Minor research project

The predictability of second language learning rate in seniors based on resting-state EEG

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ABSTRACT

Resting-state EEG research is quite a new paradigm in neurolinguistics. Some neurolinguistic studies using this technique looked into the power of frequency bands in resting-state EEG recordings and stated that the variance in second language learning rate of college-aged individuals can be predicted based on this power (e.g. Prat et al., 2016). Resting-state EEG research hitherto mainly focussed on this age group. Because of the growing senior population in our world and the presumption that second language learning supports healthy ageing, it is important to include seniors in neurolinguistic research. We therefore decided to extend the existing studies to an older population in order to determine whether also second language learning rate in this age group can be predicted based on a resting-state eyes-open EEG. Seven healthy functionally monolingual Dutch seniors completed a four-week English as a second language course and underwent a resting-state EEG. We found that resting-state EEG indices at an electrode and at the brain level could predict how fast seniors were able to learn a second language. Specifically, the low-beta and gamma frequency band were strongly significantly correlated with second language learning rate in seniors. These findings were partly in line with the results in young adult research.

Keywords: resting-state EEG, second language learning, seniors, cognition, third-age

1. Introduction

Every experience someone undergoes, modulates the brain and its functioning. Examples of these life experiences are being a chess player (Hänggi et al., 2014), being a musician (Gaser & Schlaug, 2003) or being a licensed taxi driver (Maguire et al., 2000). Learning a new language is also such a brain-changing experience: studies suggest that bilingualism and second language (L2) learning have an effect on cognition and on the functional and structural properties of the brain (e.g. Li, Legault & Litkofsky, 2014).

Executive functions are considered to be an important feature of cognition. They are defined as a set of skills responsible for cognitive processes which are often needed in order to be able to handle (ir)relevant information (Lagattuta et al., 2015). Examples of executive functions are inhibition and cognitive flexibility (Van den Noort et al., 2019). The impact of bilingualism on executive functioning has been studied intensively over the last decade. Several studies have reported improved executive functioning skills in bilinguals compared to monolinguals, for example with regard to inhibition (e.g. Bialystok et al., 2009; Bice & Kroll, 2015). Not only bilingualism, but also L2 learning is presumed to have an impact on cognition. Shoghi Javan & Ghonsooly (2017) compared advanced learners of English as a foreign language (EFL) with beginners and concluded that cognitive flexibility and working memory considerably enhanced as L2 proficiency improved. In this study, however, no difference in inhibition skills was found between the advanced EFL learners and the beginners. The exact way in which L2 learning and bilingualism affect cognition is, therefore, still debated (e.g. Leivada et al., 2020; van den Noort et al., 2019)

In addition to the effects on executive functioning, bilingualism and L2 learning seem to have an impact on the brain's structural characteristics. Brain areas appear to restructure due to these experiences (e.g. Pliatsikas, 2019). Olsen et al. (2015) investigated the brains of lifelong bilingual older adults and matched monolinguals and found that bilinguals possessed greater frontal lobe white matter volume compared to monolinguals. Research suggests that it is not necessary to be bilingual in the course of a lifetime to show structural changes: shorter periods of L2 leaning also induce structural brain changes. Li et al. (2014) wrote a review article on L2 experience-induced brain changes and concluded that structural changes in the brain's grey matter density and white matter integrity can already be found in all age groups after a short period of language training. They also reported studies showing greater cortical thickness after language training.

Not solely the static, structural properties of the brain and the brain's cognition have been found to be susceptible to change as a function of bilingual experience, also the brain's functioning is. Studies suggest that functional connectivity between and within brain areas changes (e.g. Pliatsikas, 2019). Bubbico et al. (2019), for instance, examined the effects of four months of L2 learning on brain connectivity in elderly. They found an improved functional connectivity in the language network and executive functioning network (rIFG, rSFG, ISPL). Rossi et al. (2017) looked into the changes in white-matter connectivity in late L2 learners and found a positive effect on white matter fractional anisotropy in different brain areas as a function of L2 learning.

Research, thus, suggests that L2 learning facilitates cognition and modulates the brain's structure and functioning, but is this effect bidirectional? In other words, can brain properties and executive functioning performance facilitate L2 learning and are we able to predict, based on one's brain properties, how fast someone is able to learn an L2? L2 learning is strongly characterised by individual variation, especially in adulthood: some people learn languages more easily, acquiring a higher proficiency level, than others (Chai et al., 2016). Someone's capacity to learn an L2 has traditionally been captured in the construct of language aptitude (see Wen et al., 2019 for an overview). In the early years of language aptitude research, it was hypothesized that language aptitude comprised of four abilities which predicted language learning success, namely phonemic coding ability, grammatical sensitivity, inductive language learning ability and rote learning ability (Carroll, 1968; Carroll & Sapon, 2002). Nowadays, research suggests that the cognitive construct of working memory is also an important component of language aptitude that needs to be added to this theory (Linck & Weiss, 2015; Wen, 2019).

