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EMPIRICAL STUDY



The Interface of Explicit and Implicit Knowledge in a Second Language: Insights from Individual Differences in Cognitive Aptitudes

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Recent research has called for the use of fine-grained measures that distinguish implicit knowledge from automatized explicit knowledge. In the current study, such measures were used to determine how the two systems interact in a naturalistic second language (L2) acquisition context. One hundred advanced L2 speakers of Japanese living in Japan were assessed using tests of automatized explicit knowledge and implicit knowledge, along with tests of phonological short-term memory and aptitude tests for explicit and implicit learning. Structural equation modeling demonstrated that aptitude for explicit learning significantly predicted acquisition of automatized explicit knowledge, and automatized explicit knowledge significantly predicted acquisition of implicit knowledge. The effects of implicit learning aptitude and phonological short-term memory on

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3 acquisition of automatized explicit knowledge and implicit knowledge were limited.
4 These findings provide the first empirical evidence that automatized explicit knowledge,
5 which develops through explicit learning mechanisms, may impact the acquisition of
6 implicit knowledge.

7 **Keywords** explicit knowledge; implicit knowledge; interface; aptitude; phonological
8 short-term memory; adults; second language acquisition; naturalistic context
9

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11 Introduction

12 The constructs of explicit knowledge and implicit knowledge have attracted
13 considerable attention in the field of second language acquisition (SLA). Ex-
14 plicit knowledge refers to conscious linguistic knowledge, whereas implicit
15 knowledge refers to linguistic knowledge without awareness (Andringa &
16 Rebuschat, 2015; DeKeyser, 2003; Hulstijn, 2005; Williams, 2009). The ques-
17 tion of what the nature of the relationship is between explicit and implicit
18 knowledge, the so-called interface issue, is one of the central topics in the field.
19 A number of researchers have taken theoretical positions over the decades (e.g.,
20 DeKeyser, 2015; N. C. Ellis, 2005; R. Ellis, 2008; Hulstijn, 2002; Krashen,
21 1985; McLaughlin, 1987; Paradis, 2009), but little research has been con-
22 ducted to investigate the interface empirically in naturalistic second language
23 (L2) acquisition settings (e.g., for recent laboratory intervention experiments,
24 see Andringa & Curcic, 2015; Cintrón-Valentín & N. C. Ellis, 2015). This
25 study attempted to probe the interface of explicit and implicit knowledge by
26 extending a line of recent advancements in research on measurement of implicit
27 knowledge and the role of cognitive aptitudes.

28 First, implicit knowledge and automatized explicit knowledge are dis-
29 tinct constructs (Suzuki, 2017; Suzuki & DeKeyser, 2015; Vafaei, Suzuki,
30 & Kachinske, 2017). Both implicit knowledge and automatized explicit knowl-
31 edge involve rapid access to linguistic knowledge, but they are still distin-
32 guished by the awareness criterion, that is, attention to linguistic forms. Using
33 automatized explicit knowledge involves consciousness about linguistic forms
34 even if the access is rapid or automatic, whereas using implicit knowledge
35 requires no awareness. This study attempted to measure implicit knowledge
36 and automatized explicit knowledge separately with multiple psycholinguistic
37 tests. Implicit knowledge is generally assessed through real-time comprehen-
38 sion measures that utilize reaction time (RT) and eye-movement data and that do
39 not require conscious judgments of grammaticality, thus involving lower aware-
40 ness of linguistic features (Andringa & Curcic, 2015; Dussias, Valdés Kroff,
41 Guzzardo Tamargo, & Gerfen, 2013; Godfroid, 2016; Jiang, Novokshanova,

3 Masuda, & Wang, 2011; Suzuki & DeKeyser, 2015). In contrast, automatized
4 explicit knowledge is measured by form-focused tasks, such as timed gram-
5 maticality judgment tests. Grammaticality judgment tasks inevitably direct
6 test takers' attention to forms, but grammaticality has to be judged automati-
7 cally, requiring fast language processing (DeKeyser, 2015). Therefore, timed
8 grammaticality judgment tasks are considered to tap into automatized explicit
9 knowledge (DeKeyser, 2003; Suzuki, 2017).

10 Second, a growing body of L2 aptitude research has identified new ap-
11 titude components for L2 learning (for overviews, see Linck et al., 2013;
12 Skehan, 2016). Of particular interest for the present study was the measure-
13 ment of distinct cognitive aptitudes for explicit and implicit learning (Granena,
14 2013a, 2016; Linck et al., 2013). Explicit learning refers to the process of con-
15 sciously learning grammatical rules, whereas implicit learning refers to the pro-
16 cess of learning complex regularities without intention or awareness (Hulstijn,
17 2005). Although the two learning mechanisms are distinguished by the crite-
18 rion of awareness, their exact nature has recently begun to be further examined
19 (Andringa & Rebuschat, 2015). For instance, statistical learning mechanisms
20 have attracted attention not only from first language (L1) acquisition researchers
21 but also from SLA researchers (Rebuschat & Williams, 2012). Statistical
22 learning refers to a gradual process of learning distributional properties of
23 input, which is often argued to occur implicitly and automatically (Conway,
24 Bauernschmidt, Huang, & Pisoni, 2010; Perruchet & Poulin-Charronnat, 2015).
25 In line with this approach, in this study, implicit learning aptitude was opera-
26 tionalized as the domain-general ability of statistical or probabilistic sequence
27 learning without awareness (Granena, 2013b; Kaufman et al., 2010; Suzuki &
28 DeKeyser, 2015), measured in the serial RT task (Nissen & Bullemer, 1987).
29 On the other hand, explicit learning aptitudes are ~~generally~~ operationalized as
30 inductive language learning ability or the capacity to infer rules governing a
31 given foreign language (Carroll, 1991; Granena, 2016), measured through a
32 subtest of the LLAMA test (Meara, 2005). In addition to focusing on these
33 two aptitudes, we also investigated the extent to which phonological short-
34 term memory accounts for L2 grammar acquisition. Phonological short-term
35 memory is a subcomponent of working memory that refers to a storage com-
36 ponent for phonological information, measured by a letter-span task (Linck
37 et al., 2013). Phonological short-term memory may be implicated in explicit
38 and implicit learning mechanisms because the storage space is required for the
39 manipulation and inferring of grammatical rules (Baddeley, 2012).

40 In the current study, we thus built on the two aforementioned advance-
41 ments (potentially more fine-grained measurements for implicit knowledge

3 and recent conceptualizations of cognitive aptitudes) and attempted to demys-
4 tify the complex relationships between automatized explicit knowledge and
5 implicit knowledge. We conducted structural equation modeling (SEM) analy-
6 ses and examined whether automatized explicit knowledge influences implicit
7 knowledge. Additionally, we examined the extent to which cognitive aptitudes
8 (explicit learning aptitude, implicit learning aptitude, and phonological short-
9 term memory) predict the acquisition of automatized explicit knowledge and
10 implicit knowledge.

12 **Background Literature**

13 **Interface of Explicit and Implicit Knowledge**

One of the biggest controversies in SLA, debated for decades, is the interface problem of explicit and implicit knowledge, namely, whether explicit knowledge facilitates the acquisition of implicit knowledge. The noninterface position, most notably advocated by Krashen, postulates that there is no interaction between the two types of knowledge, rejecting the idea that explicit knowledge can facilitate the acquisition of implicit knowledge (Krashen, 1981, 1985). According to Krashen, the role of explicit knowledge is limited in the sense that it can be used only as a monitor of L2 performance. On the other hand, most other SLA researchers have acknowledged the importance of explicit knowledge for facilitating the acquisition of implicit knowledge (DeKeyser, 2015; N. C. Ellis, 2005, 2015; R. Ellis, 2008; Hulstijn, 2002; Paradis, 2009).¹ The relationship between explicit and implicit knowledge has begun to be examined empirically by employing sensitive measures of learning, such as eye tracking in short-term laboratory experiments (e.g., Andringa & Curcic, 2015; Cintrón-Valentín & N. C. Ellis, 2015). However, the interface of explicit and implicit knowledge has not been explored in a naturalistic L2 acquisition context. Because the acquisition of implicit knowledge requires an extensive amount of L2 exposure (DeKeyser, 2015; Paradis, 2009; Suzuki, 2017; Suzuki & DeKeyser, 2015), examining long-term attainment of explicit and implicit knowledge in a naturalistic acquisition environment is crucial. This study thus aimed to empirically examine whether explicit knowledge plays a facilitative role in the acquisition of implicit knowledge among L1 Chinese speakers who are late learners of L2 Japanese in an immersion environment.

38 **Measurements of Implicit Knowledge and Automatized Explicit**

39 **Knowledge**

A seminal study by R. Ellis (2005) developed three time-pressure tests that were hypothesized to measure implicit knowledge: an oral narrative task, a

3 timed grammaticality judgment test, and an elicited imitation task. Ellis compared
4 participants' performance on these tasks with their performance on two
5 untimed tests that were hypothesized to assess explicit knowledge: an
6 untimed grammaticality judgment task and a metalinguistic knowledge test. The
7 results from confirmatory factor analysis showed that the two types of tests
8 were distinguished along two dimensions, namely, one factor labeled implicit
9 knowledge, based on the time-pressure tests, and the other labeled explicit
10 knowledge, based on the untimed tests. Subsequent studies have been conducted
11 by other researchers and have essentially replicated Ellis's finding with
12 different L2 (Erçetin & Alptekin, 2013; Gutiérrez, 2013; Zhang, 2015) and
13 heritage (Bowles, 2011) learner populations.

14 Recent research, however, has proposed further refinements of implicit
15 knowledge measures because prior time-pressure measures, such as elicited
16 imitation and timed grammaticality judgment tasks, are too coarse grained
17 to limit access to automatized explicit knowledge (Suzuki, 2017; Suzuki &
18 DeKeyser, 2015; Vafae et al., 2017). Time pressure during task performance
19 cannot necessarily limit access to explicit knowledge when L2 learners' explicit
20 knowledge is accessed rapidly (DeKeyser, 2003). Theoretically, automatized
21 explicit knowledge still can be distinguished from the use of linguistic knowl-
22 edge without awareness, that is, implicit knowledge. Put differently, both au-
23 tomated explicit knowledge and implicit knowledge are accessed quickly, but
24 they may still be distinguished based on the awareness criterion and possibly
25 be measured separately (Suzuki & DeKeyser, 2015). In cognitive psychology,
26 automaticity (i.e., the end point of automatization) is often characterized as lack
27 of awareness (e.g., Jacoby, 1991; Posner & Snyder, 1975). However, because
28 automatization is a long process, automatized explicit knowledge has been
29 defined as a body of conscious knowledge involving different levels of autom-
30 atization. Automatized explicit knowledge is thus conscious knowledge that is
31 partially (not fully) automatized, which can theoretically be distinguished from
32 implicit knowledge. In addition, most researchers reject the idea that (automa-
33 tized) explicit knowledge can be converted into implicit knowledge (DeKeyser,
34 2015; N. C. Ellis, 2015; Hulstijn, 2002; Paradis, 2009),² which implies that ac-
35 cumulating one type of knowledge (e.g., automatized explicit knowledge) does
36 not necessarily diminish the other type of knowledge, for instance, implicit
37 knowledge (DeKeyser, 2009; Paradis, 2009).

