.05 level (2-tailed).

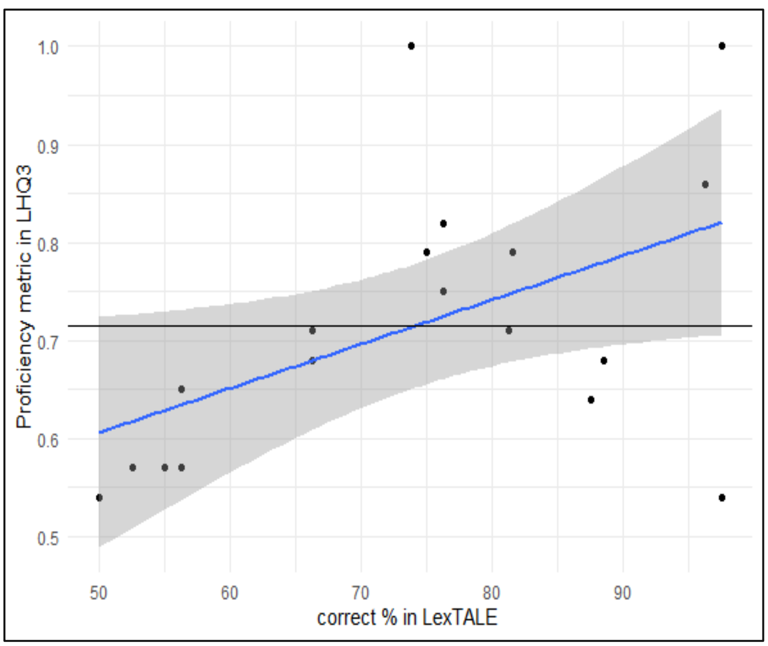


*Figure 9. Scatterplot and regression line of lexTALE and self-rating proficiency scores for Persian learners*

*Table 13. Correlation coefficients with age predictor and backward digit span*

| | | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|---|
| Native speakers | Intercept | 2.2437 | 3.2875 | 0.682 | 0.507 |
| | Age | 0.1725 | 0.1061 | 1.626 | 0.128 |
| Persian learners | Intercept | 11.80746 | 2.10249 | 5.616 | 3.87e-05 *** |
| | Age | -0.11578 | 0.06592 | -1.756 | 0.0981 |

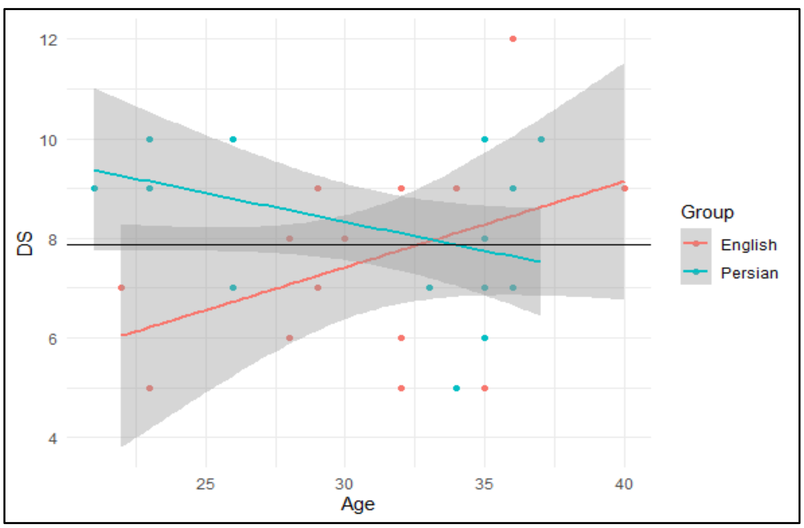


*Figure 10. Digit span as a function of age with model fit*

*Table 14. Correlation between Proficiency and Low attachment*

| | | Proficiency | Low attachment |
|---|---|---|---|
| Proficiency | Pearson Correlation | 1 | .089 |
| | Sig. (2-tailed) | | .725 |
| | N | 18 | 18 |
| Low attachment | Pearson Correlation | .089 | 1 |
| | Sig. (2-tailed) | .725 | |
| | N | 18 | 18 |