Several studies have shown that someone's executive functioning performance could predict how well someone is able to learn an L2. In the former paragraph, working memory has already been suggested as a part of language aptitude, but also inhibitory control performance seems to be able to predict how well someone is able to learn an artificial language (Kapa & Colombo, 2014). Working memory and inhibitory control, in contribution with other cognitive skills, such as attentional shifting, seem to predict language aptitude (Woumans et al., 2019).

Traditional notions of language aptitude never took brain structure and functioning into account, but in recent years this has tentatively been shown to be important. Despite the unclarities about the structural and functional neural properties underlying individual variation, studies suggest that L2 learning success can be predicted based on the brain's structural properties (Qi et al., 2015). Faster L2 learners, for example, have more white matter in specific brain areas, especially in the left hemisphere (LH) (Golestani, Paus & Zatorre, 2002; Golestani et al., 2007). Diffusion tensor imaging studies revealed that based on the microstructure of the white matter pathways in the brain one's L2 learning success can be predicted, already after 4 weeks of language learning (Flöel et al., 2009; Mamiya et al., 2016; Qi et al., 2015). These studies suggest that L2 learning success can be predicted by studying one's brain structure.

With the introduction of resting-state neuroimaging paradigms, functional brain properties at rest were also considered as vital in predicting someone's L2 learning capacities. Resting-state neuroimaging techniques measure the brain's activity at rest in the absence of any cognitively demanding tasks (Bice, Yamasaki & Prat, 2020). Several studies suggest that L2 learning success in adults can be predicted by certain functional properties, such as the resting-state functional connectivity between areas in the language network (Chai et al., 2016; Ventura-Campos et al., 2013). A relatively new technique in the area of neurolinguistic resting-state research, is resting-state EEG (Luk, Pliatsikas & Rossi, 2020). Prat et al. (2016) examined the power of frequency bands of the resting-state qEEG in college-aged individuals and tried to relate this to their second language learning rate (SLLR). Based on the frequency power spectra, Prat et al. were able to predict up to 60% of the variance in their participants' SLLR. Specifically, the power of beta and low-gamma frequencies were strongly positively correlated with SLLR. The involvement of beta activity over the right-hemisphere electrodes in language learning in adults was later confirmed by three follow-up studies on natural (Bice et al., 2020; Prat, Yamasaki & Peterson, 2019) and artificial L2 learning (Prat et al., 2020)

The studies on (resting-state) brain properties associated with L2 learning success discussed so far, all involved college-aged individuals. Our globalizing world, by contrast, is ageing (He, Goodkind & Kowal, 2016). Ageing goes hand in hand with cognitive decline and neurodegeneration (Harada, Natelson Love & Triebel, 2013). This can lead to neurodegenerative diseases, like Alzheimer's, which will become more and more common in the future (Alzheimer's Association, 2020). Neurolinguistic studies have been presuming that lifelong L2 learning can promote healthy (cognitive) ageing. Lifelong bilinguals are, for example, suggested to possess a neural and/or cognitive reserve rendering the brain more resistant to brain ageing effects (Perani et al., 2017) and to be diagnosed with Alzheimer's disease five years later than monolinguals do, due to their cognitive reserve (Alladi et al., 2013). Therefore, the goal of this study is to investigate whether SLLR in seniors can be predicted on the basis of resting-state EEG indices. A group of monolingual Dutch seniors learned English as an L2 for four weeks during an English course. Their SLLR was determined and related to the power of the frequency bands in their resting-state EEG taken before the course started. It is important to state that a faster SLLR does not automatically mean that the participants attain a higher language level. This study looks into learning rate and not into final proficiency level achieved.

We hypothesize that SLLR in seniors can be predicted on the basis of the power of frequency bands in the resting-state EEG, as this has also been the case for younger adults (Bice et al., 2020; Prat et al., 2016; Prat et al., 2019; Prat, et al., 2020). Furthermore, studies have already suggested that various qEEG indices are accurate predictors of performance on cognitive tests (e.g. Cheung et al., 2014; Choi et al., 2019; Finnigan & Robertson, 2011). Since L2 learning is highly intertwined with cognitive skills (e.g. Bialystok et al., 2009; Kapa & Colombo, 2014), it is likely that we will find a correlation between SLLR and EEG indices.

2. Methodology

2.1. Participants

Seven healthy seniors (two females; mean age = 66.1) were recruited. The participants were functionally monolingual in Dutch, meaning that they may have had minor knowledge of other languages or dialects than Dutch, but did not actively use these on a daily basis. All participants had an English proficiency lower than B2 and were cognitively healthy. This was determined based on a screening session, which consisted of a couple of questions on the participants' English proficiency and a cognitive failure questionnaire.

2.2. Language course

The participants completed a four-week English course, consisting of weekly classes of 1.5 hours at the University of Groningen including a 15-minute break. Additionally, they did homework exercises of 45 minutes for five days a week.

The participants were randomly distributed over two groups: a group receiving implicit communicative-based language instruction which mainly focussed on meaning (Long, 1991) and a group receiving explicit grammar-based instruction which mainly focussed on form (Akakura, 2011). During the classes the book *New Total English Elementary* (Hall & Foley, 2011) was used. For the homework sessions the online learning environment *My English Lab,* belonging to the course book, was used. We do not elaborate further upon the differences between explicit and implicit teaching methods in this study because we did not account for these differences in our analysis (for more information see Van der Ploeg (2020)).