38 The distinction between implicit knowledge and automatized explicit
39 knowledge may bear important theoretical implications for understanding
40 L2 learning processes through the lens of explicit/implicit learning. Ac-
41 cording to skill acquisition theory (DeKeyser, 2015; Lyster & Sato, 2013),

3 automatized explicit knowledge is acquired by first learning declarative knowl-
4 edge (i.e., knowledge about grammatical rules) and then developing procedural
5 and automatized knowledge that can be deployed more rapidly and effortlessly.
6 This declarative-procedural learning (including automatization) is considered
7 to involve explicit, that is, deliberate and conscious, learning of grammatical
8 information. In contrast, implicit knowledge can be acquired through differ-
9 ent learning mechanisms, independent of this explicit process (Rebuschat &
10 Williams, 2012; Williams, 2009). If different types of explicit knowledge can
11 be posited (e.g., automatized explicit knowledge, less automatized explicit
12 knowledge, nonautomatized explicit knowledge), then its relationships with
13 implicit knowledge (i.e., interface issues) can be examined in more detail.
14 Distinct and fine-grained measures of implicit knowledge and automatized ex-
15 plicit knowledge are thus essential to examine the relationship between the two
16 systems.

17 An emerging line of empirical research has attempted to measure implicit
18 knowledge by utilizing real-time (online) comprehension measures using RT
19 and eye-movement data. These measures prevent L2 learners from consciously
20 accessing automatized explicit knowledge (Suzuki, 2017; Suzuki & DeKeyser,
21 2015). The advantages of using real-time comprehension tasks are that (a) the
22 use of linguistic knowledge is assessed without any explicit judgment of gram-
23 matical forms (i.e., with a focus solely on meaning and arguably involving no
24 awareness) and (b) there is virtually no room to consciously use the knowledge
25 as its use is time-locked to hundreds of milliseconds (Andringa & Curcic, 2015;
26 Dussias et al., 2013; Godfroid, 2016; Suzuki, 2017; Suzuki & DeKeyser, 2015;
27 Vafaei et al., 2017). In contrast, form-focused tasks, such as timed grammati-
28 cality judgment tasks, are likely to involve more conscious processes because
29 they require attention to the grammaticality of targeted structures (DeKeyser,
30 2003; Vafaei et al., 2017; but see Godfroid et al., 2015). In other words, par-
31 ticipants performing these form-focused tasks are required to consciously and
32 quickly reflect on their own linguistic knowledge, which is very different from
33 the requirements of real-time comprehension tasks.

34 Of course, developing pure behavioral measures of automatized explicit
35 knowledge and implicit knowledge is difficult (DeKeyser, 2009). However,
36 validation of measures for these constructs is a stepping stone toward better
37 understanding of the interface issues. One such attempt was made by Suzuki
38 (2017), who carefully designed a set of language tests for implicit knowledge
39 and automatized explicit knowledge to make them maximally different for the
40 level of awareness required. He developed three online comprehension tasks
41 as implicit knowledge tests: a self-paced reading task (e.g., Jiang et al., 2011;

3 Roberts & Liszka, 2013), a word-monitoring task (Godfroid, 2016; Granena,
4 2013b; Suzuki & DeKeyser, 2015), and an eye-tracking while listening (visual-
5 world) task (Andringa & Curcic, 2015; Dussias et al., 2013). Suzuki then
6 compared participants' performance in these tasks with their performance in
7 time-pressure, form-focused tasks (timed visual/auditory grammaticality judg-
8 ment tasks and a timed fill-in-the-blanks test), used to measure automatized
9 explicit knowledge. The results from confirmatory factor analysis revealed
10 that the three real-time comprehension measures loaded onto a single implicit
11 knowledge factor, which was distinct from an automatized explicit knowledge
12 factor that was associated with the three time-pressure, form-focused tasks.
13 In the current study, the data from Suzuki's study were reanalyzed, with an
14 addition of aptitude tests to further probe the interface issue.
15

16 **Individual Differences in Cognitive Aptitudes**

17 With fine-grained measures for implicit knowledge and automatized explicit
18 knowledge, the understanding of explicit and implicit learning processes can
19 be advanced. One approach to revealing which processes are involved is to
20 examine individual learner differences to see which cognitive aptitudes predict
21 L2 knowledge. Investigating the effects of cognitive aptitudes on the acquisition
22 of linguistic knowledge (e.g., explicit and implicit) should allow for uncovering
23 the nature of learning by making an inference about a mental process that is
24 facilitated or hampered by different aptitude components (DeKeyser, 2012).
25 For instance, finding a positive relation between an outcome measure and
26 explicit learning aptitude would suggest that an explicit learning process is
27 involved in acquiring the knowledge assessed by that outcome measure. In other
28 words, explicit/implicit learning processes can be inferred from the relationship
29 between knowledge (i.e., product of learning) and aptitude.

30 With respect to L2 acquisition by late learners in immersion settings, the
31 effects of explicit learning aptitude appear to vary by the specific language tests
32 used (i.e., what types of linguistic knowledge are tapped). In earlier studies,
33 the effects of explicit learning aptitude³ emerged as significant for grammati-
34 cal knowledge measured through grammaticality judgment tasks with minimal
35 time pressure (Abrahamsson & Hyltenstam, 2008; DeKeyser, 2000; DeKeyser,
36 Alfi-Shabtay, & Ravid, 2010). When grammaticality judgment tasks were ad-
37 ministered under ~~greater~~ time pressure (allowing no pause between test items
38 and requiring participants to respond as quickly as possible), explicit learn-
39 ing aptitude was not a significant predictor of the outcomes (Granena, 2013c;
40 Granena & Long, 2013). This suggests that the role of explicit learning aptitude
41 may depend on how linguistic knowledge is measured. Instead of manipulating

2

3 the time pressure feature of grammaticality judgment tasks, in the current study,
4 the role of aptitudes was examined for linguistic measures that differ in terms
5 of allocation of attention (meaning vs. formfocused), controlling for the level
6 of awareness involved in the use of linguistic knowledge.

7 On the other hand, implicit learning aptitude, measured by the serial RT
8 task, has been found to be correlated with real-time comprehension measures
9 but not with form-focused measures. In both Granena's (2013b) and Suzuki and
10 DeKeyser's (2015) studies, serial RT scores were correlated with real-time com-
11 prehension of L2 grammatical structures (measured through a word-monitoring
12 task), while they were not correlated with performance on metalinguistic knowl-
13 edge tests. A review of previous literature has revealed no published research
14 that has yet investigated the role of explicit and implicit learning aptitudes on
15 L2 grammar acquisition simultaneously using a within-subjects design. There-
16 fore, the current study focused on the contributions of both explicit and implicit
17 aptitude components on L2 grammar acquisition.

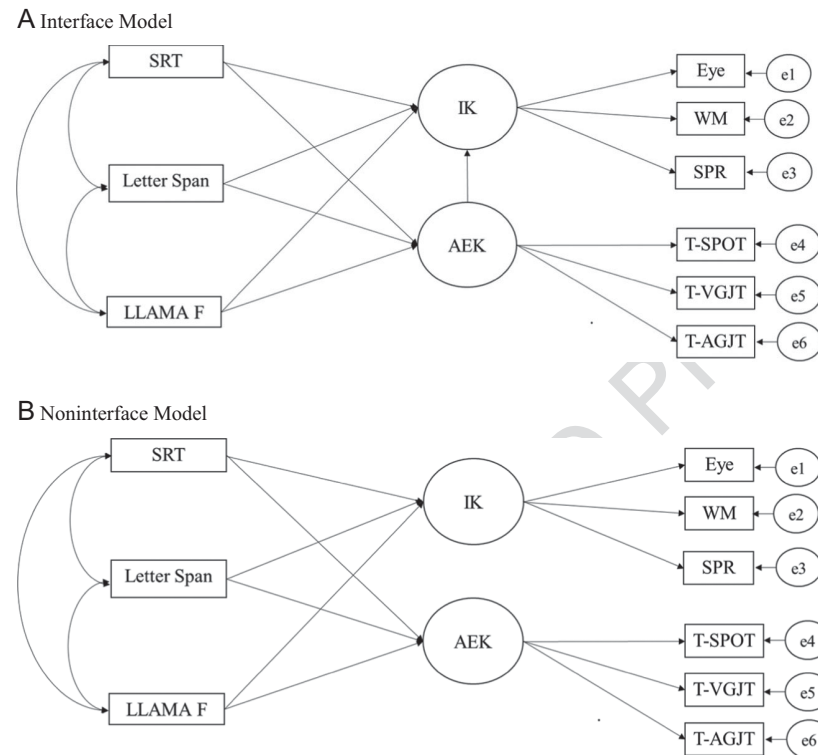
18 Additionally, this study examined the effects of phonological short-term
19 memory in combination with explicit and implicit learning aptitudes. Because
20 higher memory ability likely opens a larger window for processing language
21 sequences so that grammatical rules can be inferred, phonological short-term
22 memory was expected to correlate with both aptitudes for explicit and implicit
23 learning (Janacek & Nemeth, 2013). Little research has investigated the ef-
24 fects of phonological short-term memory in the long-term acquisition of L2
25 grammatical knowledge. Linck et al. (2013) showed that phonological short-
26 term memory was a significant predictor of long-term attainment in reading
27 and listening skills among highly advanced L2 learners. Their study focused
28 on global L2 skills, and it is less clear to what extent phonological short-term
29 memory contributes to the acquisition of grammatical knowledge of specific
30 structures (for examples of classroom studies, see French & O'Brien, 2008; for
31 examples of laboratory studies, see Williams & Lovatt, 2005; Martin & N. C.
32 Ellis, 2012). Some recent work has also started to examine the effect of phono-
33 logical short-term memory in the study-abroad context (Grey, Cox, Serafini, &
34 Sanz, 2015). Critically, no research has investigated the role of phonological
35 short-term memory along with explicit and implicit learning aptitudes on the
36 acquisition of explicit and implicit knowledge. It is important to clarify the role
37 of a fundamental storage component like phonological short-term memory in
38 L2 grammar learning (Baddeley, 2012). In sum, this study aimed to investi-
39 gate the contribution of explicit and implicit learning aptitudes, along with
40 phonological short-term memory, on the acquisition of automatized explicit
41 knowledge and implicit knowledge.

