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# The impact of second- and third-language learning on language aptitude and working memory

Ting Huang, Hanneke Loerts and Rasmus Steinkrauss

Center for Language and Cognition (CLCG), University of Groningen, the Netherlands

**ABSTRACT**

An increasing number of adults learn more than one foreign language simultaneously. While the cognitive benefits of using multiple languages from birth have been studied extensively, little is known about possible cognitive benefits of learning multiple languages simultaneously in adulthood. Among the cognitive abilities which play a role in language learning, language aptitude (LA) and working memory (WM) are argued to be crucial. Traditionally considered relatively stable, recently they are advocated to be changeable. For example, one could imagine that learning new sounds, words, and structures in a language might both enhance the ability to temporarily hold and manage information (WM) and improve the ease with which subsequent languages are learnt (LA). Therefore, this study investigates whether LA and WM change while learning languages, and whether language learning intensity, i.e. learning one versus two foreign languages simultaneously, modulates this effect. Participants consisted of first-year and second-year Chinese university students majoring in English or English & Japanese/Russian. Data were collected twice with an interval of one academic year. The results show that all learners improved in certain aspects of LA and WM, and that among the first-year students, the two-foreign-languages learners outperformed their counterparts in WM improvement. The implications are discussed.

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L2 and L3 learning; language aptitude; working memory

## Introduction

The process of second language (L2) learning is determined by complex and multifaceted factors (Dörnyei and Skehan 2003). Of these factors, language aptitude (LA) has often been considered as a set of abilities crucial for L2 learning (Skehan 2015). Traditionally, it has been argued that there are four components of LA, namely phonemic coding ability, associative memory, grammatical sensitivity, and inductive language learning ability (Carroll 1965). However, recently a new understanding of working memory (WM) triggered a discussion on the conceptualization of LA (Granena 2013; Wen 2016), and WM has been argued to be a part of LA (e.g. Miyake and Friedman 1998; Li 2013; Wen and Skehan 2011; Wen 2015, 2016, 2019). Originally proposed by Baddeley and Hitch (1974), WM refers to a memory system that both provides temporary storage and enables the manipulation of the information necessary for complex cognitive tasks such as language comprehension, learning, and reasoning (Baddeley 1992, 2003).

**CONTACT** Ting Huang t.huang@rug.nl; halliehuangting@hotmail.com
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Been considered as a relatively stable trait of language learners (Carroll 1981) for decades, LA has been viewed from a dynamic perspective by a growing number of researchers lately (e.g. Eisenstein 1980; Grigorenko, Sternberg, and Ehrman 2000; Sáfár and Kormos 2008; Singleton 2014; Singleton 2017; Thompson 2013). They argue that LA is not necessarily an unchangeable trait, instead, it is probably malleable according to the language learning experience and the language instruction a learner receives. Similar to LA, WM has been viewed as a constant trait (Klingberg 2010), but recent studies (e.g. Jaušovec and Jaušovec 2012; Klingberg 2010; Kogetsidis 2012; von Bastian and Oberauer 2013) have shown that it may be improved through training. While most of the studies investigating the changeability of LA focus on language learning effects, only few of the studies exploring the changeability of WM have examined the impact of language learning. Even fewer studies have examined the impact of language learning intensity, i.e. the number of languages being learnt or have been learnt, on the development of LA and WM jointly.

The current study tries to fill this gap and sets out to investigate, first, whether LA and WM are changeable and, second, to what extent the number of languages being learnt have an effect on LA and WM development. We assume that LA and WM are not stable as traditionally considered, but that they can develop during intensive foreign language learning. Moreover, we assume that learning one vs. two foreign language(s) simultaneously may lead to differences in LA and WM development.

## Background

### *The definition and components of LA and WM*

The recognition of an individual's LA as a factor for L2 learning may be traced back to Carroll, who defined foreign LA as an 'individual's initial state of readiness and capacity for learning a foreign language, and probable degree of facility in doing so' (Carroll 1981, 86). LA consists four components, namely phonemic coding ability, associative memory, grammatical sensitivity, and inductive language learning ability (Carroll 1965). Phonemic coding ability is the capacity to discriminate sounds and analyze foreign sounds; associative memory is the ability to make connections between stimuli and target responses in memory; grammatical sensitivity refers to the ability to identify the functions of words in sentences, and inductive language learning ability is the skill to recognize linguistic regularities in the input. This proposition that LA is not a monolithic construct has had a profound influence on subsequent LA research (Skehan 2002). While Carroll's four-factor model of LA still seems valid today, as Skehan (1991) pointed out, each of the factors might still benefit from a revision by taking into account recent developments in related disciplines. For example, when the classic LA test MLAT (Modern Language Aptitude Test) was developed by Carroll and Sapon (1959), associative memory was regarded as the dominant form of memory. However, the perspectives on memory have changed radically since, characterized by the importance now attached to WM (Skehan 2012). Following this trend, Skehan (2012) included WM into the LA repertoire. This is very much in line with Robinson's suggestion to integrate WM measures into aptitude subtests (Robinson, 2001, 2002, 2005), and with Wen's Phonological WM/Executive WM model (Wen 2015, 2016, 2019).

WM is a memory system involved in many complex cognitive tasks, such as language comprehension, learning, and reasoning, during which the system temporarily stores and manipulates the information needed (Baddeley 1992; 2003). According to Baddeley and Hitch (1974) and Baddeley (2000), WM comprises an attentional control system, the central executive, and three subsidiary slave systems: the phonological loop, the visuospatial sketchpad, and the episodic buffer. While the phonological loop stores verbal and verbal-acoustic information, the visuospatial sketchpad holds visual and visuospatial information. The episodic buffer, a limited-capacity temporary storage system, integrates this auditory and visuospatial information and is linked to long-term memory. The central executive, which controls the three subsystems, retrieves, manipulates, and modifies information

(Baddeley 2000). Each component of WM capacity is related to language learning in its own way. The phonological loop has been argued to play an important role in vocabulary learning in both the L1 (Baddeley, Gathercole, and Papagno 1998) and L2 (e.g. Service 1992; Atkins and Baddeley 1998) as the phonological loop is closely linked to verbal long-term memory (Baddeley 2015). The role of the visuospatial sketchpad and the episodic buffer in language learning is yet uncertain (Baddeley 2015), but it could be argued that they play a role in L2 reading and in the integration of auditory and visual information, respectively. The central executive is relevant to general learning mechanisms, and has been argued to be involved in shifting between and inhibiting languages (Green and Abutalebi 2013) – arguably, the more so the more languages need to be managed.

### *The effect of LA and WM on language learning*

The study of LA in SLA research can provide important insights because LA partly predicts language learning success (Skehan 1991). Therefore, recent years have witnessed a substantial amount of studies investigating how and to what extent LA can predict L2 development. LA has repeatedly been found to have a specifically powerful impact on L2 learning outcomes when compared to other factors. Those factors include age of onset, length of residence (Granena and Long 2012), first language skills, and L2 affect, such as motivation and anxiety (Sparks et al. 2009). The impact of LA on L2 learning becomes more prominent when it comes to adult L2 learning, especially in language analysis ability (e.g. Harley and Hart 1997), and for those individuals who attain native-like proficiency (e.g. Abrahamsson and Hyltenstam 2008). Similarly, LA, as measured by the High Level Language Aptitude test (Hi-LAB), has been argued to be the strongest predictor for high levels of achievement in language learning after puberty (Doughty et al. 2010; Linck et al. 2013).