2.3. Materials

2.3.1. English Language Assessment

The participants' proficiency level was assessed on the basis of an IELTS listening task (British Council, 2019) and an IELTS-inspired speaking task (Nijmeijer, Busstra & Keijzer, 2019). These tasks were administered before starting and after completing the course to record learning gains. Three versions of the speaking and listening tasks were used to avoid learning effects (see Appendix A).

The IELTS listening task was a standardized listening task, during which the participants had to listen to everyday life conversations (e.g. buying a car) and had to answer questions about these conversations. For each participant, a score for listening proficiency was calculated based on the number of correctly answered questions.

The IELTS-inspired speaking task consisted of two separate tasks, among which a free-speech task (part 2). During this task, the participants were instructed to talk about a certain topic (e.g. hobby) for approximatively two minutes and to incorporate their answers to four given questions on their instruction form in their monologue (e.g. how often do you do it?). Participants were given the opportunity to prepare the assignment for one minute. The free-speech task was chosen to be analysed because it provides a more naturalistic way of determining L2 speaking proficiency compared to standardized tests (Chai et al., 2016) and because it had a semi-controlled format created by the four questions, which has proven to elicit greater syntactic complexity than entirely free conversational tasks do (Piggott, 2019).

The speaking task was recorded and transcribed for further analysis by making use of online transcription software (www.amberscript.com). Thereupon, a fragment of the complete transcription was chosen to be analysed. This fragment was chosen based on the following criteria (a) the role of the interviewer was as minor as possible and (b) the participant was speaking spontaneously as much as possible. This enabled comparison between the participants' speech fragments. The fragments were analysed by calculating scores for different complexity, accuracy and fluency (CAF) measures based on Michel (2017), Piggott (2019) and Verspoor, Schmid & Xue (2012).

2.3.1.1. Complexity

To measure the complexity of participants' speech, the Root of the Type Token Ratio (RTTR) was analysed. A Type Token Ratio (TTR) is a measure that calculates lexical complexity and lexical diversity by dividing the total number of unique words (types) in a fragment by the total number of words (tokens) (Piggott, 2019). In this study, the root of the TTR was used to correct for the differences in fragment length between the recordings (Carroll, 1967).

Despite the discussion in the literature about measuring complexity with a TTR (e.g. Mitchell, 2014; Pallotti, 2015), this measure was chosen, because it often used in assessing language skills (e.g. Kavé & Dassa, 2017; Kochmar & Shutova, 2017; Piggott, 2019; Staples & Reppen, 2016). Moreover, we hypothesized that lexical diversity is a good indicator of language proficiency, because vocabulary range is known to extend majorly across different language proficiency levels and especially expands in the beginner levels in the CEFR (Council of Europe, 2011).

In this study, the RTTR was calculated by making use of an online tool (www.lextutor.ca/vp/eng/) based on Heatley, Nation & Coxhead (2002). The RTTR was calculated by excluding types and tokens in repetitions, revisions, filled pauses, L1 words and sentences which the participants read from the IELTS instruction form following Piggott (2019).

2.3.1.2. Accuracy

To determine the accuracy of participants' speech, verb use was analysed. We hypothesized that the accuracy of verb use is a good measure to distinguish between the different levels of beginner learners, because different verb tenses are introduced at different CEFR-levels, especially in the beginner levels (A1-B1) (Exam English, 2019) and are suggested to be more accurately present in higher proficiency levels (Verspoor et al., 2012).

First, all the verbs elicited by the participant in the fragment were collected and the total amount of congruency, time and aspect errors as a ratio of the total number of verbs in the fragment were calculated separately (Piggott, 2019; Vespoor et al., 2012). The average of these three ratios was calculated, which was considered as the participants' final accuracy score. In the calculation of the number of errors false starts, repetitions, revisions and text read out loud from the instruction form were disregarded following Piggott (2019).

2.3.1.3. Fluency

To gauge participants' fluency, the total number of words per minute phonation time was calculated. The phonation time was considered to be the time which the participants spent on speaking (Wood, 2010). We considered this measure to be more stable than other fluency measures, such as the number of false starts, because it depends less on fragment length.

First of all, the total number of words spoken in the fragment was calculated. False starts, repetitions, revisions, L1-words, filled pauses and text read out loud from the instruction paper were excluded from the calculation of the total number of words following Piggott (2019). Thereafter, the phonation time was calculated by making use of the audio software Audacity excluding L1-words, false starts, repetitions, revisions, text read out loud from the instruction paper, filled pauses and unfilled pauses longer than 0.3 seconds (Piggott, 2019; Riggenbach, 1991; Wood, 2010). After having calculated the total number of words in the fragment and the phonation time, the number of words per minute phonation time was calculated by multiplying the number of words spoken in the fragment by 60 and dividing it by the total phonation time of the fragment.

