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A Cognitive Neuroscientific Approach to Studying the Role of Awareness in L2 Learning

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Schmidt (1990, 1995) proposed a seminal theory of the role of awareness in second language (L2) learning, distinguishing two levels of awareness, noticing, argued to be necessary for L2 learning, and understanding, which was not. This theory has framed subsequent debate on the role of awareness in L2 learning, and the phrase noticing the gap has entered the common lexicon of L2 researchers. However, while Schmidt's distinction suggests hypotheses that are in principle testable, in practice, thorny difficulties have impeded progress. Theoretical difficulties arise in drawing the line between noticing and understanding, and methodological problems relate to the use of verbal protocols as the measure of understanding. Verbal protocols have created difficulties because measuring understanding depends on both how articulate the learner is and what the rater's definition of understanding is. We concur with Truscott and Sharwood Smith (2011) that one cannot non-arbitrarily distinguish between noticing and understanding and suggest that progress can be made by combining both under the heading of awareness. We also suggest that a better approach to measuring awareness is to use the cognitive neurophysiological approach of measuring event-related potentials (ERPs) while learners perform grammaticality judgment tasks (GJTs), together with behavioral measures of GJT sensitivity. If that approach is combined with provision of explicit or implicit feedback on each trial, one can observe differential awareness and differential learning within a single experiment. We briefly review recent studies that have investigated online L2 processing of grammatical violations using ERPs and shown evidence for both conscious and unconscious processing of such violations, as well as ERP studies of learners' online conscious and unconscious processing of their own response errors.

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By using the above methods, we believe it is possible to trace the trajectory of both implicit and explicit learning, to determine the role of awareness in L2 learning. However, based on the available evidence, we conclude that awareness is not necessary but is clearly facilitative of L2 learning.

Introduction

Schmidt's (e.g., Schmidt, 1990, 1995) theory of the role of awareness in second language (L2) learning has raised a number of critically important questions. Until recently, many of these questions have remained unanswered due in large part to limitations in research methodology and instrumentation. This has changed with recent advances in cognitive neuroscience in which neural and behavioral measures are providing an increasingly fine-grained picture of implicit learning processes, allowing researchers to move beyond more traditional research methods. With these changes we believe it is useful to revisit Schmidt's original awareness account and consider its viability in terms of what we are learning about the cognitive neuroscience of L2 learning.

Input is the primary stuff on which language acquisition works. At the heart of SLA theory is understanding the cognitive and linguistic mechanisms responsible for extracting from input that information used in acquisition, namely *intake* (Carroll, 2000). A key element in our understanding of how input gets converted to intake is the role played by *awareness*, or *consciousness*. The two terms are used in different contexts and for different purposes but both refer to the same phenomenon and will be used interchangeably here. A central issue concerns whether it is possible to learn an L2 without awareness. The issue of learning without awareness, or *implicit learning*, has long been debated in cognitive psychology. A key question has been whether abstract principles, such as the sequential regularities embodied in artificial grammars, can be learned implicitly, with research published that both supports (Frensch & Rünger, 2003; Nissen & Bullemer, 1987; Reber & Squire, 1998) and challenges the notion (Perruchet & Vintner, 2002; Shanks, 2003; Wilkinson & Shanks, 2004). The ongoing and vigorous debate in SLA over the possibility of implicit learning and the limits of awareness in learning has been heavily influenced by the seminal work of Schmidt. The broader research question that this chapter addresses concerns the role of conscious awareness, or what Schmidt termed *awareness at the level of understanding*, in learning L2 grammatical structures, and the roles of implicit and explicit error feedback in that process.