Still other studies demonstrated that the power of LA to predict L2 learning depends on L2 learning stages and language instruction methods (Li 2015), and that different LA components showed different predictive powers for different aspects of L2 learning (Li 2016). For example, phonemic coding ability, as measured by the LLAMA-D test, especially impacted learners at the early stages of L2 learning (Artieda and Muñoz 2016). In the same vein, Li's (2015) meta-analysis showed that LA, as measured by traditional aptitude tests such as MLAT, was more relevant to initial stages of explicit L2 learning. In sum, these studies thus show a positive effect of (components of) LA for different L2 learning methods at different stages.

Also, WM argued to be an important aspect of LA by some scholars (e.g. Miyake and Friedman 1998; Wen and Skehan 2011; Wen 2015, 2016), has increasingly drawn the attention of L2 researchers. Studies have examined which subsystem of WM is a predictor of L2 proficiency, or how the WM subsystems affect learner groups with different levels of L2 proficiency. For example, executive WM as measured by complex span tasks has been found to be a stronger predictor for L2 proficiency than WM as measured by simple span tasks (Linck et al. 2014). And executive WM and phonological WM, as assessed by an operation span task and a digit span task respectively, both tend to benefit learners with lower L2 proficiency (Serafini and Sanz 2016).

Another set of studies explores the relationship between WM and different L2 skills, such as speaking and writing. Bergsleithner (2010), for example, found that WM, as measured by means of an L1 operation-word span test, showed a significant positive correlation with L2 writing performance in terms of accuracy and complexity. L2 learners with higher WM also have a higher tendency to modify their oral production (Mackey, Adams, and Stafford 2010). Similar results were found by Payne and Ross (2005), in which the WM capacity was measured by a reading span and a non-word repetition task.

The above studies have found sufficient evidence that LA and WM play important roles in L2 learning. However, most of these studies (apart from Serafini and Sanz 2016) measured LA and WM only once, usually in the beginning of the period under investigation. As the stability of both constructs is increasingly being questioned, the question is whether LA and WM may be trained and changed in the process of L2 learning, given the critical roles that these abilities play in L2 learning. As laid out in

the following section, various studies have demonstrated that the number of languages spoken by a person is related to their scores in abilities related to WM and LA, suggesting that there might be a training effect of learning and speaking several languages.

### *Effects of multiple languages learning on LA and WM*

As argued by de Bot (2012), it may be possible that multilingual learners suffer from disadvantages in certain language learning situations, because they have the same resources, such as memory capacity and attention, but more languages to cope with. However, it is also plausible that multilingual learners are equipped with more and/or better resources, because they have learnt to cater to more linguistic systems, and are richer in language learning experience. Given the general view that LA and WM are important resources affecting language learning, it might be asked whether there is a bi-directional relationship between language learning on the one hand, and LA and/or WM on the other (Linck et al. 2014). This possible bi-directional relationship between L2 proficiency and LA and/or WM could be compared with the bi-directional relationship between muscle strength and running speed in sprinters: while gaining muscle strength will lead to faster running, running faster at the same time trains the muscles and leads to greater strength. Similarly, it might be imagined that intensive language learning will not only improve a learner's language proficiency, but also their LA and/or WM capacity simply by actively using and hence potentially training these cognitive resources. And this potential effect might increase with the number of languages as WM and LA are both more challenged by and trained by using several languages.

Research into this question is scarce, but positive correlations between the number of languages a participant had learnt and their LA and WM were discovered in previous studies. For example, Ma, Yao, and Zhang (2018) found that bi-foreign-language learners scored higher than one-foreign-language learners in the LLAMA test (Meara 2005). Similarly, Grigorenko, Sternberg, and Ehrman (2000) found a positive correlation between the number of languages that the participants used and LA scores as measured by the CANAL-F test (Grigorenko, Sternberg, and Ehrman 2000). Regarding WM, Morales, Calvo, and Bialystok (2013), for example, found that bilingual children performed significantly better than monolingual children in WM tasks, especially in those tasks demanding executive functioning. The results of this study were corroborated by a comprehensive meta-analysis conducted by Grundy and Timmer (2017), which revealed that bilinguals enjoy a greater WM capacity than otherwise comparable monolinguals.

There are thus some indications that the number of languages learnt or spoken impacts WM and LA in a positive way. However, of course, all of the findings cited are correlational in nature, and should, therefore, be interpreted with caution, because they do not necessarily reveal underlying causal relations (Grigorenko, Sternberg, and Ehrman 2000). Sound evidence from empirical studies supporting a positive effect of the intensity of language learning on LA, and more so on WM, is still lacking. At the same time, to assume that LA and WM can be affected by language learning also means that one assumes these two abilities to be changeable. As discussed in the following section, recent research indeed suggests this to be the case.

### *LA and WM as changeable cognitive abilities*

Both LA and WM have increasingly come to be considered changeable traits in recent years. While LA is traditionally thought of as a relatively stable language learner trait that is immune to training (Carroll 1965, 1981), a growing number of researchers such as Singleton (2017), who agrees with Wen's (2016) proposal of viewing WM as an important part of LA, have started to question the stability of LA. Following this line of thought, recent empirical studies involving a pre-test/post-test design have provided some evidence for the changeability of LA. For instance, in Sáfár and Kormos (2008) study, students in an intensive language instruction program gained significantly more in LA scores than their peers in a regular language instruction program. Likewise, foreign LA as measured by the

MLAT (Carroll and Sapon 1959) could be significantly improved through a language training program, even among students with an identified learning disability (Sparks et al. 1996).

Similar to LA, the flexibility of WM has long been discussed. Furthermore, Serafini (2017) proposed to investigate the dynamic nature of WM under the Dynamic System Theory framework (DST; Cameron and Larsen-Freeman 2007; de Bot, Lowie, and Verspoor 2007; de Bot and Larsen-Freeman 2011), to 'broaden and deepen our understanding' (384) of the cognitive aspects of L2 learning and their possible interactions.

Several meta-analyses on the trainability of WM have emphasized the inconsistent results concerning the presence of a training effect, the potential size of the effect, the effect of different training tasks, and the transfer effects to broader cognitive systems (e.g. Karbach and Verhaeghen 2014; Melby-Lervåg and Hulme 2013; Sala and Gobet 2017; Soveri et al. 2017). Despite these inconsistencies, some studies have demonstrated that WM is not immune to training, but rather changeable under certain interventions or treatments (Jaušovec and Jaušovec 2012; Klingberg 2010; Kogetsidis 2012; von Bastian and Oberauer 2013).

Klingberg (2010) investigated the neuroscientific reasons for the trainability of general WM capacity, and pointed out its remediating intervention function for individuals who suffer from poor academic performance resulting from lower WM capacity. Holmes, Gathercole, and Dunning (2009) trained the WM of 22 children with learning difficulties for a period of five to seven weeks. Results showed that the children improved their WM scores substantially, with regard to verbal short-term memory, visuospatial short-term memory, verbal WM, and visuospatial WM. These improvements in WM in return ameliorated those children's deficits and associated learning difficulties. Hayashi, Kobayashi, and Toyoshige (2016) argued for an insight into the dynamic nature of WM. Their study showed that the combination of language training and WM training resulted in a significant improvement in WM scores and these gains were maintained three months later. WM training was found to be effective among elderlies as well (Carretti et al. 2013), and this WM training effect transferred to language ability and was likewise maintained at the 6-month follow-up test.