2.3.2. Resting-state EEG

EEGs were collected from 34 AgI AgCl electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, PO7, PO1, PO2, PO8, O1, Oz, O2) at a sampling rate of 512 Hz using an ANT Neuro amplifier system (Advanced Neuro 409 Technologies B.V., Enschede, The Netherlands). Furthermore, two eye electrodes (EOGH, EOGV) detecting horizontal and vertical eye movements and two reference mastoid electrodes (A1, A2) were included. The electrodes were attached on a textile cap (EasyCap, Herrsching, 407 Germany) and aligned in equidistant positions following the international 10/20 408 system.

2.4. Procedure

This study was part of a bigger study on L2 learning, hence, the test battery comprised more tests than used for this analysis. The pretesting was divided into two sessions. In the first session, the participants signed the informed consent, after which three hours of psychometric testing, including pauses, were completed. The major part of the psychometric testing comprised cognitive tasks done on paper, but the last task, during which the participants were already capped, had to be fulfilled on a screen. After this task, five minutes of eyes-open resting-state EEG were taken. The participants were asked to sit still and to relax without falling asleep while looking at a fixation cross on a computer screen. The second pre-test session took two hours and during this session the participants underwent a number of language tasks including the IELTS listening task and the IELTS-inspired speaking task. The participants were asked to fill in a number of background questionnaires at home.

Subsequently, the participants completed the four-week English course as described in section 2.2. After finishing the course, the participants underwent a post-test session, consisting of a second IELTS listening and IELTS-inspired speaking task.

2.5. EEG analysis

EEGs were pre-processed using a Matlab script created by Richter (2020). Using visual inspection, all trials and channels were checked for artefacts. Channels and trials containing major deviations and participants showing over 75% of bad channels and/or bad trials were discarded from further analysis (Prat et al., 2016). Moreover, the first three minutes and last three minutes of the recording were deleted, because brain data collected during this time window could be influenced by the cognitive tasks before the resting-state recording and could be affected by movements caused by finishing the experiment (López-Zunini et al., 2013).

Thereafter, the pre-processed EEG data were analysed with the R-script of Prat et al. (2016). The EEG signals were split into two second epochs with one second overlap and a Hanning window was applied to each epoch. Each epoch's power spectrum was calculated with the Fast Fourier Transform and the mean log power spectrum was taken. The mean log power spectrum was separately calculated for theta (4-7.5 Hz), alpha (8-12.5 Hz), low-beta (13-14.5 Hz), mid-beta (15-17.5 Hz), high-beta (18-29.5 Hz), and low-gamma (30-40 Hz) frequency bands for each channel and each participant. Delta (<4 Hz) and high-gamma (>40 Hz) were not analysed due to their susceptibility to artifacts following Prat et al. (2016).

2.6. Calculation SLLR and correlations

To check whether the participants showed an improvement in their speaking and listening skills, a paired samples t-test was run in R for the different language scores on the pre- and post-test. This test was run separately for the three CAF-scores and listening scores. A significant difference between the scores on the pre- and post-test suggested that participants improved their language proficiency for that skill during the course.

When an improvement in a language skill was seen, the SLLR was calculated by extracting the beta values (or learning slopes) out of the linear functions describing the participant's learning improvement following Prat et al. (2016). The linear function was calculated based on the difference in language scores in the pre-test and post-test session. The power of the different frequencies in the resting-state EEG was, thereafter, correlated with the SLLR.

3. Results

3.1. Language learning outcomes and SLLR

For the participants' language scores, see Table 1. None of the CAF speaking measures showed a significant difference between the pre-test and post-test session. The participants did not show a significant difference ($t(6)$ = 0.06; p = .956) on complexity in the pre-test (*M* = 5.79; *SD* = 0.68) and post-test (*M* = 5.76*; SD* = 1.08). Furthermore, no significant difference ($t(6)$ = -1.22*;* p = .270) was observed concerning the accuracy scores in the pre-test (*M* = 0.94*; SD* = 0.06*)* and post-test (*M* = 0.96*; SD* = 0.03). Also for fluency no significant difference ($t(6)$ = -0.52*;* p = .620) was found between the pre-test (*M* = 163.14*; SD* = 22.41) and post-test (*M* = 166.86*; SD* = 16.12).

Contrary to the speaking skills, a significant difference was observed ($t(6)$ = -5.67*;* p = <.05) between the participants listening scores in the pre-test (*M =* 7.93; *SD* = 3.02) and post-test *(M* = 11.43*; SD* = 3.14), meaning that the participant did significantly improve their listening skills (see Figure 1).