The Current Study

The current study was motivated by two related gaps in the literature on the interface between explicit and implicit knowledge: (a) lack of valid measurements for implicit knowledge and (b) ambiguous interpretations of the role of cognitive aptitudes in acquisition of explicit and implicit knowledge. These gaps were addressed by using SEM analyses. The study employed a within-subjects, cross-sectional design to examine the relationships among implicit knowledge, automatized explicit knowledge, explicit learning aptitude, implicit learning aptitude, and phonological short-term memory. SEM provides a powerful approach for examining the causal processes of latent (i.e., unobserved) variables by taking into account the error of measured (i.e., observed) variables (Hancock & Schoonen, 2015; Kline, 2010). Based on the extant body of knowledge in the field, a statistical model is first hypothesized; the plausibility of the model is then tested using data obtained through instruments for measuring automatized explicit knowledge, implicit knowledge, and aptitudes.

Based on recent refinements of implicit knowledge measures, three real-time comprehension measures (i.e., a visual-world task, a word-monitoring task, and a self-paced reading task) were employed to assess implicit knowledge. As measures of automatized explicit knowledge, three form-focused tasks that impose time pressure (i.e., a time-pressure auditory grammaticality judgment task, a time-pressure visual grammaticality judgment task, and a time-pressure fill-in-the-blanks test called SPOT⁴) were used. In addition, three cognitive aptitude tests were administered. Explicit learning aptitude was measured through the LLAMA F subtest, implicit learning aptitude was measured by the serial RT task, and phonological short-term memory was measured by the letter-span task.

Two SEM models were constructed to empirically test the interface issue (Figure 1): the interface model and the noninterface model. In the interface model (Panel A), we hypothesized that automatized explicit knowledge significantly influences implicit knowledge. As a competing model, the noninterface model was identical to the interface model but stipulated no relationship between implicit knowledge and automatized explicit knowledge. This model was based on Krashen's claim that explicit knowledge plays a marginal role in the development of implicit knowledge (Krashen, 1981, 1985). We were particularly interested in two components of the SEM model. First, the relationship between explicit and implicit knowledge (i.e., the interface issue) was tested by directly comparing the two competing models and measuring the strength of association between automatized explicit knowledge and



26 **Figure 1** Structural equation models for the interface (A) and noninterface (B) models.
 27 AEK = Automated Explicit Knowledge, IK = Implicit Knowledge, T-AGJT = Timed
 28 Auditory Grammaticality Judgment Task, T-VGJT = Timed Visual Grammaticality
 29 Judgment Task, T-SPOT = Timed SPOT, Eye = Visual-World Task, SPR = Self-Paced
 30 Reading Task, WM = Word-Monitoring Task.

31
 32 implicit knowledge. Second, the contributions of aptitudes to the acquisition of
 33 automatized explicit knowledge and implicit knowledge were also examined.
 34 The paths from the three aptitude components (explicit learning aptitude, im-
 35 plicit learning aptitude, and phonological short-term memory) were specified
 36 to both these latent constructs in both the interface and noninterface models.
 37 Explicit learning aptitude and implicit learning aptitudes were hypothesized to
 38 load on the same factors as the two types of knowledge because SLA researchers
 39 holding views on the interface issues have provided no clear hypotheses regard-
 40 ing the role of aptitudes in the acquisition of explicit and implicit knowledge.
 41 This aspect of the SEM analysis, namely, that aptitude of one type (e.g., explicit)

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3 influences knowledge of the other type (e.g., implicit), is more exploratory in
4 nature, compared to the relationship between automatized explicit knowledge
5 and implicit knowledge. It is informative to examine all potential paths from
6 aptitudes because some of these paths could have both positive and negative
7 effects (Robinson, 2005).

8 Although this study aimed at examining the causal impact of automatized
9 explicit knowledge on implicit knowledge, the findings from the SEM analysis
10 should at best be interpreted as suggestive evidence of the influence of au-
11 tomatized explicit knowledge on implicit knowledge. SEM analysis specifies
12 and tests causal relationships among the constructs, but the current data came
13 from tests administered in a single session (cross-sectional design), with no
14 intervention taking place. We can only infer the developmental process based
15 on these relationships. In what follows, we have sometimes stated, “X influ-
16 ences/contribute to/leads to the acquisition of implicit knowledge/automatized
17 explicit knowledge.” However, we have used this language only for purposes
18 of describing the relationships specified in the SEM models. Caution should
19 be used not to draw any conclusion that automatized explicit knowledge di-
20 rectly facilitated the acquisition process or development of implicit knowledge
21 based on the results of the current cross-sectional design. Whenever a rela-
22 tionship between explicit–implicit learning aptitudes and learning outcomes
23 was found, it could not simply be assumed that explicit and implicit learn-
24 ing processes were at work in the current cross-sectional design. Longitudinal
25 studies with within-subjects designs (and/or intervention experiments) would
26 be necessary to uncover explicit–implicit learning processes. Unfortunately,
27 longitudinal studies are extremely difficult to carry out (e.g., due to high costs
28 and data attrition). Even in a cross-sectional design, no prior research has
29 measured explicit knowledge, implicit knowledge, and explicit and implicit
30 learning aptitudes all in the same study. It thus seemed a useful step to conduct
31 a cross-sectional study first in order to better understand the relationship be-
32 tween explicit and implicit knowledge, which could provide direction for more
33 extensive longitudinal research.

34 This study addressed the following four research questions:

- 35
- 36 1. Does automatized explicit knowledge contribute to the acquisition of
- 37 implicit knowledge?
- 38 2a. Does explicit learning aptitude contribute to the acquisition of automatized
- 39 explicit knowledge?
- 40 2b. Does explicit learning aptitude contribute to the acquisition of implicit
- 41 knowledge?

- 3 3a. Does implicit learning aptitude contribute to the acquisition of automatized
4 explicit knowledge?
5 3b. Does implicit learning aptitude contribute to the acquisition of implicit
6 knowledge?
7 4a. Does phonological short-term memory contribute to the acquisition of
8 automatized explicit knowledge?
9 4b. Does phonological short-term memory contribute to the acquisition of
10 implicit knowledge?
11

12 Regarding Question 1, we hypothesized that automatized explicit knowl-
13 edge would significantly contribute to the acquisition of implicit knowledge
14 based on the consensus that explicit knowledge in one way or another facili-
15 tates the acquisition of implicit knowledge (DeKeyser, 2015; N. C. Ellis, 2005,
16 2015; R. Ellis, 2008; Hulstijn, 2002; Paradis, 2009). With respect to Questions
17 2–4 targeting the effects of cognitive aptitudes (explicit learning aptitude, im-
18 plicit learning aptitude, and phonological short-term memory), we expected
19 that explicit learning aptitude would play a significant role in the acquisition
20 of automatized explicit knowledge (based on skill acquisition theory) and that
21 implicit learning aptitude would play a significant role in the acquisition of
22 implicit knowledge (based on the findings in Granena, 2013b, and in Suzuki &
23 DeKeyser, 2015). Although it was more straightforward to assume that implicit
24 learning aptitude is related to implicit knowledge and that explicit learning
25 aptitude is related to automatized explicit knowledge, it is less clear how one
26 type of aptitude (e.g., explicit) is involved in the acquisition of the other type
27 of knowledge (e.g., implicit). In the real world, the state of automatized ex-
28 plicit knowledge and implicit knowledge varies greatly among L2 learners,
29 and the contribution of aptitudes may also change depending on many factors,
30 for example, the stage of L2 development and types of linguistic structures
31 to be acquired (Serafini & Sanz, 2016). Therefore, the interpretations of the
32 relationships between aptitudes and forms of knowledge may not always be
33 straightforward, but these should be considered as facilitating the understand-
34 ing of how the two types of knowledge are related.
35

36 Method

37 Participants

38 One hundred L2 speakers of Japanese (29 male, 71 female) whose first lan-
39 guage was Chinese were recruited in Tokyo and the surrounding Kanto area.
40 Fifty-one Japanese native speakers were also recruited to serve as a baseline
41 group for the linguistic knowledge tasks. All participants were compensated

Table 1 Background information for L2 speakers

Variable	M	SD	Min	Max
Age at time of testing (years)	25.97	4.47	19	47
Age on arrival (years)	21.36	2.66	17	30
Length of residence (months)	47.29	27.71	24	197
Onset of instruction (years)	19.01	2.25	13	27
Length of instruction (months)	41.11	17.44	3	84

Note. None of the variables was normally distributed according to the Kolmogorov-Smirnov test ($p < .05$).

for their participation in the study. Four requirements had to be met by L2 speakers in order to participate: (a) proficiency, (b) age of arrival in Japan, (c) length of residence, and (d) educational background. First, only advanced-level L2 speakers of Japanese were recruited. They were screened for Japanese proficiency, which had to be equivalent to or higher than N1 in the standardized Japanese Language Proficiency Test.⁵ Second, only late L2 speakers who had arrived in Japan after the age of 17 were included, because they show considerable variability in attainment in immersion settings, compared to early L2 speakers, such as those whose age of arrival is before 6 (Abrahamsson & Hyltenstam, 2009). Third, length of residence in Japan had to be 2 years or longer. This cutoff point for length of residence was roughly based on previous findings that implicit knowledge seemed to be exhibited most efficiently in online measurements (i.e., word-monitoring tasks) when L2 speakers had been immersed in the target country for 2.5 years of residence or longer (Suzuki & DeKeyser, 2015).⁶ Fourth, participants had to possess at least a bachelor's degree or be enrolled in a 4-year undergraduate program. The sampled population consisted of undergraduate students ($n = 34$), master's degree students ($n = 40$), Ph.D. students ($n = 14$), and office workers ($n = 12$). Detailed background information about the L2 speakers is presented in Table 1.

Target Structures

Three Japanese linguistic structures were tested across the six language tests: (a) transitive/intransitive verb pairs, (b) classifiers, and (c) locative particles (*ni/de*). These structures were chosen because they generate some prediction of upcoming information, which can be demonstrated by the visual-world task. All target structures are usually explicitly taught in beginner-level Japanese L2 classes. Because all L2 speakers had learned Japanese in classroom settings (see Table 1), it could be assumed that they possessed (nonautomatized) explicit knowledge to some extent.

3 *Transitive–Intransitive Verb Pairs*

4 Sixteen transitive–intransitive verb pairs were chosen (Jacobsen, 1992). The
5 pairs share their stem, but morphological markings distinguish transitive from
6 intransitive. For instance, the transitive verb *war-u* (“to break”) has the intransitive
7 counterpart *war-eru* (“to be broken”). The theme is discernible from the
8 object-marking particle *o* for the transitive verb (e.g., *sara-o waru*, “someone
9 breaks the dish”). For the intransitive verb, the theme should be marked with
10 the subject-marking particle *ga* rather than *o* (e.g., *sara-ga wareru*, “the dish
11 got broken”). The case marking (*wa* or *ga*) and the verbal morphology (*u* or
12 *eru*) were cues for prediction of upcoming nouns. In the transitive sentence,
13 for example, they predict a noun in the agent role (see the visual-world task
14 below).

15
16 *Classifiers*

17 Eight classifiers were chosen and matched with four nouns, yielding 32
18 classifier–noun pairs. For instance, *chaku* is a classifier for clothes, as in *go-*
19 *chaku no doresu* (five-CHAKU-Genitive dress, “five dresses”). Although some
20 classifiers are shared between Japanese and Chinese, classifier–noun pairs that
21 are not shared were chosen in order to avoid mere transfer from Chinese to
22 Japanese. Each classifier was used as a unique cue to predict an upcoming
23 noun.