To look into the changeability of LA and WM under the circumstance of language learning, a setting where a comparison between different language learning intensity groups can be made and where a pre-test-and-post-test design can be applied is needed. Bi-foreign-language programs in China offer a quasi-experimental condition suited for such an investigation. They are a new type of program for teaching foreign languages at the university level where the bi-foreign-language majors learn English and an additional foreign language (AFL) simultaneously, while their peers in the English major learn English only. In spite of this, both groups have exactly the same curriculum for English instruction. In the first two years of university, for learners from both groups, the courses are focused on training listening, reading, writing and speaking. The English majors are trained in English language skills, while the bi-foreign-language majors are trained in English and in the other foreign language.

The current study aims at exploiting this unique context to investigate the following issues: the potential changeability of LA and/or WM, and the possible language learning intensity effect on LA and/or WM. The research questions are:

First, do foreign language learners improve in LA and WM after one academic year?

Second, do bi-foreign-language learners outperform one-foreign-language learners in LA and WM development?

According to previous findings suggesting that LA and WM are changeable abilities (Sáfár and Kormos 2008; Klingberg 2010; Holmes, Gathercole, and Dunning 2009), and that LA and WM can be influenced by language experiences (Ma, Yao, and Zhang 2018; Morales, Calvo, and Bialystok 2013), we hypothesize that:

First, our participants' LA and WM scores will improve after one academic year of foreign language learning.

Second, different language learning groups will differ from each other in LA and WM improvement, with the bi-foreign-language learners outperforming one–foreign-language learners.

## Methodology

To investigate the potential effects of the number of languages being learnt on the development of LA and/or WM, the present study compared subjects from three different language learning conditions (English, English/Japanese, and English/Russian majors) from two different cohorts of subjects (first- and second-year students). Using a pre/post-test design, each subject was tested twice on both LA and WM with an interval of 9 months (one academic year).

### *Participants*

The study was carried out in a Chinese university belonging to an elite group of 'National Key Universities'. To be admitted to the foreign language programs in this university, the applicants need to gain a certain total score in the China National Higher Education Entrance Examination (Gaokao), and also score above the cutoff score for the English test. Even though socio-economic status was not examined in the present study, these entry requirements warrant a comparable level of general intelligence and academic aptitude among all participants. None of the students suffered from a learning disability.

The participants consisted of English majors (henceforth L2 learners), who study English only, and bi-foreign-language majors (henceforth L2 + 3 learners),[1] who study English and another foreign language simultaneously. Of the 79 participants, 71 were female and the average age was 18.63 ($SD = 0.89$). All had started to learn English at around the age of 9 years and all the L2 + 3 majors started to learn the additional foreign language upon entering the university (around the age of 18). Although all participants had been learning English for 9 years before enrolled in university, their English proficiency was not yet developed up to an advanced level. English proficiency was therefore assessed and also compared between groups to ensure that all participants started with a comparable level, and actually still continued learning English while at university.

The participants were recruited from the first-year and second-year cohorts. Each cohort consisted of L2 learners and L2 + 3 learners. Within the L2 + 3 learners' group were two sub-groups: one English/Japanese learner group and one English/Russian learner group. In the second-year, the students who had been English majors (L2 learners) in the first year also started to learn an additional foreign language for four hours per week (see Table 1), Since these learners were still mainly learning English and received comparatively little instruction in their additional language, they are labeled L2+ learners to distinguish them clearly from the L2 + 3 learners who, as bi-foreign language majors, received about equally much English and additional language instruction. See the details in Table 1.

As shown in Table 1, first-year L2 learners and L2 + 3 learners had the same amount of English instruction, but L2 + 3 learners had 8 hours of instruction for the second foreign language. Second-year L2+ and L2 + 3 learners had the same amount of English instruction, but while the L2 + 3 learners received 10 hours of AFL instruction per week, the L2+ learners only received 4 hours of that in their AFL.

**Table 1.** Participant groups and the type and amount of instruction.

| Participants | First year | | | Second year | | |
|---|---|---|---|---|---|---|
| Groups | L2 learner | L2 + 3 learner | | L2+ learner | L2 + 3 learner | |
| | | E/J | E/R | | E/J | E/R |
| Sample Population | 12 | 21 | 16 | 9 | 12 | 9 |
| Instruction | E: 16 | E:16 | E:16 | E:12 | E:12 | E:12 |
| (h/week) | | J:8 | R:8 | FL:4 | J:10 | R:10 |

Note: *E/J: English/Japanese learners; E/R: English/Russian learners; E: English; J: Japanese; R: Russian; FL: foreign languages, including Japanese, Russian, German and French.

## Instruments

### LA test

The LLAMA test (Meara 2005) was chosen to assess LA for its attested validity and reliability (e.g. Granena 2013; Rogers et al. 2017), and its free accessibility and convenience of administration (Rogers et al. 2017). The test was administered on computers using the LLAMA software, which is free to download (http://www.lognostics.co.uk/tools/llama/). Loosely based on the MLAT (Carroll and Sapon 1959), the LLAMA test consists of four subtests, namely LLAMA-B, LLAMA-D, LLAMA-E and LLAMA-F (Meara 2005). All tests include a learning phase and a testing phase, and use stimuli based on an artificial language. LLAMA-B is a vocabulary learning task, which measures the ability to learn vocabulary in a relatively short time. LLAMA-D is a sound recognizing task, which measures the ability to recognize short sound patterns in spoken language. LLAMA-E is a sound-symbol correspondence task, testing the subjects' ability to work out the relationship between recorded syllables and their corresponding transliteration. Finally, LLAMA-F is a grammatical inferencing task. It requires the subjects to match pictures with corresponding descriptions in the artificial language.

### WM span task

The Operation Span task (OSP) was used to measure WM capacity. Although WM is recognized as a system comprising both domain-general executive functions such as information updating, switching and inhibition, and domain-specific storage mechanisms for verbal and visuospatial information (Wen 2016; Williams 2012), domain-general WM tasks enjoy higher validity and reliability than domain-specific WM tasks (Sanchez et al. 2010). The OSP is a complex domain-general WM span task which measures both the ability to maintain information and the ability to manage and manipulate the information. It differs from other complex domain-specific span tasks, such as the reading span task and the speaking span task, in that it is language independent (Wen 2016), which makes the OSP task particularly suitable for L2 learning research (Williams 2012).

An automatic version of the OSP task published by Unsworth et al. (2005) (see Figure 1) created in E-Prime 2.0 (Schneider, Eschman, and Zuccolotto 2002) was used in the present study. The participants need to remember letters they have been shown after judging whether a math equation is correct or not. After three to seven math problems and letters shown, the subjects are asked to recall the letters in the order they were shown. In this way, both the memory span (how many letters were remembered correctly) and the ability to maintain information while focusing on a different task, i.e. solving a math problem, are assessed.