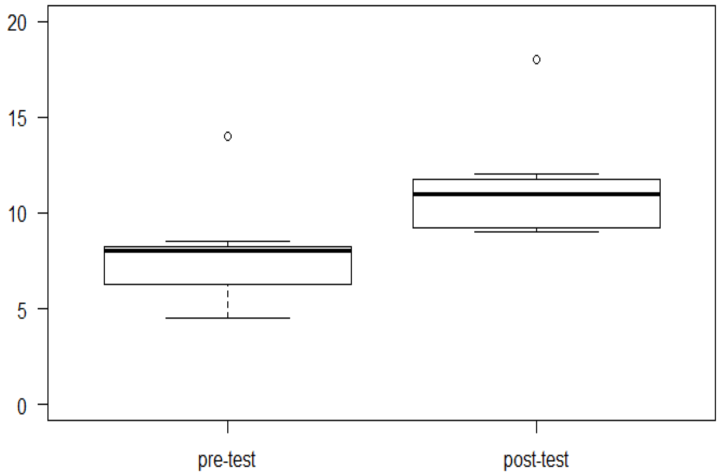

Figure 1. Visualisation significant difference pre- and post-test listening skills

Table 1. *Summary L2 proficiency data analysis*

In this table, both the participants' scores on the CAF-measures and the listening task are depicted and the learning slopes showing the participants' improvements on listening. [1] *is not included in the final analysis, because the corresponding EEG data were too bad.*

Participant	Condition	Speaking			Listening	
		Complexity score	Accuracy Score	Fluency Score	Score	Learning Slope
1	Pre	5.8	0.86	164	8.0	1.0
	Post	4.7	0.92	163	9.0	
2	Pre	5.8	0.92	180	8.5	3.5
	Post	7.1	0.94	171	12.0	
3	Pre	5.2	0.91	205	6.5	5.0
	Post	5.5	0.95	185	11.5	
4	Pre	5.3	0.87	148	8.0	1.5
	Post	5.4	1.00	136	9.5	
5	Pre	5.2	1.00	154	14.0	4.0[1]
	Post	5.5	1.00	182	18.0	
6	Pre	6.1	1.00	141	4.5	4.5
	Post	7.4	0.94	163	9.0	
7	Pre	7.1	1.00	150	6.0	5.0
	Post	4.7	1.00	168	11.0	

Since the participants did not show a significant improvement for the speaking measures examined in this study, whereas listening skills did, we decided to work with the participants' SLLR regarding listening skills only. As described in 2.6, beta values were calculated from the learning curve on listening and were interpreted as SLLR (*range* = 1.0-5.0*; M* = 3.5*; SD* = 1.51), see Table 1.

3.2. Correlations resting-state indices and SLLR

The power of the frequency bands in the resting-state EEG was correlated to the participants' SLLR in listening to see whether we could predict SLLR based on resting-state EEG indices. This was done at a brain level and at an electrode level. Since the resting-state EEG recordings of one participant (participant 5, Table 1) consisted of more than 75% bad channels and trials, this participant's results were excluded from the EEG-analysis.

3.2.1. Correlations resting-state indices at a brain level

For each frequency band separately, the average power per frequency band over all electrodes was calculated and correlated to SLLR. The average power of the alpha frequency band (8-12.5 Hz) showed a strong, positive correlation with SLLR ($r(4)$ = .85, p = <.05). The average powers of the other frequency bands did not show significant correlations with SLLR (see Appendix 2).

3.2.2. Correlations resting-state indices at an electrode level

In addition to correlations at a brain level, also correlations at an electrode level were found (see Table 2). These correlations were reported at different electrodes, in different brain areas, in both hemispheres and pertained to different frequency bands.

The predictive power of the significant correlations was calculated, by calculating the squared Pearson product-moment correlation coefficient following Prat et al. (2016), see Table 2. Resting-state EEG indices explained up to 90% of the variance observed among the individuals. The most predictive frequency bands were low-beta (13-14.5 Hz) and gamma (30-40 Hz): the low-beta frequency band was significantly negatively correlated with SLLR (r = -.94, p = .018) over the LH in frontal regions. The gamma frequency band was strongly significantly positively correlated in the frontal area of the right hemisphere (RH) (r = .94, p = .017) and strongly negatively correlated in the parietal area of the RH (r = -.95, p = .004). Other relatively strong positive correlations between high-beta (18-19.5 Hz, r = .82, p < .05) and theta (4-7.5 Hz, r = .83-.95, p < .05) were found more spread over the scalp including frontal (F7), central (FC3) and parietal (P3 & P4) regions in both the LH and RH. For an overview and a visualisation of the results, see Table 2 and Figure 2.

Table 2. *Correlations between resting-state EEG and SLLR of listening skills*

Frequency band (Hz)	**Electrode**	**Location**	***N***	***r***	***r*²**	***p***
Theta (4-7.5)	F7	LH Frontal	5	.95	.89	.015*
	FC3	LH Central	6	.83	.69	.041*
	P4	RH Parietal	6	.83	.69	.039*
Low-Beta (13-14.5 Hz)	F7	LH Frontal	5	-.94	.88	.018*
	F3	LH Frontal	5	-.94	.88	.018*
High-Beta (18-29.5 Hz)	P3	LH Parietal	6	.82	.66	.048*
Gamma (30-40 Hz)	F4	RH Frontal	5	.94	.89	.017*
	P4	RH Parietal	6	-.95	.90	.004**

**Indicates that p <.05, ** indicates p <.005*

4. Discussion

4.1. General discussion

The goal of this study was to determine whether resting-state EEG indices could predict SLLR in elderly after four weeks of L2 learning. We therefore expanded Prat et al.'s (2016) study by extending their design to an older adult population for the first time. Our results show that several EEG indices correlate significantly with SLLR in older adults' listening skills. The average alpha power over all electrodes and the power over different frequencies at specific electrode sites showed significant correlations with SLLR in listening skills. Contrary to the listening skills, no significant improvement in spoken proficiency was attested based on the speaking measures taken. Therefore, speaking skills were excluded from the correlational analysis. In the upcoming section, the language data will be discussed first, after which the (significant) correlations found at a brain and at an electrode level and the comparison between college-aged individuals and seniors will be considered.