24
25 *Locative Particles: Ni/De*

26 The particles *ni* and *de* are multifunctional case markers, and only the uses for
27 location were targeted in this study. In particular, *de* indicates the place where
28 an action takes place (e.g., *watashi-wa toshokan-de benkyousuru*, “I study in
29 the library”), whereas *ni* is used to indicate the place where a thing or a person
30 exists (e.g., *watashi-wa toshokan-ni iru*, “I will be in the library”). It has been
31 found that Chinese speakers tend to overuse *ni* for *de* (Hasuike, 2004). Not all
32 uses of *ni* are difficult, and a relatively easier usage is to express destination
33 with motion verbs (e.g., *watashi-wa cafe ni hairu*, “I enter the café”). In sum,
34 action verbs agree with the location particle *de*, static verbs with the location
35 particle *ni*, and motion verbs with the destination particle *ni*. Thus, *de* was a
36 cue to predict an action verb, whereas *ni* was a cue to predict a motion verb or
37 stative verb.

38
39 **Instruments**

40 Table 2 illustrates the language test battery used for assessment of automatized
41 explicit knowledge and implicit knowledge. The critical features of the tasks

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Table 2 Characteristics of the tests of implicit knowledge and automatized explicit knowledge

Characteristic	Implicit knowledge			Automatized explicit knowledge		
	Visual-world	Word-monitoring	Self-paced reading	Timed AGJT	Timed VGJT	Timed SPOT
Data	Fixation proportion	RT	RT	Accuracy	Accuracy	Accuracy
Focus of attention	Meaning	Meaning ^a	Meaning	Form	Form	Form
Real-time processing	Yes	Yes	Yes	No	No	No
Modality	Aural	Aural	Written	Aural	Written	Written

Note. RT = reaction time; AGJT = auditory grammaticality judgment task; VGJT = visual grammaticality judgment task; SPOT = fill-in-the-blank task. ^aThe focus of attention is also directed to the word being monitored.

3 between the two types of tests lie in (a) focus of attention and (b) real-time
4 sentence processing. All implicit knowledge tests assessed real-time language
5 processing while attention was directed to meaning (Andringa & Curcic, 2015;
6 Dussias et al., 2013; Granena, 2013b; Jiang et al., 2011; Paradis, 2009; Roberts
7 & Liszka, 2013; Suzuki & DeKeyser, 2015). Comprehension questions were
8 included in the tests, and the instructions told the participants to read/listen to
9 the stimulus for comprehension. The objective of these tests was to understand
10 the meaning of sentences, and participants were never told that the tests aimed
11 to measure their grammatical knowledge. This principle was also applied strin-
12 gently to data analysis. When an individual's accuracy for the comprehension
13 questions was below 75%, all the responses from that person were excluded
14 (Jiang et al., 2011). These characteristics of the tests were designed to prevent
15 L2 learners from attending to grammatical forms consciously. The three im-
16 plicit knowledge tests were chosen because they have been found to successfully
17 capture implicit language processing in previous studies: a self-paced reading
18 task (e.g., Jiang et al., 2011; Roberts & Liszka, 2013), a word-monitoring task
19 (Godfroid, 2016; Granena, 2013b; Suzuki & DeKeyser, 2015), and an eye-
20 tracking while listening (visual-world) task (Andringa & Curcic, 2015; Dussias
21 et al., 2013). In contrast, all automatized explicit knowledge tests required fo-
22 cus on form or grammatical features under time pressure. Even if time pressure
23 is applied, participants are more likely to use explicit knowledge because the
24 tasks inherently predispose them to focus on form (DeKeyser, 2003; Vafae
25 et al., 2017). Specifically, in the grammaticality judgment tasks, they searched
26 for grammatical errors in sentences by attending to grammatical features, and
27 in the timed SPOT task, they needed to fill in the blanks with the target grammar
28 structure (i.e., the attention was directed to the target form).

29 Due to space limitations, we demonstrate how each language test worked,
30 using only the transitive/intransitive structure as an example. The stimulus
31 sentences for all target structures are reported in Appendixes S1–S5 in the
32 Supporting Information online. Across the six language tests, all the stimulus
33 sentences were different in order to reduce practice effects. Before each task
34 was administered, the instructions and a practice session with several items
35 were provided to familiarize participants with the task procedure.

37 *Visual-World Task*

38 In the visual-world task, participants were first presented with a scene consisting
39 of four pictures on the computer screen for 5.5 seconds. They then listened to a
40 short story consisting of two sentences while their eye movements were being
41 tracked, using an EyeLink II system (2004) with a sampling rate of 500 Hz.

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2

3 After the sentences were presented, a yes/no comprehension question appeared
4 on the computer screen.

5 Participants were presented with a total of 64 trials: 48 critical trials and
6 16 filler trials. Sixteen trials were prepared for each of the three linguistic
7 structures tested (16 trials \times 3 structures = 48 trials). In each trial, the critical
8 sentence was presented first, followed by a grammatical filler sentence, which
9 served to divert the participants' attention from the critical sentence and to
10 avoid revealing the purpose of the study (48 grammatical filler sentences).
11 Critical sentences were always presented first in order to prevent participants
12 from being influenced by the information in the filler sentences. The filler trials
13 comprised two grammatical filler sentences each, resulting in 32 grammatical
14 filler sentences. In sum, the task presented 48 critical sentences and 80 filler
15 sentences. All trials were presented in a semirandomized order, such that the
16 same trial type never occurred more than twice in a row. The location of the
17 four objects on display was rotated across trials. After each trial, a yes/no
18 comprehension question was asked to ensure that participants' attention was
19 focused on the meaning of the sentence (cf. Dussias et al., 2013). Half of the
20 questions were about the critical sentences, and the other half about the filler
21 sentences.

22 The display always involved a target object and a competitor object. There
23 were two types of trials for each target structure: target trials (where the target
24 object was mentioned in the critical sentence) and competitor trials (where
25 the competitor object was mentioned). As shown in Figure 2, each display
26 for transitive/intransitive structures consisted of a person (e.g., the mother), a
27 contrast object (e.g., the table), a theme (e.g., the broken dish), and a distractor.
28 The person was defined as a target, whereas the contrast object was defined
29 as a competitor. Two types of critical trials were created: (a) transitive and (b)
30 intransitive trials. Equal numbers of target and competitor trials were prepared
31 for each target structure (8 target trials \times 3 structures + 8 competitor trials \times
32 3 structures = 48 trials).

33 The first part of both sentences always followed the same form: noun phrase
34 (NP)₁-ACC-transitive verb-*iru-no-wa*-adverb-NP₂ (which means "It is NP₂ that
35 transitive verb NP₁," as in "It is the mother that is breaking the dish") and
36 NP₁-SUB-intransitive verb-*iru-no-wa*-adverb-NP₂ (which means "The reason
37 is NP₂ why NP₁ intransitive verb," as in "The dish is broken because it fell off
38 the table"). NP₂ was always a person (e.g., the mother) in the transitive trials
39 (defined as target trials), whereas it was always a contrast object (e.g., the table)
40 in the intransitive trials (defined as competitor trials). In other words, NP₂ served
41 as disambiguation information for the referent, and the analysis of predictive

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Interface of Explicit and Implicit Knowledge

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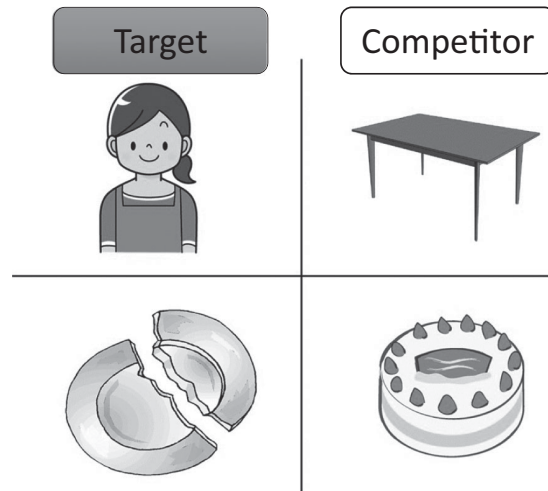
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**Transitive trials (Target trials)**

Osara wo | watte | iru | no | wa | soko ni | iru | okaasan | desu.

Dish-ACC | breaking | be | NOMINALIZER | TOP | there-LOC | exist | mother | be.

It is the mother that is breaking the dish.

Intransitive trials (Competitor trials)

*Osara ga | warete | iru | no | wa | soko ni | aru | teeburu | kara | ochite
shimatta | kara desu.*

Dish-SUB | breaking | be | NOMINALIZER | TOP | there-LOC | exist | table | from | fall off

| because.

The dish is broken because it fell off the table.

Figure 2 Illustration of a visual scene and critical sentences for the transitive/intransitive structure. The labels for the target and competitor items were added for illustrative purposes.

processing focused on the time regions prior to the disambiguation point. The eye movements were analyzed from the onset of the case marker (*ga* or *o*). If participants were sensitive to the transitivity of the verb, then looks to the target (e.g., mother) would be greater in the target trials than in the competitor trials. This is because a segment of NP-ACC and *te*-form of a transitive verb (i.e., *osara-wo watte*) implied an agent. The task design for the other two structures is described in Appendix S1 in the Supporting Information online.

We were primarily interested in looks to the two possible locations, coded as targets and competitors. Before the primary analyses, each time window was shifted 200 milliseconds after the linguistic cues in the speech stream to account for the time it takes to generate a saccadic eye movement (Matin, Shao, & Boff, 1993). In order to compute a sensitivity index for individuals, target

3 advantage scores were first computed separately for target trials and competitor
4 trials as follows: target looks divided by the sum of target looks and competitor
5 looks. Target advantage scores were then standardized (z transformed) across
6 the three structures, and the sensitivity index was computed as the target advan-
7 tage difference score, that is, target advantage in the target trials minus target
8 advantage in the competitor trials. A higher sensitivity score indicated more
9 developed linguistic knowledge. These sensitivity scores were computed after
10 time locking eye movements to 200 milliseconds from the data-driven onset
11 where Japanese native speakers used the linguistic trigger to differentiate the
12 target from the competitor in the display, which came before the disambiguation
13 information (NP₂) was presented (see figures in Appendix S2 in the Supporting
14 Information online for details).

15 *Word-Monitoring Task*

16 In the word-monitoring task, participants were instructed to listen to a sentence
17 for a target word and to press a button as soon as they had identified it in
18 the spoken sentence. The target word written in Japanese characters remained
19 on the screen until the response was made. Participants were told to answer
20 a yes/no comprehension question that appeared on the screen after they had
21 heard the stimulus sentence. A sample sentence targeting a transitive structure
22 is presented in Example 1.