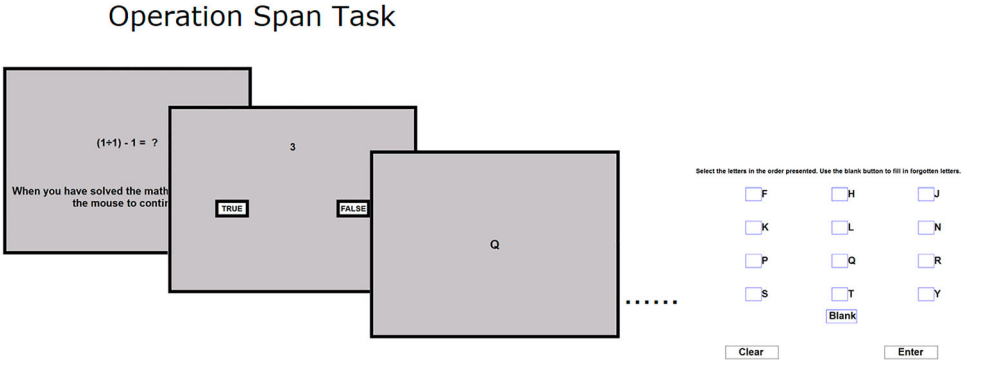


**Figure 1.** The automatic version of operation span task.

### English language proficiency assessment

The English proficiency was represented by the participants' writing and speaking proficiency. Writing proficiency was assessed by writing tasks from the comprehensive English course. All of the writing texts were rated holistically following Hou, Verspoor, and Loerts's (2016) CAFIC model, covering complexity, accuracy, fluency, idiomaticity and coherence. The mean scores of the first two and the last two writing samples served as pre-test and post-test writing proficiency scores respectively. Speaking proficiency was assessed by adjusted Student Oral Proficiency Assessment (SOPA) interviews (Thompson, Kenyon, and Rhodes 2002) developed by the Center for Applied Linguistics. The participants' interviews were rated using the SOPA Rating Scale which evaluates oral proficiency in four dimensions: oral fluency, vocabulary, grammar, and listening comprehension. Each dimension has nine sublevels, ranging from junior novice low to junior advanced high. The proficiency score used for analysis was the total score of the four sub-measures.

### Procedures

The LLAMA test and OSP task were administered at the beginning (September 2017) and at the end of the academic year (June 2018). The LLAMA test was carried out in a multimedia room, in which 20 participants took the test simultaneously. Before the test, written instructions in the participants' L1 were provided. During the test, a technician and the first author of the present study were present, ready to help. The test took half an hour on average. The OSP task was administered in a well-prepared quiet room with two computers, where two participants did the test simultaneously. The task *per se* is language-neutral, but a written instruction was provided in the participants' L1. A technician always introduced the task to the participants before the test began.

The writing texts used for the analysis of English writing proficiency were collected for one academic year, but in the current study, only the first and last two texts were analyzed to assess the proficiency at the beginning and the end of the academic year. These texts were collected in the same period when the LA and WM tests were administered. The adjusted SOPA interviews were taken at the same day as the WM test, in a separate room where the participants took the interview in pairs.

### Analyses

The aims of the current study were to examine (1) whether LA and WM are changeable, and (2) if so, whether there is a language learning intensity effect.

Before answering these two research questions, a preliminary analysis on the participants' L2 English proficiency was carried out to ensure that the L2 learners and L2 + 3 learners started with comparable levels of proficiency continued learning the L2. This analysis was conducted in order to avoid a possible interference of English proficiency with the findings on LA and WM, and to confirm that the participants' L2 English was still under development at the time of observation. Independent-samples t-tests were used to compare the L2 and L2 + 3 initial English scores, and paired-samples t-tests were run to compare each learner group's pre- and post-scores for English, both written and oral.

To answer the main research questions, the two cohorts were analyzed separately. The first research question was investigated by a repeated-measures ANOVA analysis on the scores of all the different tests, with one within-subject factor with two levels, pre-test score vs. post-test score. The second question was investigated by an ANCOVA analysis on each test. In this analysis, the post-test scores of each test were taken as the dependent variable. Language group was taken as a fixed factor and pre-test scores were taken as a covariate factor.

The dependent variable used in all analyses was the score of the respective test. For LA, this was LLAMA subtests scores (LLAMA-B/D/E/F), each ranging from 0 to 100 (Meara 2005). For WM capacity, this was the absolute score for the OSP task, which is the sum of all perfectly recalled sets (Unsworth et al. 2005). This score ranged from 0 to 75. Regarding the first research question, a significant main

effect of testing time on test scores would indicate that LA and WM are changeable. Regarding the second question, a significant effect of learning one vs. two languages on post-test scores while controlling for the pre-test scores would point to a language learning intensity effect on the change in LA and WM.

## Results

### *The preliminary analysis of English proficiency*

No significant differences were found between L2 learners and L2 + 3 learners in their initial English proficiency level. The results also demonstrate that both groups were still in the process of learning English as an L2, as they increased significantly from pre- to post-test in both writing and speaking proficiency. An exception was the second-year L2 learners which however showed a strong trend towards significance ($p = 0.065$) regarding their gains in writing proficiency. Table 2 shows the details of the groups' English writing proficiency and Table 3 provides an overview of their English speaking proficiency.

### *Changeability of LA and WM*

The main effect of testing time, indicating the changeability of LA and WM, was found for the OSP task scores and the LLAMA subtest scores, but the effect varied for different cohorts (see Table 4 for details). While descriptive statistics show an improvement of all participants on all tests, not every difference was significant. Table 4 shows the details for the first-year students and Table 5 summarizes the results for the second-year students.

Unlike the first-year students, whose improvement only reached significance in the LLAMA-D and LLAMA-E scores, the second-year students significantly improved in LLAMA-B and LLAMA-F. Both cohorts significantly improved on the OSP task, however, with the effect size being large in the first-year students and medium in the second-year students.

**Table 2.** Initial status and development of writing proficiency.

| Writing proficiency | Independent Sample *T*-Test for pre-scores | | Paired Sample *T*-Test for pre-scores and post scores | |
|---|---|---|---|---|
| | *t* | $r^2$ | *t* | $r^2$ |
| First year | *t* (47) | | | |
| L2 | 0.61 | / | **6.52***** | 0.79 |
| L2 + 3 | | | **9.79***** | 0.72 |
| Second year | *t* (28) | | | |
| L2+ | 0.39 | / | 2.13 | / |
| L2 + 3 | | | **2.78*** | 0.28 |

Note:*The difference is significant at the 0.05 level; ***the difference is significant at the 0.001 level.

**Table 3.** Initial status and development of speaking proficiency.

| Speaking proficiency | Independent Sample *T*-Test for pre-scores | | Paired Sample *T*-Test for pre-scores and post scores | |
|---|---|---|---|---|
| | *t* | $r^2$ | *t* | $r^2$ |
| First year | *t* (47) | | | |
| L2 | 0.37 | / | **3.43**** | 0.52 |
| L2 + 3 | | | **12.65***** | 0.82 |
| Second year | *t* (28) | | | |
| L2+ | 0.36 | / | 1.64 | / |
| L2 + 3 | | | **4.78***** | 0.53 |

Note: **The difference is significant at the 0.01 level; ***the difference is significant at the 0.001 level.

**Table 4.** Results for main effect of testing time for the first-year students.

| | Descriptive statistics | | Repeated measures ANOVA | |
|---|---|---|---|---|
| | *M*(*SE*) | | *F*(1,48) | $\eta^2$ |
| | Pre | Post | | |
| LLAMA-B | 49.08(2.56) | 53.47(2.98) | 2.26 | / |
| LLAMA-D | 29.29(2.14) | 37.55(2.26) | **12.01**** | **0.20** |
| LLAMA-E | 62.45(3.72) | 72.04(3.67) | **5.90*** | **0.12** |
| LLAMA-F | 50.10(2.72) | 54.69(3.06) | 1.20 | / |
| OSP | 45.88(1.90) | 57.65(1.63) | **35.27**** | **0.42** |

Note:*The effect is significant at the 0.05 level; **the effect is significant at the 0.01 level.