In the current study, speaking skills did not improve during a four-week English course. A possible explanation for this lack of improvement might be the fact that the participant only had a limited exposure to English during the course, namely a total of 19 hours. The CEFR states that motivated adult learners need between 100 and 200 hours of guided learning to improve their proficiency level with one level and that this number of hours increases as a function of increased proficiency: more hours are needed to progress from B1 to B2 than from A2 to B1, for instance (Knight, 2018). 19 hours of exposure in four weeks is, thus, even on a beginner's level, very little. The fact that no difference in speaking skills could be attested, moreover, may be explained by the way of assessment. Speaking recordings were assessed on only three CAF-measures. A more extended rating on (different) CAF-measures or, as suggested by Révéz, Ekiert & Torgersen (2016), a holistic rating by experts might enable to analyse the speaking data more elaborately and to determine more detailed differences in speaking proficiency. Additionally, as stated in the methodology, three different versions of the IELTS-inspired speaking task were used. These versions were not fully comparable. The tasks provoked linguistic structures having different levels of difficulty, mainly in terms of specialised vocabulary needed, grammar skills needed and possibilities to elaborate on the task topic. Therefore, spoken proficiency might be assessed differently in the three versions.

Contrary to speaking skills, listening skills did improve after four weeks of L2 learning. An explanation for the difference between speaking and listening could be that leaners must be able to understand a language, before being able to produce it (Ahmadi, 2016; Astorga-Cabezas, 2015). In general, speaking skills are more complex to acquire and demand more involvement of cognitive skills, such as inhibition and cognitive flexibility (Declerck & Philipp, 2017). Because of the difficulty of enhancing speaking skills compared to listening skills, it might therefore be possible that listening skills improved before speaking proficiency showed a change. Furthermore, the fact that passive exposure to English is very common in the Netherlands could elucidate why passive listening skills improved after a four-week English course, whereas active speaking skills did not: English tv series in the Netherlands, for example, are often not dubbed, but subtitled (Edwards, 2014). Therefore, the participants' passive English exposure probably has been greater than their active English use, which in turn might explain the difference in proficiency improvement in listening and speaking skills. This is in line with the literature. Kurkela et al., (2018), for example, found that participants, after having a period of passive exposure to foreign speech sounds, were better able to recognize and discriminate these speech sounds than before. The authors concluded that passive exposure alone can, thus, enhance L2 learning.

With regard to the resting-state EEG data, we found a significant correlation between SLLR of the participants' listening skills and the average alpha power over all electrodes. Alpha is a multifunctional frequency band which has been found to be related to many different skills and characteristics, such as intelligence (Doppelmayr et al., 2002) and attention (Benedek et al., 2014). Alpha activity is known to be involved in resting wakefulness and in difficult tasks requiring internal attention (Benedek et al., 2014; Bice et al., 2020): alpha power increases in periods of rest and decreases when someone performs well on a doable task. When the task becomes more difficult and demands (more) internal attentional focus, alpha power increases (Bice et al., 2020). Alpha power is involved in inhibition. It increases with inhibition of the environment when at rest and with inhibition of irrelevant information in completing difficult tasks in order to provide internal attention (Benedek et al., 2014; Bice et al., 2020). Inhibition and attention are executive functions known to be involved in many different tasks and likely to be important in L2 learning: it is hypothesized that when learning an L2, the learner's L1 has to be constantly inhibited (Kroll & Bialystok, 2013) and that L2 learning creates an environment in which attention to the target language and inhibition of attention to the non-target language is needed (Bialystok, 2015). Since inhibition and attention are considered to be important executive functions in L2 learning, the correlation between alpha power and SLLR could be related to the participants' inhibition and attention skills. Clinical studies underscore this statement by suggesting that alpha frequency is not only related to inhibition and attention, but also to cognitive function in general. Alpha power has been shown to be decreased in patients with cognitive deficits, such as Alzheimer's Disease and Mild Cognitive Impairment (Giattino et al., 2017; Van der Hiele et al., 2007). Since overall cognition and L2 learning are highly interconnected, it may be hypothesized that participants showing a higher alpha frequency, possess better overall cognition, attention or inhibition and therefore show a faster SLLR.