23 *Example 1*

24
25 *Ao to kiiri no | enogu o/*ga mazeru | to, | kirei na | mimdori ni | naru.*
26 *Blue and yellow | paint-ACC/SUB mix | if, | beautiful | green | become.*
27 *When you mix blue and yellow paints, it becomes beautiful green.*
28 *Target word: mazeru*

29
30
31 The target sentence always included a segment of the case-marking particle
32 (*ga* or *o*) and a verb (transitive or intransitive). The target word was always
33 the verb following the particles (*ga* or *o*). A sensitivity index was computed
34 as the RT difference score (ungrammatical RT – grammatical RT) across the
35 three structures, then the average RTs of grammatical and ungrammatical items
36 were standardized (z scores) in order to treat the sensitivity across the target
37 structures equally. The magnitude of this sensitivity index was used as a measure
38 of how developed a speaker's implicit knowledge was (Granena, 2013b; Suzuki
39 & DeKeyser, 2015).⁷

40 The list of stimulus sentences included 48 target sentences (16 × 3 struc-
41 tures) and 48 filler sentences. An equal number of transitive and intransitive

3 sentences (8) was prepared (for all six language tests). Filler sentences were all
4 grammatical sentences in which the target (monitoring) word appeared in dif-
5 ferent locations so that the participants could not predict where the target word
6 would appear. Half of the items in each condition were followed by a yes/no
7 comprehension question. The ratio between positive and negative responses
8 was kept equal. Stimulus sentences for the other structures are presented in
9 Appendix S3 in the Supporting Information online.

11 *Self-Paced Reading Task*

12 In the self-paced reading task, participants were asked to read a sentence word
13 by word as quickly as possible while paying attention to its meaning in order
14 to answer a comprehension question accurately. The first word of a sentence
15 appeared on the left side of the screen and when the button was pressed, the
16 next word appeared to the right of the preceding word, which disappeared upon
17 the presentation of the following word (moving-window presentation). When
18 participants read the final word followed by a period, they pressed a second
19 key to continue to either the next test item or a comprehension question. As
20 in the word-monitoring task, participants were told that they would answer
21 comprehension questions after reading the sentences. Words were presented in
22 Japanese characters in chunks consisting of a clause or *bunsetsu* (i.e., content
23 word + function word). Example 2 shows a sample sentence with the transitive
24 structure (a slash indicates a unit of presentation).

26 Example 2

27 *Uta no gurupu o / tsukuru tokini / danshi to / joshi o (*ga) / mazeru to / ii*
28 */ baransu ni / naru to omou.*

29 Singing group-OBJ / make when / boy and / girls-OBJ / mix if / good /
30 balance / becomes think.

31 When you form a singing group, I think it makes a good balance if you
32 mix boys and girls.

33 Region 1 = *mazeru to*, Region 2 = *ii*.

35 The region of interest where RTs were compared between grammatical and
36 ungrammatical sentences was at the critical word where the error occurred
37 in the ungrammatical sentences (Region 1). This word was located in the
38 same position as that in the word-monitoring task so that the effects could be
39 compared fairly between the word-monitoring task and the self-paced reading
40 task. RTs for the word immediately following the critical word (Region 2)
41 were also included to capture spillover effects. As in the word-monitoring

3 task, the sensitivity index was computed for individuals as z-standardized RT
4 scores (ungrammatical RT – grammatical RT) at Regions 1 and 2 combined. As
5 in the word-monitoring task, stimulus sentences included 48 target sentences
6 (16 × 3 structures) and 48 grammatical filler sentences. Half of the items in
7 each condition were followed by a yes/no comprehension question. The ratio
8 between positive and negative responses was kept equal. Stimulus sentences for
9 the other structures are presented in Appendix S4 in the Supporting Information
10 online.

11 *Timed Auditory Grammatical Judgment Task*

12 In the computer-delivered timed auditory grammaticality judgment task, partici-
13 pants listened to an aural stimulus sentence and indicated whether each
14 sentence was grammatical or ungrammatical by pressing a response button.
15 The grammaticality judgment task procedure followed the instructions used in
16 Granena's (2013c) study. The instructions stated, "You will hear a sentence and
17 make a grammatical judgement as quickly as possible. You are also allowed to
18 respond before the end of the sentence presentation." The time limit imposed
19 on the task was 10 seconds across all the items. Responses that were longer
20 than predetermined time limits were then dealt with after administering the test
21 (see below for details). The stimulus sentences consisted of 48 target sentences
22 (16 × 3 structures), half grammatical and half ungrammatical, as well as
23 16 filler sentences. All fillers were grammatical, resulting in 40 grammatical
24 and 24 ungrammatical sentences in total (8 sentences × 3 structures). The
25 percentage accuracy score was calculated for all items.⁸ One item in the au-
26 ditory grammaticality judgment task was excluded from the analyses because
27 the sentence was not unambiguously grammatical or ungrammatical (58% in
28 native speaker accuracy ratings).
29

30 *Timed Written Grammatical Judgment Task*

31 Like the timed auditory grammaticality judgment task, the timed visual gram-
32 maticality judgment task was also administered on a computer. The procedure
33 was identical to the one in the timed auditory grammaticality judgment task
34 except for the modality of the stimulus sentences. The instructions for the
35 timed written task were also similar: "You will read a sentence and make a
36 grammatical judgement as quickly as possible. You are also allowed to press
37 the key when you detect the error even before you finish reading the whole sen-
38 tence." The time limit imposed on the task was 10 seconds across all the items
39 (see below for details). The stimulus sentences consisted of 48 target sentences
40 (16 sentences × 3 structures), half grammatical and half ungrammatical, as
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3 well as 16 filler sentences. All fillers were grammatical, resulting in 40 gram-
4 matical and 24 ungrammatical sentences in total (8 sentences \times 3 structures).
5 The percentage accuracy score was calculated for all items. One item in the
6 written grammaticality judgment task was excluded from the analyses because
7 the sentence was not unambiguously grammatical or ungrammatical (68% in
8 native speaker accuracy ratings).

9

10 *Timed SPOT (Fill-in-the-Blanks) Test*

11 In the timed SPOT test, participants were presented a single sentence with
12 some blanks on the computer screen. They were instructed to fill in the blanks
13 with Japanese characters (*hiragana*) on an answer sheet as quickly as possible.
14 The number of characters to be filled in the sentence was indicated by the
15 number of blank circles in the sentence (see sample items in Appendix S5
16 in the Supporting Information online). A blank was left in each sentence to
17 specifically target one of the linguistic structures. Once participants had filled
18 in the answer on the sheet, they pressed a computer button to move on to
19 the next item. The time limit was accidentally set to 100 seconds, instead of
20 10 seconds (see below).⁹ The stimulus set consisted of 48 target sentences
21 (16 per structure) and 16 filler sentences. The percentage accuracy score was
22 calculated over all items for the target sentences.

23

24 *LLAMA F (Explicit Learning Aptitude)*

25 An adapted version of LLAMA F (Meara, 2005) was administered on the
26 computer to measure explicit learning aptitude. Participants were required to
27 infer the rules of grammar by looking at pictures and word sequences. The word
28 sequences were written in alphabet letters. They were told that the test consisted
29 of a 5-minute learning phase and a test phase. In the learning phase, participants
30 were given 5 minutes to learn a new language by studying sentences matched
31 with pictures. In the testing phase, the program displayed a picture and two
32 sentences, one grammatical and the other ungrammatical, and their task was to
33 choose the grammatical sentence. The test consisted of 30 items.¹⁰ There was
34 no time limit for completing all the items, but participants were not allowed to
35 return to the items they had already answered.

36

37 *Serial RT Task (Implicit Learning Aptitude)*

38 A serial RT task was administered to measure implicit learning aptitude. The
39 probabilistic serial RT task used in the present study was adopted from Kaufman
40 et al. (2010). In this task, participants saw a dot appearing at one of four
41 locations on the computer screen and responded to it as quickly and accurately

3 as possible by pressing the corresponding key. Unbeknownst to participants,
4 the sequence of stimuli was generated by a probabilistic rule: 85% of the
5 sequences followed the rule (probable, training condition), whereas the other
6 15% of the sequences was generated by another rule (improbable, control
7 condition). The probabilistic nature of the serial RT task made it difficult to
8 learn the sequence explicitly (Kaufman et al., 2010). There were eight blocks,
9 and each block consisted of 120 trials, with 960 trials in total. The task was
10 scored by subtracting the mean RTs in the training condition (Sequence A)
11 from those in the control condition (Sequence B), which reflected the amount of
12 learning.

14 *Letter-Span Task (Phonological Short-Term Memory)*

15 The letter-span test from the High-Level Language Aptitude Battery was used
16 to measure phonological short-term memory (Linck et al., 2013). In this task,
17 a list of letters was presented on the screen at 900- millisecond intervals, and
18 participants were asked to recall the letters in order. The length of the list
19 varied from three to nine letters, and for each of the seven lengths, three lists
20 were presented, for a total of 21 lists, in pseudorandom order. The letters were
21 drawn from a set of 12 consonants. Following Linck et al., the score was
22 calculated as the total number of letters recalled in their correct positions re-
23 gardless of the accuracy of the whole letter string. The possible maximum score
24 was 126.

26 **Procedure**

27 Participants were tested individually in a soundproof booth with the nine tests
28 in the fixed order described in Table 3. After the consent form and the back-
29 ground questionnaire had been completed, the linguistic tasks were adminis-
30 tered beginning with the most implicit linguistic tasks and ending with the
31 most explicit ones. Individual difference measures were administered after the
32 linguistic test battery. A 3-minute break was interspersed between the tasks.
33 Participants were also provided with snacks and drinks and allowed to take a
34 break between the tests as needed. The whole session took between 2.5 and
35 3 hours.

37 **Data Analysis**

38 **Real-Time Comprehension Tasks**

39 For all three implicit knowledge tests (i.e., visual-world task, word-monitoring
40 task, self-paced reading task), accuracy on the comprehension questions
41 was computed. Following the standard procedure (e.g., Jiang et al., 2011),

Table 3 Order of tests

Tasks	Targeted constructs	Minutes
1. Consent form & background questionnaire		10
2. Visual-world task	Implicit knowledge	30
Break		3
3. Word-monitoring task	Implicit knowledge	20
4. Self-paced reading task	Implicit knowledge	20
Break		3
5. Timed auditory grammaticality judgment task	Automatized explicit knowledge	10
6. Timed visual grammaticality judgment task	Automatized explicit knowledge	10
7. Fill-in-the-blanks task	Automatized explicit knowledge	10
Break		3
8. Serial reaction time task	Implicit learning aptitude	15
9. Letter-span task	Phonological short-term memory	10
10. LLAMA F	Explicit learning aptitude	10

a participant whose error rate was higher than 25% would be excluded from RT analysis to ensure that each individual was paying attention to meaning. None of the participants scored below 75% for the three tests, thus all participants' eye-movement and RT data were analyzed. Further eye-movement and RT analyses were conducted only over trials in which the comprehension questions were answered correctly. Detailed information about data-cleaning procedures is presented in Appendix S6 in the Supporting Information online.