**Table 5.** Results for main effect of testing time for the second-year students.

| | Descriptive statistics | | Repeated measures ANOVA | |
|---|---|---|---|---|
| | *M*(*SE*) | | *F*(1,29) | $\eta^2$ |
| | Pre | Post | | |
| LLAMA-B | 49.33(4.19) | 59.50(4.26) | **7.27*** | **0.20** |
| LLAMA-D | 39.50(2.09) | 41.83(3.58) | 0.59 | / |
| LLAMA-E | 76.50(3.27) | 79.83(3.26) | 0.71 | / |
| LLAMA-F | 49.33(4.29) | 63.83(4.58) | **8.35**** | **0.22** |
| OSP | 50.40(2.02) | 54.97(2.43) | **6.39*** | **0.18** |

Note: *The effect is significant at the 0.05 level; **the effect is significant at the 0.01 level.

### *Language learning intensity effects on LA and WM*

As can be seen in Table 6, a main effect of language learning intensity (one- vs. two foreign languages) was only found for the OSP task scores among the first-year students. Descriptive statistics show that the L2 + 3 learners scored higher than the L2 learners in the OSP task.[2] This effect was not found for other tasks or cohorts. The details are shown in Table 6.

## Discussion

This study sought to investigate the changeability of LA and WM in the context of foreign language learning by testing different foreign language learning groups twice, with an interval of 9 months. The results revealed an improvement in LA and WM for all groups as well as a difference between different learning groups in WM capacity improvement.

The preliminary analysis on English proficiency confirmed that the L2 and L2 + 3 learners started from a similar proficiency level, which implies that any difference in gains in LA and WM found cannot be influenced by a difference in their initial English proficiency level. Similarly, our analysis showed that the L2 + 3 learners (and first-year L2 leaners) were not merely consolidating their English but improving significantly, ensuring that any difference between L2 and L2 + 3 learners may be related to actively learning 1 vs. 2 foreign languages, i.e. to language learning intensity.

### *The improvement in LA and WM*

The first research question investigated the changeability of LA and WM. The results showed, as was hypothesized, a significant increase between pre- and post-test scores. This indicates that LA and WM

**Table 6.** ANCOVA results and descriptive statistics for language learning intensity effect on WM among the first-year students.

| | ANCOVA | | | Descriptive statistics | | |
|---|---|---|---|---|---|---|
| | *F*(2,45) | $\eta^2$ | Group | *n* | Observed Mean (SD) | Adjusted Mean(SE) |
| OSP task | **7.39*** | **0.14** | L2 | 12 | 49.42(12.35) | 50.65(2.98) |
| | | | L2 + 3 | 37 | 60.32(9.85) | 59.92(1.66) |

Note: *The effect is significant at the 0.05 level.

are changeable, and is line with the previous studies reporting a changeability of LA (Sáfár and Kormos 2008; Sparks et al. 1996; Ma, Yao, and Zhang 2018) and WM (Klingberg 2010; Holmes, Gathercole, and Dunning 2009).

Regarding the LLAMA scores, students of both cohorts improved on all subtests, but the increase became significant for different subtests in the different cohorts. This finding disproves the concern that the improvement in LLAMA scores could be a testing effect. If the improvements would constitute a testing effect, i.e. if the participants had developed strategies in taking the LLAMA test and improve because of those, then the first- and second-year students should have improved in the same LLAMA subtests. This is, however, not the case and the improvement thus more likely results from a development in language aptitude.

While the first-year students significantly improved in the sound recognition and sound-symbol correspondence abilities (LLAMA-D and -E), the second-year students significantly improved in vocabulary learning and grammar inference abilities (LLAMA-B and -F). This result resonates with Artieda and Muñoz's (2016) study, which demonstrated that the impact of each LA component on L2 proficiency differs per proficiency level. In their study, the ability to recognize new short sound patterns in a new language, as measured by LLAMA-D, had a larger impact on beginning L2 learners, while the grammatical inferencing ability, as measured by LLAMA-F, had a greater effect on intermediate L2 learners. We see the same pattern as a training effect in our participants.

While LLAMA-D measures rather implicit cognitive processes, LLAMA-B, E, and F tap into more explicit processes (Granena 2013). Cross-cutting this division, the LLAMA-D and LLAMA-E subtests which the first-year students significantly improved on share the similarity of involving sounds. That the first-year students improved in LLAMA-D and LLAMA-E while the second-year students did not may suggest that intensive language learning initially trains learners' ability to deal with unfamiliar sounds, both in terms of recognizing them and associating them with symbols. This seems plausible given that learners of a new language first have to deal with the new sounds, and learn how to read and write them – specifically in an instructional setting as in the current study where the students were exposed to not only spoken but also written language from the beginning, and where the L3 learnt (Russian/Japanese) involves learning a new writing system. In that sense, sound recognition and sound-symbol corresponding abilities are heavily involved and trained from the start. This demand may also lie at the base of Serafini and Sanz (2016) finding that it is especially in lower L2 levels that phonological WM shows a relationship with L2 proficiency.

The second-year students improved in the other two abilities, i.e. vocabulary learning and grammar inferencing (LLAMA-B and -F), while the first-year students did not. This may indicate that rote memory and grammar analytical abilities, which require more explicit cognitive processes, are relatively more stable, but still changeable, although this change plays out only later.

The improvement in those aspects of LA measured by LLAMA-B, E, and F could also be related to an enhancement in meta-linguistic awareness. According to Jessner (2014), meta-linguistic awareness is the ability to focus on linguistic form as well as switch the focus between form, function and meaning. Consequently, the development of meta-linguistic awareness is linked to explicit and implicit learning. As Hofer and Jessner (2019) found, bilingual learners benefit from higher meta-linguistic awareness in additional language learning, compared to monolingual learners. This may suggest that learning a second/foreign language trains learners' meta-linguistic awareness because of the constant exposure to new linguistic forms and the need to associate new forms with meanings, which might be a reason for the participants' better performance in rote learning, explicit associative learning, and analytic ability found in our first- (LLAMA-E) and second-year (LLAMA-B and -F) students.

Regarding the WM scores, both cohorts significantly improved, but the two cohorts improved to different degrees. The improvement was more pronounced among first-year students, as revealed both by the mean scores and the effect sizes. The finding that participants in different cohorts and language learning groups improved in OSP scores to different degrees dispels the doubt whether the improvement in WM scores is merely a test-retest effect.

Previous research had already shown that the relationship between L2 proficiency level and WM capacity, as measured by the OSP task, is stronger in lower level L2 learners (Serafini and Sanz 2016). This suggests that WM is more actively engaged in the beginning stages of learning a new language. The result in the current study is compatible with this finding in that WM is activated more, and trained more, in the early stages of learning a new language.

### *The effect of learning two foreign languages simultaneously on WM*

Previous studies showed evidence of a positive impact of WM on the L2 learning process and outcomes, but whether this relationship is bi-directional, and if so, what types and durations of L2 experience will contribute to an improvement in WM remained unclear (Linck et al. 2014). The second question, therefore, addressed the effect of learning two foreign languages simultaneously on LA and WM. Such an effect was found for WM, but not for LA. Moreover, the effect was only found among the first-year learners, not the second-year learners. We may thus conclude that starting to learn an additional foreign language affords more benefits to WM than merely continuing to learn one foreign language does.