Schmidt was one of the first SLA researchers to systematically address the relationship between awareness and L2 learning (Schmidt, 1990, 1995; Schmidt & Frota, 1986). Schmidt proposed two levels of awareness when processing language, according to whether noticing or understanding is involved. Noticing was defined as the "conscious registration of the occurrence of some event," while understanding was the "recognition of a general principle, rule or pattern" (Schmidt, 1995, p. 29). Noticing was posited to be a necessary condition for the conversion of input into intake; that is, learning is not possible without it, while understanding was not. Although both levels were assumed to involve conscious awareness, they differ markedly in how that awareness was conceptualized and how it could be empirically observed. Both will be briefly described here.

Awareness at the level of noticing: The need for focal attention

According to Schmidt, noticing is the *conscious registration* of specific attended features of the target language. What does this conscious registration entail? Williams (2005) invokes Cowan's (1999) model of working memory as a framework for characterizing attention and memory (see also Robinson, 1995). In Cowan's model of working memory, representations are activated by external stimuli or internally generated associations. These activations dissipate quickly unless they receive focal attention, which serves to increase the activation level of a limited number of the representations. The attended-to representations remain active longer, are often of higher quality, and become available to a wider range of information processes than would otherwise be the case. Focal attention processes are partly voluntary but are also controlled by an attentional orienting system that automatically directs attention to unexpected stimuli. Thus the representations can be a novel combination of existing objects or a novel combination of features making up a novel object (Daheane & Naccache, 2001; Williams, 2005). For Cowan (1999, p. 89) focal attention is synonymous with conscious awareness (but see Koch and Tsuchiya, 2007, who have forcefully argued for the logical and empirical independence of consciousness and attention) and necessary for language use.

Focal attention also plays a key role in Schmidt's definition of noticing, which is generally understood as necessary for learning (Schmidt, 1995; Hama & Leow, 2010; Williams, 2005), though recently Schmidt seems to suggest that noticing may be best understood as having a graded, facilitative effect (Schmidt, 2001). The outcome of a single noticing event is an episodic, instance-based representation of a specific form-meaning link. These instances are the basis for the generalizations from which language rules emerge. The way in which these generalizations emerge is beyond the noticing account proper and most likely involves significant implicit learning (Hulstijn, 2005; Schmidt, 1995). It is the process of generalization, of rule-learning in general, that has come to be associated with noticing. The terms *noticing* and *noticing the gap* have entered into common usage by L2 researchers and teachers alike and are used in ways that ignore the original distinction Schmidt made between noticing, on the one hand, and the rule-learning process that can be reflected in metalinguistic awareness in the form of understanding, on the other (Egi, 2004; Izumi & Bigelow, 2000; Leow, 1997; Mackey, 2006; Nicholas, Lightbown, & Spada, 2001; Philp, 2003; Qi & Lapkin, 2001). More broadly, the term *noticing* has taken on the more general meaning of involving some sort of focus on form (Nassaji & Fotos, 2004; Ortega, 2009). Thus, among the wide and varied contributions that Dick Schmidt has made to the SLA and applied linguistics literature, the noticing account is arguably his most lasting legacy, but in a manner that bears only minimal resemblance to the original proposal.