In addition to the correlation found for alpha power over all electrodes, we found several significant correlations between the power of certain frequency bands and SLLR at different electrode sites (Figure 2). Most of the electrode sites showing significant correlations are closely located to Broca's area, which is often located at electrode F5 (Marangolo et al., 2013; Naeser et al., 2005) or FC5 (Suh & Yim, 2018), and to a lesser degree to Wernicke's area, which is often located at electrode CP5 (Fiori et al., 2011; Marangolo et al., 2013) or T7 (Mohamad et al., 2018; Suh & Yim, 2018). It could, therefore, be that power of the frequency bands close to language areas specifically predicts SLLR the best. This observation, however, should be interpreted with caution, because EEG is known for its bad spatial resolution (Liu, Ding & He, 2006). This means that an electrical current measured at a certain electrode site, is not necessarily produced by a neuron located proximate to that electrode. Another observation about the location of the electrodes, is that most of the electrodes showing significant correlations with SLLR were situated in the LH, which is often considered to be the hemisphere most important to language production and comprehension (McAvoy et al., 2016). Language laterality itself is, however, still highly debated, because the RH too has been found to be involved in language use (McAvoy et al., 2016; Prat, Mason & Just, 2011; Price, 2012). The current study seems to underscore the LH dominance in language production and comprehension in seniors. Again, this observation should be interpreted cautiously, because of the poor spatial resolution of EEG (Liu et al., 2006).

The results of our experiment seem to differ substantially from the results of Prat et al. (2016), see Figures 2 and 3, in which the electrodes showing significant correlations found in both studies pertaining to different frequency bands are displayed. Prat and colleagues found more significant correlations, which were primarily situated in the RH and were found for all different brain lobes. Our correlations, by contrast, were primarily located in the LH and were not found in the occipital lobe. Furthermore, the frequency bands attested were found to be different. Seniors and college-aged individuals, thus, showed differences in their correlations with SLLR, suggesting that SLLR should be predicted based on other the power frequency of other electrodes between these age groups. A possible explanation for the differences is the fact that the physical characteristics of brain waves, such as power, are suggested to change over lifespan (Anderson & Perone, 2018). The power of faster frequency ranges, such as alpha, for instance, increases from childhood to adulthood, but decreases again from adulthood to old age (Klimesch, 1999). By contrast, the power of slow frequency ranges, such as delta and theta, has been shown to increase in power while ageing (Babiloni et al., 2006; Vlahou et al., 2014). Brain ageing, thus, may explain the differences in correlations found. The exact effect of ageing on the brain's functional organization in general and frequency power specifically, however, remains poorly understood (Schlee et al., 2012). Furthermore, methodological differences between our study and Prat et al.'s study could explain the differences in results. The studies varied, among others, in English exposure, SLLR assessment and number of participants. The most important difference between the studies is probably the fact that Prat and colleagues used an eyes-closed resting-state EEG, whereas we used an eyes-open paradigm. Eyes-open resting-state is known to reflect a state of higher arousal, which has an effect on topography and power levels of EEG measures (Barry et al., 2007).

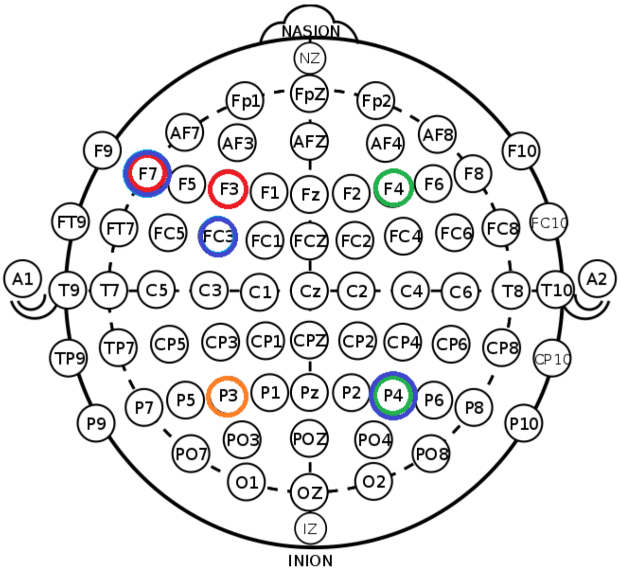

Figure 2. Visualisation of electrodes showing significant correlations.
The different colours represent the different frequency bands involved in the correlation. Blue = theta (4-7.5 Hz), red = low-beta (13.5-14 Hz), grey = upper-beta (15-17.5 Hz), orange = high-beta (18-29.5 Hz) and green = gamma (30-40 Hz).