The improvement in L2 + 3 learners' WM might be due to the intensive cognitive demands placed on them. The WM capacity measured by the OSP task in the present study is executive WM, according to Wen's Phonological WM/Executive WM model (PWM/EWM model; 2015, 2016, 2019). EWM encompasses executive functions such as information updating, switching and inhibition, which regulates control processes and attention monitoring in language learning (Wen 2019; also see Miyake and Friedman 2012). Learning two languages simultaneously demands that the learners not only process a substantial amount of new information, which is taxing for WM capacity, but also that they inhibit, or in a broader sense manipulate the already existing linguistic information and integrate it with the new knowledge of the other language. More specifically, the simultaneous language learners need to shift between similar sets of linguistic representations depending on the language context, and inhibit goal-irrelevant linguistic representations, and this part is largely dependent on EWM. These processes may lead to a WM training effect for language learners.

An analogous line of argumentation has been pursued in the literature on what is sometimes called the 'bilingual advantage' where some authors have found evidence of an enhanced WM in bilinguals, particularly of those WM aspects involving executive functioning (e.g. Morales, Calvo, and Bialystok 2013). This has been explained with the assumption that executive functioning is engaged in sustaining and retrieving information for undergoing cognitive activities such as language use, and may be also deployed to inhibit goal-irrelevant responses elicited by the environment (Kane et al. 2007). Our finding, however, goes beyond these earlier results by demonstrating that the enhancement of WM found for long-time bilingual speakers might already occur at the very first stages of intensive multilingual language processing.

This interpretation of our findings is supported by the lack of a difference in WM improvement between the second-year English/Russian learners and English/Japanese learners on the one hand and the L2+ learners on the other: since the English majors also started to learn an additional language in their second year, they were simultaneous language learners as well – albeit to a lesser extent than the L2 + 3 majors – which could mean that this leads to a similar increase in WM capacity in all second-year learner groups, removing the advantage of the L2 + 3 over the English majors regarding WM training.

Our finding also contributes to answering de Bot's (2012) question whether multilinguals have the same amount of resources at their command as monolinguals, or whether they have more resources. In the first case, the resources (such as memory capacity, LA, available time and attention, among others) would need to be distributed across different languages, leaving fewer resources for each, while in the second scenario language learning would be facilitated. For WM as a resource, our results suggest that learning multiple languages does not result in less of that resource for each

individual language. Instead, multilinguals' resources, in this case, WM, were enhanced among first-year L2 + 3 learners.

## Conclusion and limitations

The present study investigated whether LA and WM are changeable under the circumstance of foreign language learning and whether there is an effect of learning two foreign languages simultaneously on these two cognitive abilities. The results revealed that both LA and WM are changeable, and there is a positive effect of learning two foreign languages as opposed to just learning one language on WM development at the early stages of learning a new language. This could be the result of the constant and intensive learning of two foreign languages simultaneously, which calls for not only taking in and maintaining new information, but also manipulating and selecting between old and new information. Our results not only add to the small but growing body of literature that both LA and WM are not unchangeable, as traditionally was assumed, but also demonstrate that the relationship between LA and WM on one hand and language learning on the other hand is bi-directional: LA and WM not only affect language learning, but language learning also affects LA and WM, with bi-foreign language learning exerting an especially beneficial effect on WM capacity.

A question that arises from these results and that is amenable for future studies is what amount of simultaneous language learning experience is needed for an extra effect of WM capacity enhancement. In this respect, it is interesting to note that the L2 + 3 learners studied by Ma, Yao, and Zhang (2018) performed better than L2 learners on some aspects of LA by the time they had had 60 hours of L3 instruction, which is substantially less than what our subjects had received after one academic year (224 hours for the first-year students, and 288 hours for the second-year students).

Apart from the above findings, there are also some limitations of the present study which could inform future research. Firstly, some groups have a limited sample size, which may have affected the power and effect sizes. Secondly, from our data, it is unclear whether the language learning effect on WM is the result of learning two foreign languages simultaneously, or the result of learning a new foreign language *per se*. Thirdly, as the second-year English majors also started to learn a new foreign language, albeit to a very limited extent, the data do not allow a conclusion of whether this differential effect on WM between learning one or two foreign languages found in the first year might have extended into the second year. Fourthly, LA and WM were measured only with the LLAMA test and the OSP task, respectively. Future studies might consider using even more comprehensive measures such as, for example, a dedicated digit span task to test phonological WM. Lastly, the relationship between LA and WM is of growing interest to researchers in the field, but the current study did not address this issue and focused solely on the changeability of the two separately. Future studies might focus on the relationship between the two and, especially, the degree to which WM can be considered as a part of LA.

## Notes

1. For all of our participants, English and – if applicable – the other foreign language were the first- and second-foreign language learnt, both in an instructional context and with very little extramural exposure. We have therefore labeled the English majors and bi-foreign-language majors as L2 and L2+3 learners, respectively. We would like to acknowledge however that some participants might also have been growing up speaking a dialect next to Mandarin.
2. An ANOVA test was further carried out to confirm that first-year English/Japanese learners and English/Russian learners did not show any significant difference in WM gain scores.

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## Notes on contributors

***Ting Huang*** (MA) is a PhD student in the Faculty of Arts, University of Groningen.

***Hanneke Loerts*** is an assistant professor in the Faculty of Medical Sciences and the Faculty of Arts, University of Groningen. Her expertise is in Psycholinguistics, AppliedLinguistics, Research Methodology, Basic Statistics, Eye Tracking, Event-Related Potentials.

***Rasmus Steinkrauss*** is an assistant professor in the Faculty of Arts, University of Groningen. His expertise is in L1 and L2 development and Usage-based/CognitiveLinguistics.

## ORCID

*Ting Huang* http://orcid.org/0000-0001-5922-0460
*Hanneke Loerts* http://orcid.org/0000-0001-8764-0905
*Rasmus Steinkrauss* http://orcid.org/0000-0002-3643-8704

## References

Abrahamsson, N., and K. Hyltenstam. 2008. "The Robustness of Aptitude Effects in Near-Native Second Language Acquisition." *Studies in Second Language Acquisition* 30 (4): 481–509.

Artieda, G., and C. Muñoz. 2016. "The LLAMA Tests and the Underlying Structure of Language Aptitude at Two Levels of Foreign Language Proficiency." *Learning and Individual Differences* 50: 42–48.

Atkins, P. W. B., and A. D. Baddeley. 1998. "Working Memory and Distributed Vocabulary Learning." *Applied Psycholinguistics* 19 (4): 537–552.

Baddeley, A. 1992. "Working Memory." *Science* 255 (5044): 556–559.

Baddeley, A. 2000. "The Episodic Buffer: A New Component of Working Memory?" *Trends in Cognitive Sciences* 4 (11): 417–423.

Baddeley, A. 2003. "Working Memory and Language: An Overview." *Journal of Communication Disorders* 36 (3): 189–208.

Baddeley, A. 2015. "Working Memory in Second Language Learning." In *Working Memory in Second Language Acquisition and Processing*, edited by Z. Wen, B. M. Mailce, and M. Arthur, 17–28. Bristol: Multilingual Matters.

Baddeley, A., S. Gathercole, and C. Papagno. 1998. "The Phonological Loop as a Language Learning Device." *Psychological Review* 105 (1): 158–173.

Baddeley, A. D., and G. J. Hitch. 1974. "Working Memory." In *Recent Advances in Learning and Motivation*, edited by G. A. Bower, 47–90. New York: Academic Press.

Bergsleithner, J. M. 2010. "Working Memory Capacity and L2 Writing Performance." *Ciências & Cognição* 15 (2): 002–020.

Cameron, L., and D. Larsen-Freeman. 2007. "Complex Systems and Applied Linguistics." *International Journal of Applied Linguistics* 17 (2): 226–240.