The strong claim that noticing is necessary for learning provides a categorical prediction that is in principle open to disconfirmation. However, to date the noticing construct has resisted empirical validation or even attempts to test it. Studies that have discussed the proposal at length (e.g., Leow, 1997) only address it in theoretical terms. The strong claim about noticing is regarding the conditions needed for learning novel form-function mappings. But this is not a simple issue. As Truscott and Sharwood Smith (2011) note, the most problematic aspect of the noticing account concerns *what* is noticed, namely what constitutes an "event" or, for that matter, "an aspect of the stimuli" (Gass, 1988) or "features" (Robinson, 1995). The upper bound of a noticing event consists of general principles, rules, and patterns—the stuff that Schmidt considers to be the *understanding* that emerges from the noticing process. The lower bound might be simple perceptual recognition processes, for example that what is being heard is a human language, or is spoken by a young female, or that it is Brazilian Portuguese, etc. However, it is clear that Schmidt's concept of noticing means more than just a simple detection of perceptual aspects of the current input. Instead, what is being registered must have something to do with formal linguistic knowledge of the input. This could be, for example, that the perceived utterance is a noun, or a modifier, or a grammatical affix like English -*s* (Schmidt, 1995). Noticing requires the form be processed in such a way that it is consciously registered (i.e., recognized) but without involving recognition of any rules or patterns (which would then be called *understanding*). And this is presumably only in the case of noticing a morphosyntactic form. Learning meaning/semantics is another matter entirely and one that seems to be ignored in the theory of noticing (see Truscott & Sharwood Smith, 2011, pp. 14–15). However, as Truscott and Sharwood Smith (2011) note, it is hard to imagine a case of noticing something morphosyntactic that involves no understanding of the rules or patterns of the language. And we should add that such understanding would relate to both the target L2 as well as the learner's native or other existing languages. Noticing that the perceived object is a noun implies an understanding of *nouniness* and the language structure in which it exists.

Given these issues, it is understandable that researchers interested in the role of awareness in L2 learning have ignored noticing and focused instead on the role of awareness at the level of understanding. But this leaves open the question as to whether the noticing account is testable. Is it possible to operationalize noticing in a way that in principle separates noticing from understanding such that unambiguous evidence for its role in learning can be established? Truscott and Sharwood Smith suggest that it is not, that the distinction between noticing and understanding is "probably impossible to operationalize in any nonarbitrary way" (Truscott & Sharwood Smith, 2011, p. 37). Likewise, as discussed above, setting the lower bound of noticing seems equally arbitrary. For example, Leow (1997) operationally defined noticing as "*some form of subjective awareness* of new targeted linguistic forms in L2 data as revealed in learners' think aloud protocols" [emphasis added] (p. 474). While we laud this attempt at operationally defining this elusive construct, we feel that any such operational definitions necessarily depend on 1) how articulate the learner is, 2) the researcher's interpretation of the learner's verbalization, and 3) where the researcher decides the lower bound is. Thus, operationally defining noticing and distinguishing it from understanding become inherently subjective and noisy.

Awareness at the level of understanding

Awareness in Schmidt's account also plays a role in learning at the metalinguistic level at which the learner consciously recognizes rules or patterns in the input. Awareness at the level of understanding often (but not always) involves explicit learning and thus plays a facilitative but not necessary role in learning. Implicit learning is also assumed to play an important role (Schmidt, 1995, 2001). From the time Schmidt's original proposal appeared, researchers have been interested in showing whether, and to what degree, awareness at the level of understanding is needed in L2 learning. The problem has been approached from two perspectives. Experimental research has sought evidence for the role of understanding using implicit learning designs. In these studies learners are trained on a task involving materials that embody abstract grammatical rules unrelated to the task and then given a posttest to assess if the rules can be used correctly (DeKeyser, 1995; Hama & Leow, 2010; Robinson, 1995; Williams, 2005). Metalinguistic self-report responses are also elicited to assess if the learner was aware of what was learned. Evidence that participants can perform above chance at test, without being able to provide any kind of verbal report as to the nature of the rule or pattern, is taken as evidence that learning without awareness is possible (DeKeyser, 1995; Hama & Leow, 2010; Robinson, 1995; Williams, 2005). For example, Williams (2005) reported a statistically significant learning effect in a posttest for participants who otherwise indicated no awareness of any underlying regularities for modifier-noun combinations in an artificial language learning task. Alternatively, above-chance performance on posttests only by participants who are also able to verbalize to some degree knowledge of an underlying rule or pattern is taken as evidence that learning without understanding is impossible (Hama & Leow, 2010; Leow, 2000). Both approaches rely crucially on verbal self-report. The verbal reports can be obtained *off-line*, elicited as part of the posttest as done by Williams (2005), or they can be collected *online* in the form of verbal reports while the participant is undergoing training, as in Hama and Leow (2010). Verbal self-reports can be informative, but the methodology also has significant limitations as a window on underlying cognitive processes as discussed above.