Timed Form-Focused Tasks

For the timed form-focused tasks (i.e., timed visual grammaticality judgment task, timed auditory grammaticality judgment task, and timed SPOT task), a data screening procedure was conducted. Previous studies, including those by R. Ellis (2005) and Bowles (2011), set the time limit for presenting each sentence based on the native speakers' average response time plus an additional 20%. A more lenient time pressure was imposed for the current tasks—10 seconds across all test items. Instead of imposing a strict timeout for duration of sentence presentation, L2 learners' responses were screened after the data were collected. If the response time was not within a certain time limit based on the native speakers' RTs, those responses were scored as incorrect. An

3 initial review of data revealed that 15–30% of the responses would be dis-
4 carded even for native speakers' responses for the three form-focused tasks if
5 the criterion of the average native speakers' RT plus 20% for each item were
6 imposed. Therefore, it seemed more reasonable to impose time pressure in
7 which most native speakers can perform the task accurately and quickly (An-
8 dringa, 2014). By adopting a range of native speakers' performance values as a
9 criterion, we ensured that timed form-focused task performance would reflect
10 at least partially automated, rather than nonautomatized, explicit knowledge for
11 L2 learners. We thus decided to identify a different percentage value so that
12 90% of the native speakers' responses were scored as correct. In other words,
13 percentages to be added to the native speakers' mean RT were determined such
14 that their mean error rate for the total score was kept to less than 10%. The
15 cutoff percentages that retained 90% of native speakers' data were mean RTs
16 plus 50% for the auditory grammaticality judgment task (37.38% of responses
17 were excluded), mean RTs plus 120% for the visual grammaticality judgment
18 task (52.94% were excluded), and mean RTs plus 50% for the SPOT (67.63%
19 were excluded). These cutoff points were then used to score the responses of
20 L2 learners in the three tests.
21

22 **Data Preparation for SEM Analysis: Missing Data and Data** 23 **Transformation**

24 Descriptive statistics and reliability values for all measures are presented in
25 Table 4 (see Appendix S7 for the native speakers' performance on the language
26 tests). Reliability may seem low for the serial RT task (.52) but is acceptable in
27 light of other studies of implicit learning (Granena, 2013b; Reber, Walkenfeld,
28 & Hernstadt, 1991; Suzuki & DeKeyser, 2015). The internal consistency (e.g.,
29 Cronbach's alpha) was not computed for the visual-world task in the current
30 study because no standard procedure exists for estimating internal consistency
31 in this task. One promising approach is to examine test-retest reliability (Farris-
32 Trimble & McMurray, 2013). The test-retest reliability was not available in this
33 study, and the current attempt to include the visual-world task in the language
34 test battery should be regarded as exploratory.

35 Out of 100 participants, there was one missing case for timed SPOT task and
36 five missing cases for the LLAMA F subtest, due either to experimenter error or
37 the fact that participants did not follow the instructions. These random missing
38 scores were deleted listwise. The total number of remaining participants was 94.
39 Direct maximum likelihood estimation or full information maximum likelihood
40 estimation is usually recommended for treating missing cases (Brown, 2006),
41 but the listwise deletion procedure was chosen because there were only six

Table 4 Descriptive statistics for the language tests

Measure	Targeted construct	k	Possible maximum score	M	SD	Min	Max	Reliability
Eye	IK	100	—	0.01	0.09	-0.26	0.24	—
WM	IK	100	—	22.10	54.47	-110.52	161.66	.91 ^a
SPR	IK	100	—	35.99	90.47	-198.47	351.27	.96 ^a
T-AGJT	AEK	100	100	43.43	12.12	14.58	76.19	.67 ^a
T-VJGT	AEK	100	100	30.64	16.28	2.08	82.74	.85 ^a
T-SPOT	AEK	99	100	27.13	23.37	0.00	91.67	.95 ^a
SRT	Aptitude	100	—	17.36	16.55	-35.00	71.00	.52 ^b
Letter-span	Aptitude	100	126	89.87	14.61	52.00	121.00	.92 ^a
LLAMA F	Aptitude	95	30	23.18	4.19	11.00	30.00	.88 ^a

Note. IK = implicit knowledge; AEK = automatized explicit knowledge; Eye = visual-world task; SPR = self-paced reading task; WM = word-monitoring task; T-AGJT = timed auditory grammaticality judgment task; T-VGJT = timed visual grammaticality judgment task; T-SPOT = timed fill-in-the-blank task. ^aCronbach's alpha; ^bSplit-half reliability, corrected using Spearman-Brown formula.

missing cases, so it allowed for a wider variety of fit indices in the LISREL program.¹¹ Tests of univariate normality were examined for the nine test scores. The total scores of the timed SPOT task were positively skewed; square-root transformation was applied to reduce skewness. The distribution of LLAMA F scores was negatively skewed, so they were transformed to reduce the skewness using inverse transformation. The assumption of univariate normality was met for all the variables ($ps > .05$). Assumption of multivariate normality for all nine variables was also met; Mardia's coefficient was .014 ($p = .99$).

SEM Analysis: Interface Model Versus Noninterface Model

SEM analyses were implemented in LISREL 9.1 (Jöreskog & Sörbom, 2013) using the data from the nine tests. SEM analysis essentially involves four steps: (a) model specification of the original model, which represents the hypothesis based on a theory; (b) specification of rival model(s), which theoretically contradict the original model; (c) data-model fit assessment of models; and (d) comparison of the original and rival model(s) (Hancock & Schoonen, 2015; Kline, 2010).

First, the original model was the interface model (see Panel A in Figure 1). The model consisted of measurement (right) and structural components (left). On the measurement side, three timed form-focused language tests (measured

3 variables) were hypothesized to measure automatized explicit knowledge (a
4 latent factor), whereas the other three online comprehension tests were hypothesized
5 to measure implicit knowledge (another latent factor). The significance
6 of the paths and the magnitudes of loadings from the automatized explicit
7 knowledge and implicit knowledge factors to the language tests indicated the
8 extent to which the two factors were estimated validly. On the structural component
9 side, the relationships between the latent factors (i.e., automatized explicit
10 knowledge and implicit knowledge) and the three aptitude components were
11 examined. The most important path in this model was the one from automatized
12 explicit knowledge to implicit knowledge, which examined whether automatized
13 explicit knowledge significantly influenced implicit knowledge.

14 Second, the noninterface model was constructed as a rival model (see
15 Panel B in Figure 1). In the noninterface model, all the variables and paths
16 were identical to the interface model except for the path from automatized
17 explicit knowledge to implicit knowledge. Third, in order to assess the model
18 fit, a maximum-likelihood method was used to estimate model parameters, and
19 multiple fit indices were jointly used in addition to the chi-square statistics
20 (Brown, 2006). According to the findings of simulation studies conducted by
21 Hu and Bentler (1999), a good fit between the target model and the observed
22 data (maximum likelihood estimation) is obtained in instances where (a) standardized
23 root mean square values are below .09, (b) root mean square error
24 of association values are below .06, and (c) comparative fit index and Bentler-
25 Bonnet nonnormed fit index are above .96. Based on these empirically derived
26 criteria, when the indices in two or three categories out of three meet the
27 criteria above, the model is considered to be a good fit. After assessing the two
28 models individually, the final analysis statistically compared the interface and
29 noninterface models through goodness-of-fit testing indexed by the chi-square
30 statistics (Bryant & Satorra, 2012; Kline, 2010).

31 32 **Results**

33 Table 5 shows the correlation matrix for the linguistic and aptitude test scores
34 for the L2 speakers. Significant moderate relationships were found among the
35 timed form-focused tasks ($.51 < r < .68$), whereas the correlations among
36 the three online tests were weak, and the only significant relationship among
37 the online measures was found between the word-monitoring and the self-paced
38 reading tasks ($r = .26, p < .05$). The correlation coefficients among the three
39 aptitude tests show that no relationship existed between the serial RT score and
40 the LLAMA F score. The letter-span score was weakly related to the serial
41 RT score and the LLAMA F score ($r = .17$ and $r = .21$, respectively). When

Table 5 Intercorrelations between the language and aptitude test scores ($N = 94$)

	1	2	3	4	5	6	7	8	9
	Implicit knowledge			Automatized explicit knowledge			Aptitudes		
1. Eye	—	.11	.12	.17	.20	.23*	.20	-.01	-.09
2. WM		—	.26*	.06	-.09	.05	.07	.05	.10
3. SPR			—	.16	.06	.08	.05	-.01	.06
4. T-AGJT				—	.68**	.51**	.09	-.02	.20
5. T-VGJT					—	.55**	.15	-.10	.19
6. T-SPOT						—	.11	.10	.24*
7. SRT							—	.17	.01
8. L-SPAN								—	.21*
9. LLAMA F									—

Note. Eye = visual-world task; WM = word-monitoring task; SPR = self-paced reading task; T-AGJT = timed auditory grammaticality judgment task; T-VGJT = timed visual grammaticality judgment task; T-SPOT = timed fill-in-the-blank task; L-SPAN = letter-span task. * $p < .05$, ** $p < .01$.

Table 6 Summary of fit indices for structural equation modeling analyses ($N = 94$)

Model	Df	χ^2	NNFI	CFI	SRMR	RMSEA [90% CI]
Interface	20	20.20	.45	1.00	0.06	0.01 [0.0, 0.09]
Noninterface	21	22.18	.39	0.98	0.07	0.02 [0.0, 0.09]

Note. NNFI = Bentler-Bonnet nonnormed fit index; CFI = comparative fit index; SRMR = standardized root mean square; RMSEA = root mean square error of association; CI = confidence interval. The cutoff values for good fit: SRMR < .09; RMSEA < .06; CFI and NNFI > .96.

comparing the aptitude scores with the language tests, the scores on the explicit knowledge tests were weakly correlated with LLAMA F scores ($.19 < r < .24$). The serial RT score was related to the eye-tracking scores more than to the other language tests ($r = .20, p = .05$).

As shown in Table 6, all the fit indices indicated a good fit to the data for both models. However, a scaled chi-square difference test (Bryant & Satorra, 2012) indicated that there was no significant difference between the two models, $\chi_{dif} = 1.30, df = 1, p = .25$. Even though the difference between the two models was not significant, all four fit indices were higher for the interface model than the noninterface model. Estimated parameters of the two models are presented in Figure 3.

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A Interface Model

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B Noninterface Model

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Figure 3 Structural equation models for the interface (A) and noninterface (B) models with parameter estimates ($n = 94$). AEK = Automated Explicit Knowledge, IK = Implicit Knowledge, T-AGJT = Timed Auditory Grammaticality Judgment Task, T-VGJT = Timed Visual Grammaticality Judgment Task, T-SPOT = Timed SPOT, Eye = Visual-World Task, SPR = Self-Paced Reading Task, WM = Word-Monitoring Task. ⁺Standardized coefficient $p < .10$. *Standardized coefficient $p < .05$. **Standardized coefficient $p < .01$.