Carretti, B., E. Borella, M. Zavagnin, and R. De Beni. 2013. "Gains in Language Comprehension Relating to Working Memory Training in Healthy Older Adults." *International Journal of Geriatric Psychiatry* 28 (5): 539–546.

Carroll, J. B. 1965. "The Prediction of Success in Foreign Language Training." In *Training, Research, and Education*, edited by R. Glaser, 87–136. New York: Wiley.

Carroll, J. B. 1981. "Twenty-Five Years of Research on Foreign Language Aptitude." In *Individual Differences and Universals in Language Learning Aptitude*, edited by K. C. Diller, 83–118. Rowley, MA: Newbury House Publishers.

Carroll, J. B., and S. M. Sapon. 1959. *Modern Language Aptitude Test*. San Antonio, TX: Psychological Corporation.

de Bot, K. 2012. "Rethinking Multilingual Processing: From a Static to a Dynamic Approach." In *Third Language Acquisition in Adulthood*, edited by J. C. Amaro, S. Flynn, and J. Rothman, 79–94. Amsterdam: John Benjamins Publishing Co.

de Bot, K., and D. Larsen-Freeman. 2011. "Researching Second Language Development from a Dynamic System Theory Perspective." In *A Dynamic Approach to Second Language Development: Methods and Techniques*, edited by Marjolijn H. Verspoor, Kees de Bot, and Wander Lowie, 5–23. Amsterdam: John Benjamins Publishing Co.

de Bot, K., W. Lowie, and M. H. Verspoor. 2007. "A Dynamic Systems Theory Approach to Second Language Acquisition." *Bilingualism: Language and Cognition* 10 (1): 7–21.

Dörnyei, Z., and P. Skehan. 2003. "Individual Differences in Second Language Learning." In *The Handbook of Second Language Acquisition*, edited by C. J. Doughty and M. H. Long, 589–630. Malden, MA: Blackwell Publishing Ltd.

Doughty, C. J., S. G. Campbell, M. A. Mislevy, M. F. Bunting, A. R. Bowles, and J. T. Koeth. 2010. "Predicting Near-Native Ability : The Factor Structure and Reliability of Hi-LAB." In *Selected Proceedings of the 2008 Second Language Research Forum*, edited by M. T. Prior, Y. Watanabe, and S.-K. Lee, 10–31. Somerville, MA: Cascadilla Proceedings Project.

Eisenstein, M. 1980. "Childhood Bilingualism and Adult Language Learning Aptitude." *Applied Psychology* 29 (1–2): 159–172.

Granena, G. 2013. "Cognitive Aptitudes for Second Language Learning and the LLAMA Language Aptitude Test." In *Sensitive Periods, Language Aptitude, and Ultimate L2 Attainment*, edited by Gisela Granena and Michael H. Long, 105–129. Amsterdam: John Benjamins Publishing Company.

Granena, G., and M. H. Long. 2012. "Age of Onset, Length of Residence, Language Aptitude, and Ultimate L2 Attainment in Three Linguistic Domains." *Second Language Research* 29 (3): 311–343.

Green, D. W., and J. Abutalebi. 2013. "Language Control in Bilinguals: The Adaptive Control Hypothesis." *Journal of Cognitive Psychology* 25 (5): 515–530.

Grigorenko, E. L., R. J. Sternberg, and M. E. Ehrman. 2000. "A Theory-Based Approach to the Measurement of Foreign Language Learning Ability: The Canal-F Theory and Test." *The Modern Language Journal* 84 (3): 390–405.

Grundy, J. G., and K. Timmer. 2017. "Bilingualism and Working Memory Capacity: A Comprehensive Meta-Analysis." *Second Language Research* 33 (3): 325–340.

Harley, B., and D. Hart. 1997. "Language Aptitude and Second Language Proficiency in Classroom Learners of Different Starting Ages." *Studies in Second Language Acquisition* 19 (3): 379–400.

Hayashi, Y., T. Kobayashi, and T. Toyoshige. 2016. "Investigating the Relative Contributions of Computerised Working Memory Training and English Language Teaching to Cognitive and Foreign Language Development." *Applied Cognitive Psychology* 30 (2): 196–213.

Hofer, B., and U. Jessner. 2019. "Multilingualism at the Primary Level in South Tyrol: How Does Multilingual Education Affect Young Learners' Metalinguistic Awareness and Proficiency in L1, L2 and L3?" *Language Learning Journal* 47 (1): 76–87.

Holmes, J., S. E. Gathercole, and D. L. Dunning. 2009. "Adaptive Training Leads to Sustained Enhancement of Poor Working Memory in Children." *Developmental Science* 12 (4): 9–15.

Hou, J., M. Verspoor, and H. Loerts. 2016. "An Exploratory Study into the Dynamics of Chinese L2 Writing Development." *Dutch Journal of Applied Linguistics* 5 (1): 65–96.

Jaušovec, N., and K. Jaušovec. 2012. "Working Memory Training: Improving Intelligence - Changing Brain Activity." *Brain and Cognition* 79 (2): 96–106.

Jessner, U. 2014. "On Multilingual Awareness or Why the Multilingual Learner is a Specific Language Learner." In *Essential Topics in Applied Linguistics and Multilingualism*, edited by Mirosław Pawlak and Larissa Aronin, 175–184. Wien, New York: Springer.

Kane, M. J., A. R. A. Conway, D. Z. Hambrick, and R. W. Engle. 2007. "Variation in Working Memory Capacity as Variation in Executive Attention and Control." In *Variation in Working Memory*, edited by A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, and J. N. Towse, 21–48. Oxford: Oxford University Press.

Karbach, J., and P. Verhaeghen. 2014. "Making Working Memory Work: A Meta-Analysis of Executive-Control and Working Memory Training in Older Adults." *Psychological Science* 25 (11): 2027–2037.

Klingberg, T. 2010. "Training and Plasticity of Working Memory." *Trends in Cognitive Sciences* 14 (7): 317–324.

Kogetsidis, H. 2012. "Dopamine and Training-Related Working-Memory Improvement." *Journal of Transnational Management* 17 (3): 189–204.

Li, S. 2013. "The Interactions Between the Effects of Implicit and Explicit Feedback and Individual Differences in Language Analytic Ability and Working Memory." *Modern Language Journal* 97 (3): 634–654.

Li, S. 2015. "The Associations Between Language Aptitude and Second Language Grammar Acquisition: A Meta-Analytic Review of Five Decades of Research." *Applied Linguistics* 36 (3): 385–408.

Li, S. 2016. "The Construct Validity of Language Aptitude." *Studies in Second Language Acquisition* 38 (04): 801–842.

Linck, J. A., M. M. Hughes, S. G. Campbell, N. H. Silbert, M. Tare, S. R. Jackson, and C. J. Doughty. 2013. "Hi-LAB: A New Measure of Aptitude for High-Level Language Proficiency." *Language Learning* 63 (3): 530–566.

Linck, J. A., P. Osthus, J. T. Koeth, and M. F. Bunting. 2014. "Working Memory and Second Language Comprehension and Production: A Meta-Analysis." *Psychonomic Bulletin & Review* 21 (1531–5320 (Electronic)): 861–883.

Ma, D., T. Yao, and H. Zhang. 2018. "The Effect of Third Language Learning on Language Aptitude Among English-Major Students in China." *Journal of Multilingual and Multicultural Development* 39 (7): 590–601.

Mackey, A., R. Adams, and C. Stafford. 2010. "Exploring the Relationship Between Modified Output and Working Memory Capacity." *Language Learning* 60 (3): 501–533.