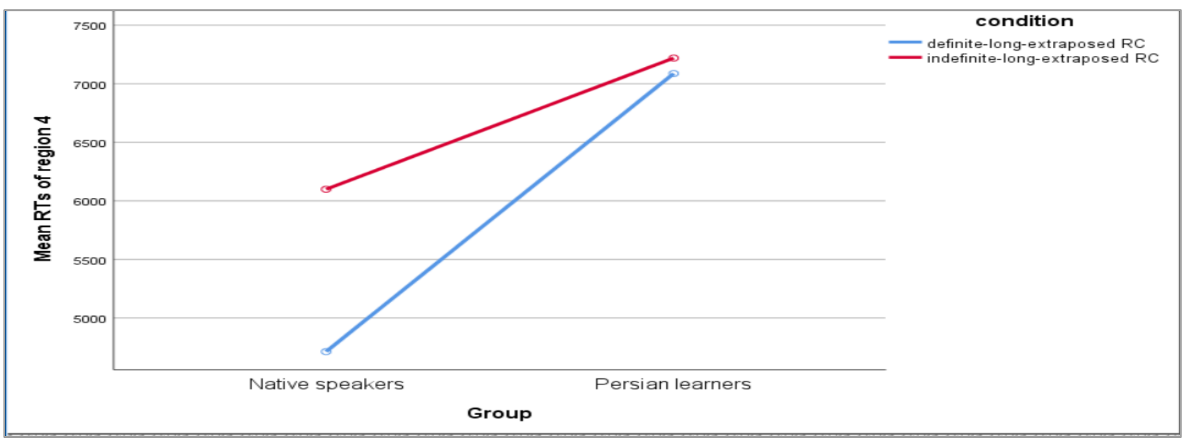


*Figure 11. Mean RTs of region 4 across conditions in groups*

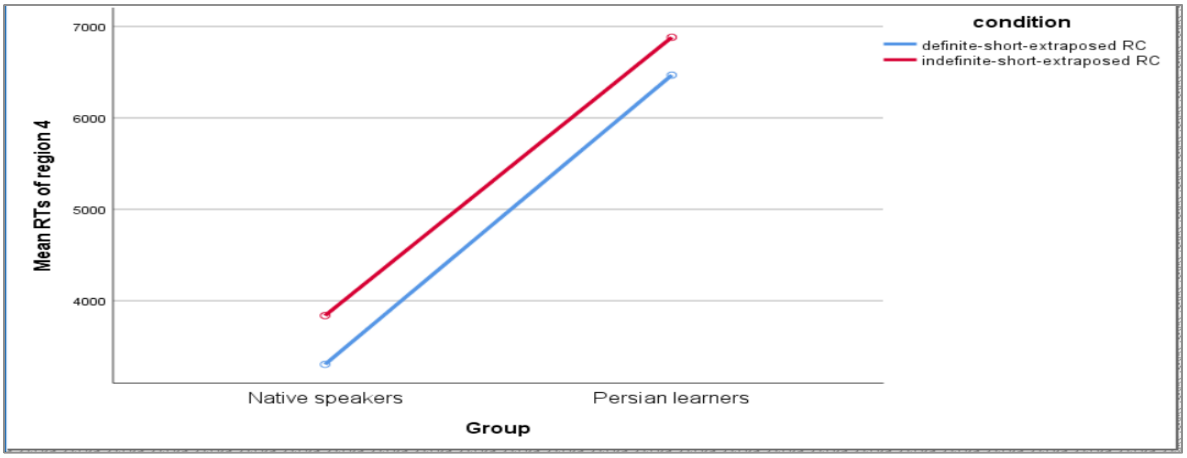


*Figure 12. Mean RTs of region 4 across conditions in groups*

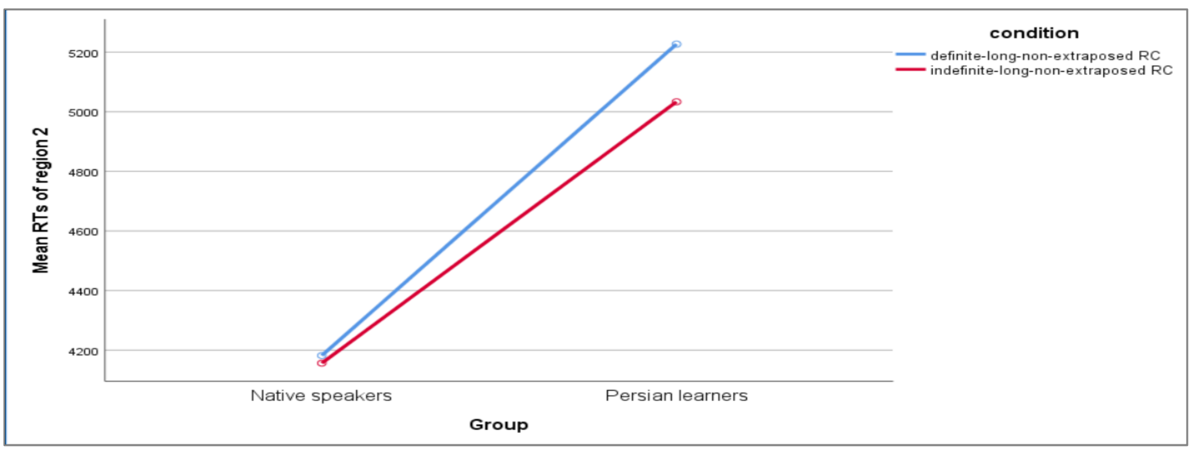


*Figure 13. Mean RTs of region 2 across conditions in groups*

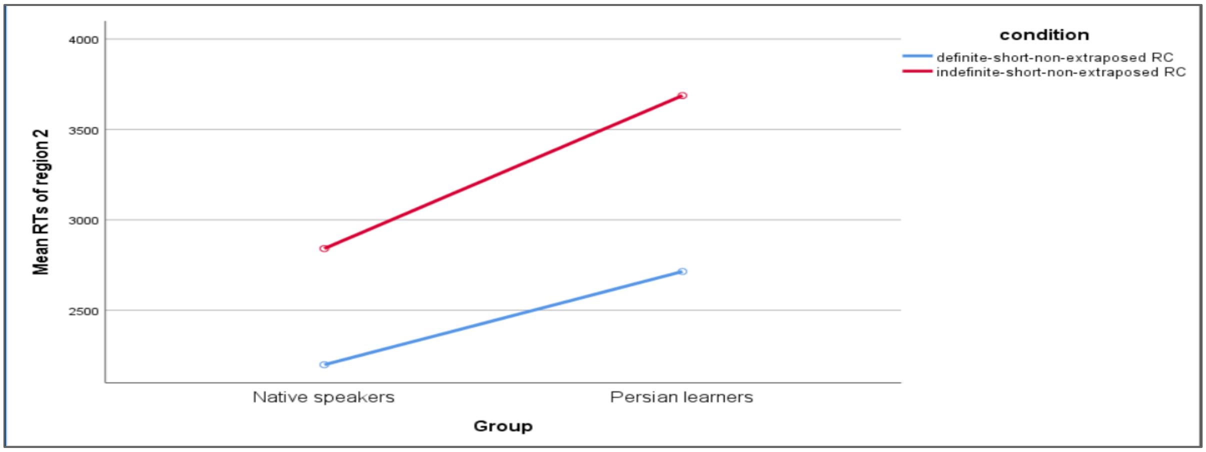


*Figure 14. Mean RTs of region 2 across conditions in groups*

*Table 15. Regression analysis for predicting L2 online processing*

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| Intercept | 1.589349 | 1.124759 | 1.413 | 0.16866 |
| Proficiency | -0.00345 | 0.009579 | -0.361 | 0.72098 |
| Digit pan | 0.104822 | 0.076246 | 1.375 | 0.18010 |
| Age | 0.042423 | 0.029411 | 1.442 | 0.16028 |

*Table 16. Statistics summary for overall model fit*

| Regression statistics | |
|---|---|
| Residual standard error | 0.7552 |
| Multiple R-squared | 0.3887 |
| Adjusted R-squared | 0.3014 |
| F-statistic | 4.452 |
| p-value | 0.006 |

# Appendix G

Table 17. Results of self-paced reading task per condition by high-low attachment