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In both models, all the factor loadings from automatized explicit knowledge were statistically significant, whereas those from implicit knowledge were not. The factor loadings were consistently high from the automatized explicit knowledge ($.64 < r < .87$), while those from implicit knowledge varied greatly ($.17 < r < .69$). Inspecting the relationships among automatized explicit knowledge, implicit knowledge, and aptitude, the magnitudes of the paths were similar between the two models. The path from LLAMA F (explicit learning aptitude) to automatized explicit knowledge was significant in both the interface model, $r = .27$, $z = 2.09$, $p = .04$, and the noninterface model, $r = .27$, $z = 2.41$, $p = .02$. Critically, despite the fact that no statistical difference was found

3 between the two models, the path from automatized explicit knowledge to implicit
4 knowledge was significant in the interface model, $r = .35$, $z = 2.42$,
5 $p = .02$. None of the other paths were statistically significant in either model
6 ($p > .05$).
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8 **Discussion**

9 This study empirically investigated whether automatized explicit knowledge
10 significantly contributes to the acquisition of implicit knowledge (Question 1).
11 Furthermore, the effects of explicit learning aptitude, implicit learning aptitude,
12 and phonological short-term memory were simultaneously investigated for the
13 acquisition of automatized explicit knowledge and implicit knowledge among
14 late L2 learners (Questions 2–4). Although there was no statistically significant
15 difference between the interface and the noninterface models, the path from
16 automatized explicit knowledge to implicit knowledge was statistically significant
17 only in the interface model. These two pieces of evidence cannot provide
18 the absolute answer to the first research question, but they suggest that automa-
19 tized explicit knowledge does impact implicit knowledge. For the relationship
20 between aptitudes and linguistic knowledge, SEM analyses revealed only one
21 significant path, that is, from explicit learning aptitude to automatized explicit
22 knowledge, $r = .32$, $p = .02$. Explicit learning aptitude was not related to the
23 acquisition of implicit knowledge, and implicit learning aptitude did not seem
24 to have a systematic relationship with either automatized explicit knowledge or
25 implicit knowledge. In sum, the broader picture of the interface model demon-
26 strated the following significant paths: Explicit learning aptitude predicted the
27 acquisition of automatized explicit knowledge, and then automatized explicit
28 knowledge had an impact on the acquisition of implicit knowledge.
29

30 **Interface of Automatized Explicit Knowledge and Implicit Knowledge**

31 This study provides the first empirical evidence for the impact of automatized
32 explicit knowledge on implicit knowledge at the latent construct level. This
33 is consistent with the current view taken by most SLA researchers that ex-
34 plicit knowledge facilitates the development of implicit knowledge (DeKeyser,
35 2015; N. C. Ellis, 2005, 2015; R. Ellis, 2008; Hulstijn, 2002; Paradis, 2009).
36 Automatized explicit knowledge, developed through deliberate practice, is
37 likely to facilitate the acquisition of implicit knowledge in at least two ways
38 (N. C. Ellis, 2005, 2015; Paradis, 2009).¹² First, automatized explicit knowl-
39 edge might allow L2 learners to process language input more efficiently. For
40 example, as learners attend to relevant grammatical features in input, these
41 features might be gradually picked up by the implicit learning system. Second,

1 Suzuki and DeKeyser Interface of Explicit and Implicit Knowledge
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3 automatized explicit knowledge might also allow learners to frequently use rel-
4 evant grammatical structures accurately, which also helps learners accumulate
5 input feeding into implicit learning systems. Because less or nonautomatized
6 explicit knowledge was not measured here, whether less automatized explicit
7 knowledge has a similar impact on the development of implicit knowledge
8 remains an open question. It is speculated, however, that explicit knowledge
9 that is at least partially automatized may be necessary for both comprehen-
10 sion and production because communicative interactions often take place in
11 real time, and more automatized explicit knowledge, which can be deployed
12 quickly, should be more beneficial in attending to the relevant input.
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14 **Effects of Explicit and Implicit Learning Aptitudes**

15 The current findings showed that explicit learning aptitude did not significantly
16 predict learners' performance on measures of implicit knowledge *directly*. The
17 lack of a significant relationship between implicit knowledge and explicit learn-
18 ing aptitude seems to be consistent with the neurolinguistics view on the dis-
19 tinction between explicit and implicit learning systems (Paradis, 2009). Explicit
20 learning aptitude seems to have played facilitative roles in the acquisition of
21 implicit knowledge **indirectly** through the acquisition of automatized explicit
22 knowledge. Specifically, explicit learning aptitude significantly predicted au-
23 tomated explicit knowledge, and then automatized explicit knowledge sig-
24 nificantly predicted implicit knowledge. What is needed for acquiring implicit
25 knowledge appears to be automatized explicit knowledge, the acquisition of
26 which was facilitated by explicit learning aptitude.

27 All L2 participants had received classroom instruction, and about half of
28 them (43 of 100) had majored in Japanese studies in undergraduate programs
29 in China prior to their arrival in Japan. Anecdotally, Japanese language courses
30 in Chinese universities tend to focus on explicit grammar instruction and form-
31 focused practice. Although no information was available as to what kind of
32 classroom instruction each learner received, many of them had likely received
33 some explicit form-focused instruction in earlier stages of L2 learning. We
34 can speculate that these learners had acquired declarative knowledge first and
35 engaged in further conscious, deliberate practice to automate their explicit
36 knowledge, a process facilitated by explicit learning aptitude (DeKeyser, 2015;
37 Lyster & Sato, 2013; McLaughlin, 1987).

38 In contrast, implicit learning aptitude (measured through performance in
39 a serial RT task) made little contribution to the acquisition of either automa-
40 tized explicit knowledge or implicit knowledge. Yet, in the interface model, the
41 coefficient for the path from implicit learning aptitude was larger to implicit

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3 knowledge ($r = .24, p = .10$) than to automatized explicit knowledge ($r = .18,$
4 $p = .24$). Perhaps these late L2 learners had not completely lost the capacity for
5 learning implicitly to acquire some aspects of L2 grammar (Leung & Williams,
6 2012; Williams, 2005). Although adults' implicit learning mechanisms may be
7 diminished to some extent, compared to children's (DeKeyser, 2000; DeKeyser
8 et al., 2010; Janacek, Fiser, & Nemeth, 2012), these mechanisms may still
9 provide a viable learning route at least for some adult L2 learners and for cer-
10 tain structures under specific circumstances. Based on the empirical evidence
11 shown here (i.e., significant effect of explicit aptitude on automatized explicit
12 knowledge), however, we argue that a more dominant learning route is ex-
13 plicit learning, which can help learners proceduralize and automatize linguistic
14 knowledge, ultimately impacting the acquisition of implicit knowledge.

15 Somewhat unexpectedly, the correlation between explicit learning aptitude
16 and implicit knowledge was negative when the path from automatized explicit
17 knowledge to implicit knowledge was presupposed ($r = -.18, p = .11$). Al-
18 though the interpretation of this nonsignificant correlation requires caution, a
19 negative correlation between IQ and learning outcome in an incidental (im-
20 plicit) task of learning artificial grammar was also found by Robinson (2005).
21 In that study, learners with higher IQ were more analytic learners, and they ap-
22 proached the learning task more actively to infer rules. Their performance was
23 inferior to that of less analytic learners because the more analytic learners' em-
24 phasis on problem solving may have failed them in their attempts to understand
25 complex rules of the artificial language. A similar interpretation may apply to
26 the current findings, such that analytic learners' greater aptitude for explicit
27 learning might have interfered with their learning of the complex linguistic
28 systems implicitly in naturalistic acquisition settings. Further research should
29 examine the role of explicit learning aptitude in the development of implicit
30 knowledge.

31

32 **Effects of Phonological Short-Term Memory**

33 This study also investigated the role of phonological short-term memory
34 because this memory component was assumed to underlie the ability for
35 both explicit and implicit learning and was previously found to predict the
36 acquisition of L2 grammar in classroom and laboratory settings (e.g., French
37 & O'Brien, 2008; Martin & N. C. Ellis, 2012; Williams & Lovatt, 2005).
38 The current study, however, showed that the effects of phonological short-term
39 memory were insubstantial in the naturalistic acquisition context ($-.14 < r <$
40 $.01$). This is consistent with and extends the previous finding from short-term
41 study-abroad research, where no relationship was found between phonological

short-term memory and learning gains in morphosyntactic knowledge (Grey et al., 2015).

Furthermore, because this study examined the role of phonological short-term memory in combination with explicit and implicit learning aptitude, it may be the case that higher-order cognitive aptitudes (explicit analytic/inductive and implicit sequence learning abilities) play more important roles in grammar learning, compared to the role played by phonological short-term memory. Nevertheless, previous research has shown that phonological short-term memory, in combination with implicit sequence learning and memory abilities for paired-associate learning, predicted high-level attainment in L2 reading and listening proficiency (Linck et al., 2013). Because Linck et al. did not focus on the acquisition of specific grammatical structures, nor did they include a measure of language-analytic ability, it is yet to be determined whether phonological short-term memory plays a role in L2 grammar learning independently of those other aptitudes. It may be the case that other components of working memory, such as executive function (Engle, 2002), are related to the development of morphosyntactic knowledge (Brooks, Kempe, & Sionov, 2006; Trofimovich, Ammar, & Gatbonton, 2007). To the best of our knowledge, the current study is the first attempt to examine the effect of phonological short-term memory, contrasted with the impact of explicit and implicit learning aptitudes, in developing knowledge of specific L2 grammatical structures.

Limitations and Future Directions

This study marked the first empirical attempt to investigate the interface issue in a naturalistic L2 acquisition setting, and it has opened a number of avenues for future research. First and foremost, the validity of measures targeting implicit knowledge should be examined further. A weak convergence across the three measures of implicit knowledge is a serious limitation. The current findings thus should be interpreted cautiously and regarded as exploratory in nature. One possible reason why the three implicit knowledge tests did not converge to the extent of the tests targeting automatized explicit knowledge may be that implicit knowledge tests utilize fine-grained measures, based on eye-movement and RT data and are therefore more variable than accuracy scores from form-focused tasks (see further discussion of the quality of implicit knowledge measures in Suzuki, 2017). Furthermore, L2 learners' backgrounds (e.g., length of residence and classroom instruction) might also influence the stability of implicit knowledge measures (Suzuki, 2017; Suzuki & DeKeyser, 2015). Critically, if one takes a continuum view from automatized explicit knowledge to implicit knowledge—rather than our view of two distinct systems of (automatized)

3 explicit knowledge and implicit knowledge—then the distinctions made here
4 and the path from automatized explicit knowledge to implicit knowledge may
5 not always be tenable. Because our best attempt was to distinguish automatized
6 explicit knowledge and implicit knowledge from behavioral measures, new
7 insights may be obtained from a different experimental procedure, for exam-
8 ple, using a neurophysiological approach (Morgan-Short, Faretta-Stutenberg,
9 & Bartlett-Hsu, 2015).