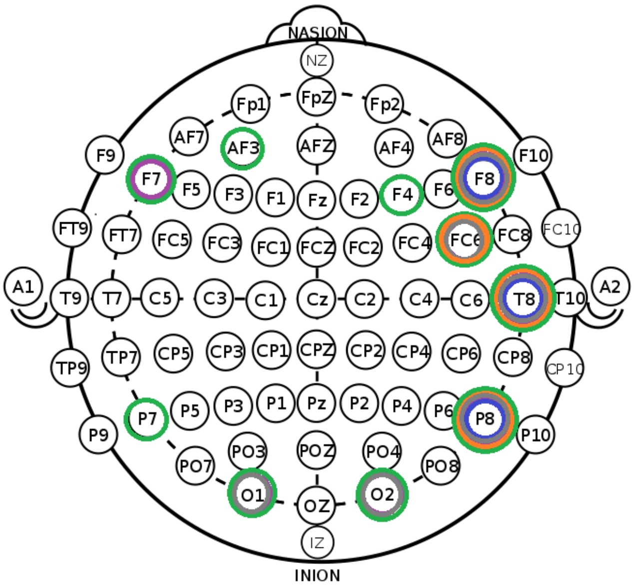

Figure 3. Visualisation of electrodes showing significant correlations in Prat et al. (2016).
The different colours represent the different frequency bands involved in the correlation. Blue = theta (4-7.5 Hz), red = low-beta (13.5-14 Hz), grey = upper-beta (15-17.5 Hz), orange = high-beta (18-29.5 Hz) and green = gamma (30-40 Hz).

Despite all the differences found in significant correlations between college-aged individuals and seniors, the frequency bands being most predictive for SLLR were the same in both age groups. Prat et al. (2016) found that their most predictive frequency bands were the low-beta and gamma frequency bands, explaining up to 60% of the variance in SLLR in college-aged individuals. In the current study, the same frequency bands were the most predictive for SLLR in seniors. In this age group, however, up to 90% of the variance in SLLR could be explained by the low-beta and gamma frequency bands. The percentage of variance explained by the model is extremely high, whereas the number of participants is low. This raises concerns and should therefore be interpreted with caution. Based on this study, we cannot explain what this difference comes from and why the predictive power in our participant group is so high, but it might have something to do with the limited number of participants.

4.2. Limitations

This study had a number of limitations. Firstly, the number of participants in this study was low: seven participants completed the study and data from only six participants were included in the final analysis. A greater number of participants would enhance the generalisability of the results. Secondly, the participants' L2 exposure was very limited. Therefore, our results may differ from longitudinal studies in which the participants learn an L2 for a longer period of time, which better resembles natural L2 learning A greater amount of L2 exposure would improve the generalisability of the results to natural L2 learning.

Secondly, the SLLR assessment in this research could be attested more precisely. The versions of the IELTS-inspired speaking task, for instance, were not fully comparable. Furthermore, the CAF-measures used were probably too restricted to find minor proficiency improvements in beginner's speech. The use of more comparable and compatible versions of the speaking task and the addition of holistic measures may improve the proficiency analysis.

Moreover, the resting-state EEG had a number of limitations. Firstly, the raw resting-state EEG data was pre-processed on the basis of visual inspection. It was, however, difficult to detect bad trials and channels, since deviations were minor and difficult to observe with a naked eye. This could be overcome by using an independent component analysis (ICA) or by letting more researchers pre-process the data. Another limitation was the order of the tasks. The resting-state default brain network is highly plastic and therefore very sensible for influences of cognitively loaded tasks completed beforehand (López-Zunini et al., 2013). Therefore, our resting-state EEG indices may be influenced by former tasks. It would have been better to first do a resting-state EEG, before fulfilling other cognitive tasks.

It is important to state that this study was an explorative study. Therefore, improvements to the study's methods need to be made to generalise the outcomes.

4.3. Resting-state EEG in future research

Resting-state EEG is a promising technique, which offers a new perspective on neurolinguistic research and should therefore undoubtedly be used in future research, which should also include seniors: the senior population in our world is growing (He et al., 2016). Additionally, as stated in the introduction, L2 learning may improve healthy ageing (e.g. Alladi et al., 2013; Perani et al., 2017). Therefore, it is important to include this age group in neurolinguistic, resting-state EEG research.

Currently, many neurolinguistic studies report the behavioural consequences, such as reaction times, of L2 learning on cognition and have linked these consequences to L2 learning progress and vice versa. Despite the academic debate, we are, therefore, rather well informed about the effects L2 learning could have on cognition and the effects cognitive skills have on L2 learning behaviourally. We do not, however, know what exactly happens at a functional brain level forming the link between the behavioural outcomes and L2 learning. Resting-state EEG could clarify this link by defining the functional brain properties which underly cognition and L2 learning. Furthermore, jargon on cognitive skills, such as inhibition, is often not well defined (Hartsuiker, 2015). Resting-state research might be able to explore the exact underlying mechanisms of these cognitive skills, thereby giving the opportunity to better define unclear jargon. Therefore, resting-state techniques are highly useful and should definitely be used in future research.

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Appendix A. IELTS listening and speaking tasks

This appendix is not included in the public version of this thesis.

Appendix B: Correlations between the average power of frequency bands at a brain level and SLLR

Table 3. *Correlations between the average power of frequency bands at a brain level and SLLR*
In the table, the correlations between the average power of the different frequency bands at a brain level and SLLR are displayed.

Correlation	r	p
Gamma ~ SLLR	0.396	.437
Alpha ~ SLLR	0.845	<.05*
Low Beta ~ SLLR	0.438	.385
Upper Beta ~ SLLR	-0.594	.214
High Beta ~ SLLR	0.477	.339

*indicates a significant finding