| | definite-long-RC | indefinite-long-RC | definite-short-RC | indefinite-short-RC | definite-long-non_RC | indefinite-long-non_RC | definite-short-non_RC | indefinite-short-non_RC |
|---|---|---|---|---|---|---|---|---|
| Persian | | | | | | | | |
| High | Mean (4332) SD (109.42) | Mean (5052) SD (288.16) | Mean (3783) SD (60.32) | Mean (6866) SD (619.18) | Mean (8452) SD (77.16) | Mean (8105) SD (170.84) | Mean (5446) SD (317.49) | Mean (9709) SD (231.25) |
| Low | Mean (6475) SD (112.18) | Mean (7371) SD (281.61) | Mean (5478) SD (55.32) | Mean (9155) SD (612.12) | Mean (10361) SD (50.29) | Mean (9927) SD (179.74) | Mean (7236) SD (379.86) | Mean (11243) SD (193.28) |
| English | | | | | | | | |
| High | Mean (2319) SD (20.49) | Mean (2641) SD (10.85) | Mean (1608) SD (33.49) | Mean (2110) SD (14.16 | Mean (4745) SD (41.82) | Mean (4938) SD (74.37) | Mean (2385) SD (96.82) | Mean (4044) SD (19.81) |
| Low | Mean (3140) SD (45.53) | Mean (2641) SD (10.51) | Mean (2536) SD (44.84) | Mean (2997) SD (17.66) | Mean (5281) SD (73.86) | Mean (5436) SD (38.28) | Mean (3296) SD (78.59) | Mean (4475) SD (40.37) |