Meara, P. 2005. *LLAMA Language Aptitude Tests: The Manual*. Swansea: Lognostics. http://www.lognostics.co.uk/tools/llama/.

Melby-Lervåg, M., and C. Hulme. 2013. "Is Working Memory Training Effective? A Meta-Analytic Review." *Developmental Psychology* 49 (2): 270–291.

Miyake, A., and N. Friedman. 1998. "Individual Differences in Second Language Proficiency: Working Memory as Language Aptitude." In *Foreign Language Learning: Psyhcolinguistic Studies on Training and Retention*, edited by A. F. Healy and L. E. J. Bourne, 339–364. Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.

Miyake, A., and N. P. Friedman. 2012. "The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions." *Current Directions in Psychological Science* 21 (1): 8–14.
Morales, J., A. Calvo, and E. Bialystok. 2013. "Working Memory Development in Monolingual and Bilingual Children." *Journal of Experimental Child Psychology* 114 (2): 187–202.
Payne, J. S., and B. M. Ross. 2005. "Synchronous CMC, Working Memory, and L2 Oral Proficiency Development." *Language Learning & Technology* 19 (3): 35–54.
Robinson, P. 2001. "Individual Differences, Cognitive Abilities, Aptitude Complexes and Learning Conditions in Second Language Acquisition." *Second Language Research* 17 (4): 368–392.
Robinson, P. 2002. "Effects of Individual Differences in Intelligence, Aptitude and Working Memory on Adult Incidental SLA: A Replication and Extension of Reber, Walkenfield and Hernstadt." In *Individual Differences and Instructed Language Learning*, edited by P. Robinson, 211–266. Amsterdam: John Benjamins Publishing Co.
Robinson, P. 2005. "Aptitude and Second Language Acquisition." *Annual Review of Applied Linguistics* 25: 46–73.
Rogers, V., P. Meara, T. Barnett-Legh, C. Curry, and E. Davie. 2017. "Examining the LLAMA Aptitude Tests." *Journal of the European Second Language Association* 1: 49–60.
Sáfár, A., and J. Kormos. 2008. "Revisiting Problems with Foreign Language Aptitude." *IRAL - International Review of Applied Linguistics in Language Teaching* 46 (2): 113–136.
Sala, G., and F. Gobet. 2017. "Working Memory Training in Typically Developing Children: A Meta-Analysis of the Available Evidence." *Developmental Psychology* 53 (4): 671–685.
Sanchez, C. A., J. Wiley, T. K. Miura, G. J. H. Colflesh, T. R. Ricks, M. S. Jensen, and A. R. A. Conway. 2010. "Assessing Working Memory Capacity in a Non-Native Language." *Learning and Individual Differences* 20 (5): 488–493.
Schneider, W., A. Eschman, and A. Zuccolotto. 2002. *E-Prime User's Guide*. Pittsburgh: Psychology Software Tools Inc.
Serafini, E. J. 2017. "Exploring the Dynamic Long-Term Interaction Between Cognitive and Psychosocial Resources in Adult Second Language Development at Varying Proficiency." *Modern Language Journal* 101 (2): 369–390.
Serafini, E. J., and C. Sanz. 2016. "Evidence for the Decreasing Impact of Cognitive Ability on Second Language Development as Proficiency Increases." *Studies in Second Language Acquisition* 38: 607–646.
Service, E. 1992. "Phonology, Working Memory, and Foreign-Language Learning." *Quarterly Journal of Experimental Psychology* 45 (1): 21–50.
Singleton, D. 2014. "Apt to Change: The Problematic of Language Awareness and Language Aptitude in Age-Related Research." *Studies in Second Language Learning and Teaching* 3 (3): 557–571.
Singleton, D. 2017. "Language Aptitude: Desirable Trait or Acquirable Attribute?" *Studies in Second Language Learning and Teaching* 7 (1): 89.
Skehan, P. 1991. "Individual Differences in Second Language Learning." *Studies in Second Language Acquisition* 13 (2): 275–298.
Skehan, P. 2002. "Theorising and Updating Aptitude." In *Individual Differences and Instructed Language Learning*. 2nd ed., edited by P. Robinson, 69–93. Amsterdam: John Benjamins Publishing Co.
Skehan, P. 2012. "Language Aptitude." In *The Routledge Handbook of Second Language Acquisition*, edited by S. M. Gass and A. Mackey, 381–395. Oxon: Routledge.
Skehan, P. 2015. "Foreign Language Aptitude and Its Relationship with Grammar: A Critical Overview." *Applied Linguistics* 36 (3): 367–384.
Soveri, A., J. Antfolk, L. Karlsson, B. Salo, and M. Laine. 2017. "Working Memory Training Revisited: A Multi-Level Meta-Analysis of n-Back Training Studies." *Psychonomic Bulletin and Review* 24 (4): 1077–1096.
Sparks, R. L., L. Ganschow, K. Fluhary, and S. Little. 1996. "An Exploratory Study on the Effects of Latin on the Native Language Skills and Foreign Language Aptitude of Students with and Without Learning Disabilities." *The Classical Journal* 91 (2): 165–184.
Sparks, R. L., J. Patton, L. Ganschow, and N. Humbach. 2009. "Long-Term Relationships Among Early First Language Skills, Second Language Aptitude, Second Language Affect, and Later Second Language Proficiency." *Applied Psycholinguistics* 30 (4): 725–755.
Thompson, A. S. 2013. "The Interface of Language Aptitude and Multilingualism: Reconsidering the Bilingual/Multilingual Dichotomy." *Modern Language Journal* 97 (3): 685–701.
Thompson, E., M. Kenyon, and C. Rhodes. 2002. *A Validation Study of the Student Oral Proficiency Assessment (SOPA)*. Washington, DC: Center for Applied Linguistics/Iowa State University National K-12 Foreign Language Resource Center Ames. Educational Resources Information Center (ERIC). https://files.eric.ed.gov/fulltext/ED465287.pdf.
Unsworth, N., R. P. Heitz, J. C. Schrock, and R. W. Engle. 2005. "An Automated Version of the Operation Span Task." *Behavior Research Methods* 37 (3): 498–505.
von Bastian, C. C., and K. Oberauer. 2013. "Effects and Mechanisms of Working Memory Training: A Review." *Psychological Research* 78 (6): 803–820.
Wen, Z. 2015. "Working Memory in Second Language Acquisition and Processing: the Phonological/Executive Model." In *Working Memory in Second Language Acquisition and Processing*, edited by Z. Wen, M. B. Mota, and A. Mcneill, 41–62. Bristol: Multilingual Matters.
Wen, Z. 2016. *Working Memory and Second Language Learning: Towards an Integrated Approach*.. Bristol: Multilingual Matters.

Wen, Z. 2019. "Working Memory as Language Aptitude: The Phonological/Executive Model." In *Language Aptitude: Advancing Theory, Testing, Research and Practice*, edited by Z. Wen, P. Skehan, A. Biedroń, S. Li, and R. L. Sparks, 187–214. New York: Routledge.

Wen, Z., and P. Skehan. 2011. "A New Perspective on Foreign Language Aptitude Research: Building and Supporting a Case for "Working Memory as Language Aptitude." *Ilha Do Desterro A Journal of English Language, Literatures in English and Cultural Studies* 60 (October): 15–44.

Williams, J. N. 2012. "Working Memory and SLA." In *The Routledge Handbook of Second Language Acquisition*, edited by S. M. Gass and A. Mackey, 427–441. Oxon: Routledge.