10 In addition, an unexpected finding was the significant positive correlation
11 between the visual-world task scores (implicit knowledge) and the timed SPOT
12 test scores (automatized explicit knowledge), which could have been due to
13 the fact that both tests used grammatical stimulus sentences only. All the other
14 tasks (i.e., word-monitoring, self-paced reading, and grammaticality judgment
15 tasks) also involved ungrammatical sentences and required test takers to register
16 grammatical errors (regardless of awareness involved/raised). The processing
17 of grammatical sentences, measured by the visual-world task and the timed
18 SPOT test, may potentially induce cognitive processing that is different from
19 the processing of ungrammatical sentences.

20 Second, the reliability of the visual-world task was not assessed. Farris-
21 Trimble and McMurray (2013) examined test-retest reliability of a visual-world
22 task by requiring participants to complete the task for spoken word recognition
23 twice (Day 1 and Day 2, separated by 1 week). Results showed that eye-
24 movement patterns were closely related between Days 1 and 2, suggesting
25 that the task is stable enough to index an individual's language processing.
26 The present study could not assess the reliability of the task, and it should
27 be examined in future research. Third, the range of target linguistic structures
28 to be tested through implicit knowledge measures should be expanded. Three
29 linguistic structures were tested here, and knowledge of them was successfully
30 assessed via the visual-world task, which requires the most effort to design.
31 It may not be possible to assess all existing grammatical structures using
32 the same task, but a wider variety of target structures should be explored
33 in future studies. This is particularly important for investigating the interface
34 issue because the role of explicit and implicit learning may vary depending on
35 the type of linguistic structure (e.g., DeKeyser, 2012; Granena, 2013b).

36 Fourth, because a single test was used to target each aptitude construct,
37 the effects of aptitudes were tested at the measurement level rather than at
38 the latent level. Further research should avail itself of recent advances in apti-
39 tude research on L2 learning (e.g., Linck et al., 2013), and validation research
40 should be conducted hand in hand for both language and aptitude tests. Fifth,
41 the current study did not include a debriefing session. Some participants might

3 have become aware of the study goals. Future research should examine how
4 L2 learners perform on each of the targeted tests in more depth through mul-
5 tiple measures, such as retrospective verbal reports and think-aloud protocols
6 (e.g., Rebuschat, Hamrick, Riestenberg, Sachs, & Ziegler, 2015). Sixth, the cur-
7 rent study could not examine individual differences in overall L2 proficiency,
8 amount and type of L2 experience in the immersion setting, and amount and
9 type of instruction. They are all potentially relevant factors that may influence
10 explicit and implicit learning processes as well as the relationship between
11 automatized explicit knowledge and implicit knowledge. Systematic investi-
12 gations of individual differences in L2 experience and proficiency may help
13 clarify the interface issue.

14 Finally, the current findings did not indicate a causal relationship among the
15 constructs. Given the nature of cross-sectional research designs, SEM analysis
16 cannot establish causality (Hair, Anderson, Tatham, & Black, 1998). One of the
17 requirements for establishing a causal relationship is time sequence, that is, the
18 cause must be established prior to the effect. Because this cross-sectional study
19 *suggested* causality, it can provide guidance for designing a future longitudinal
20 study. The most logical next step is to conduct longitudinal research in which
21 explicit/implicit knowledge and cognitive aptitudes are measured at earlier
22 stages of L2 learning (e.g., first exposure in immersion settings) to predict the
23 development of linguistic knowledge later on. Based on the current findings, it is
24 hypothesized that explicit learning aptitude, measured at Time 1, would predict
25 the acquisition of automatized explicit knowledge at Time 2, and automatized
26 explicit knowledge would further predict the acquisition of implicit knowledge.

27 **Conclusion**

29 The present study set out to empirically explore the interface issue between ex-
30 plicit and implicit knowledge to better understand explicit and implicit learning
31 systems in adult L2 acquisition. The body of literature on the interface issue
32 suggests a facilitative role of explicit knowledge in the development of im-
33 plicit knowledge, but no empirical investigations had been conducted due to
34 methodological limitations (e.g., lack of valid and finely tuned implicit knowl-
35 edge tests). The present study addressed this gap and provided supporting
36 evidence for the claims regarding the facilitative role of explicit knowledge
37 (e.g., DeKeyser, 2015; N. C. Ellis, 2005; R. Ellis, 2008; Hulstijn, 2002; Krashen,
38 1985; McLaughlin, 1987; Paradis, 2009). These findings thus contribute to the
39 understanding of explicit and implicit learning processes in adult L2 learning:
40 Automatized explicit knowledge, fostered by explicit learning mechanisms,
41 influences the acquisition of implicit knowledge.

3 The current findings, if replicated, would have broad implications for effective
4 L2 instruction and learning. The fact that automatized explicit knowledge
5 was significantly associated with implicit knowledge may underscore the value
6 of explicit learning. Because the participants' experiences varied greatly (e.g.,
7 3 to 84 months of instruction and 24 to 197 months of immersion in the L2),
8 the present findings cannot be used to establish learning processes that apply
9 to all L2 learners. With this caveat in mind, however, we speculate that many
10 participants engaged in explicit learning, that is, deliberate practice for achieving
11 automatized explicit knowledge (DeKeyser, 2015), because all learners had
12 received some form of classroom instruction. According to skill acquisition
13 theory (DeKeyser, 2015; Lyster & Sato, 2013; McLaughlin, 1987), as a first
14 step, acquiring solid declarative knowledge is essential for further systematic
15 practice leading up to proceduralization and partial automatization. Through
16 more extensive practice, full automatization and implicit knowledge can eventually
17 be attainable for some structures.

18 Because full automatization of explicit knowledge and attainment of implicit
19 knowledge require considerable time and effort, realistic goals for L2
20 classroom instruction and learning include the attainment of proceduralization
21 and partial automatization, which build on initial declarative learning. However,
22 the learning processes delineated above may be most efficient for learners with
23 a high level of education and ample experience with formal instruction; aptitude
24 differences among late L2 learners should also be considered (DeKeyser,
25 2015). Indeed, a significant contribution of explicit learning aptitude to the
26 acquisition of automatized explicit knowledge highlights the importance of
27 language-analytic ability. In order to further clarify the learning processes for
28 late L2 learners, future research needs to examine interactions between aptitudes
29 and instruction/learning variables (e.g., DeKeyser, 2012; Morgan-Short,
30 Faretta-Stutenberg, Brill-Schuetz, Carpenter, & Wong, 2014).

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34 Notes

- 35 1 These researchers have often been categorized into weak and strong interface
36 positions. The first position postulates that the role of explicit knowledge is
37 indirect (e.g., N. C. Ellis, 2015), whereas the second position claims explicit
38 knowledge plays a causal role in facilitating the acquisition of implicit knowledge
(e.g., DeKeyser, 2015).
- 39 2 A proponent of the strong interface position, DeKeyser, claims that explicit
40 knowledge does not transform into implicit knowledge. To date, there have been
41 several studies focusing on the strong-interface claim that explicit knowledge can

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- 3 convert into implicit knowledge (e.g., Andringa & Curcic, 2015; Zhang, 2015).
4 However, recent publications by DeKeyser have provided clear evidence against
5 the idea of one knowledge type turning into the other type (DeKeyser, 2015).
6 3 Aptitude tests for explicit learning were also different in the previous studies
7 reviewed here (e.g., MLAT and LLAMA tests), but they all required conscious
8 reflection on formal aspects of (novel) languages.
9 4 Because this procedure was similar to the format of existing tests in the Japanese
10 education system, where it is called the Simple Performance-Oriented Test (SPOT)
11 (Kobayashi, Ford-Niwa, & Yamoto, 1996), this task is called the timed SPOT test
12 here.
13 5 Japanese Language Proficiency Test (JLPT) N1 (which corresponds to the
14 previous JLPT Levels 1) is roughly equivalent to the ACTFL Superior in the Oral
15 Proficiency Interview scale (Kanno, Hasegawa, Ikeda, & Ito, 2005) and
16 corresponds to the C2 level in the Common European Framework of Reference for
17 Languages (Tschirner, Bärenfänger, & Wanner, 2012). JLPT Level 1 is the
18 minimum requirement for acceptance into a regular college undergraduate/
19 graduate program in Japan.
20 6 The cutoff point of 2.5 years indicated by Suzuki and DeKeyser (2015) does not
21 mean that 2.5 years is the definitive threshold. Although we have referred to Suzuki
22 and DeKeyser's findings, the length of residence requirement (i.e., 2 years) was
23 slightly adjusted for this study to allow for data collection within time constraints.
24 7 Although the word-monitoring and self-paced reading tasks use ungrammatical
25 sentences, the registration/detection of errors (Tomlin & Villa, 1994) in the
26 ungrammatical sentence should occur without awareness at the exact time of the
27 error's occurrence. Registered errors may rise to the level of conscious awareness
28 after a task response has been recorded. However, these online tasks might capture
29 sensitivity to errors before detected ungrammaticality triggers explicit knowledge.
30 See Suzuki and DeKeyser (2015) for detailed accounts of registration/detection
31 based on Tomlin & Villa's attention framework; for a similar approach, see other
32 experiments by Granena (2013b), Jiang et al. (2011), Roberts and Liszka (2013),
33 and Leung and Williams (2012).
34 8 Because most L2 research that has used confirmatory factor analysis to analyze
35 grammaticality judgment task performance is based on average accuracy scores
36 (e.g., R. Ellis, 2005; Vafaei et al., 2017), this study followed the same procedure.
37 However, as pointed out by a reviewer, calculating d' would account for response
38 bias and could be exploited in future research.
39 9 Most L2 speakers did not dwell on the items for more than a few seconds (80.6%
40 of the responses were within 10 seconds).
41 10 Ten additional items were added to the original 20 items in order to obtain higher
reliability.
11 The results obtained with direct maximum likelihood estimation did not change
the overall pattern of results.

3 12 Although no researchers have publicly stated that explicit knowledge that has been
 4 automatized should influence implicit knowledge, at least two prominent scholars
 5 (N. C. Ellis and Paradis) seem to agree with the idea that automatized explicit
 6 knowledge may influence the acquisition of implicit knowledge (N. C. Ellis,
 7 personal communication, October 24, 2014; M. Paradis, personal communication,
 8 October 21, 2014).

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13 **Supporting Information**

14 Additional Supporting Information may be found in the online version of this
15 article at the publisher's website:

16
17 **Appendix S1.** Visual-World Task: Classifiers and *Ni/De*.

18 **Appendix S2.** Analyses of the Visual-World Task.

19 **Appendix S3.** Stimulus Sentences for the Word-Monitoring Task.

20 **Appendix S4.** Stimulus Sentences for the Self-Paced Reading Task.

21 **Appendix S5.** Stimulus Sentences for the Timed SPOT Task.

22 **Appendix S6.** Data Cleaning Procedures and Results of Eye-Movement and
23 RT Analyses.

24 **Appendix S7.** Descriptive Statistics for the Language Tests by Native Speakers.

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