Interactionist researchers have been interested in understanding as it relates to the recognition, uptake, and integration of recasts in interactional feedback (Gass & Varonis, 1994; Izumi & Bigelow, 2000; Long, Inagaki, & Ortega, 1998; Mackey, 2006; Mackey & Philp, 1998; Nicholas et al., 2001; Philp, 2003). However, as indicated above, some of the latter (e.g., Mackey, 2006; Mackey & Philp, 1998; Philp, 2003) use the term *noticing* for what could also be taken to mean *understanding*. A now substantial research literature has established that recast behavior is pervasive in NS-NNS interactions, but the role of understanding in the uptake of recasts by learners, as well as the effect of recast behavior on learning outcomes, is highly variable (Mackey & Goo, 2007). As is the case for the experimental research, evidence for understanding has come from verbal self-report.

The varying and sometimes conflicting evidence from the experimental and interactionist research as to the role of understanding in L2 rule learning reflects both conceptual and methodological limitations. At a conceptual level is the fact that, as we have discussed above, it is difficult to draw a line between *noticing* and *understanding*. This then leads to methodological complications in separating the two. In particular, verbal self-reports provide only limited evidence of learner sensitivity to grammatical patterns and regularities. Given that even highly trained linguists often cannot agree as to what a correct statement of a grammatical rule is, it seems that reportability of a rule may be a poor measure of understanding by learners. Taken together, these conceptual and methodological limitations lead us to suggest dropping Schmidt's distinction between *noticing* and *understanding*. Given that noticing was defined as "conscious registration of the occurrence of some event" and understanding was defined as the "[conscious] recognition of a general principle, rule or pattern" (Schmidt, 1995, p. 29), if we drop any attempt to distinguish between noticing and understanding, we are left with the role of consciousness, or *awareness* in learning, namely the limits of implicit learning. Truscott and Sharwood Smith (2011) note that the noticing construct has had no counterpart in the implicit learning literature (p. 12), despite attempting to account for the same problem of how abstract knowledge can be acquired without awareness of some kind. The lack of progress to date in providing empirical evidence for noticing may simply reflect the fact that it doesn't exist.

Recent work in experimental cognitive neuroscience has sought to establish if and how awareness contributes to L2 learning outcomes at a neurobehavioral level (Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Tanner, McLaughlin, Herschensohn, & Osterhout, 2012). Evidence from event-related brain potentials (ERPs) is being used to test the claim that L2 grammar learning can take place outside the awareness of the individual, such that it does not rely on verbal self-report (Davidson & Indefrey, 2008; McLaughlin et al., 2010; Tokowicz & MacWhinney, 2005), though as we will see, some sort of overt behavior of the learner is still required to substantiate claims about awareness.

An important element in this research is the systematic manipulation of feedback and the measurement of error processes as a window on the role of awareness in learning.

Roles of implicit and explicit feedback in learning

There is compelling evidence that negative feedback, of both the explicit and implicit types, facilitates L2 grammar learning. Tomasello and Herron (1989) found that negative feedback on elicited L1–L2 transfer errors, using the garden path technique, produced better learning at three retention intervals (from 1 to 17 days) than simply explaining what errors to avoid. Likewise, Carroll, Roberge, and Swain (1992) and Carroll and Swain (1993) found that four different feedback conditions, ranging from implicit (telling learners they were wrong or asking if they were sure) to explicit (with grammatical explanations) all produced superior learning of the dative alternation in English compared to a no-feedback control condition, but that explicit feedback was most effective. Finally, Rosa and Leow (2004) compared the effects of several types of explicit feedback (with grammatical explanations) with the effects of an implicit feedback condition (only reporting if a response was incorrect) and found that all feedback produced better long-term learning of several Spanish "contrary-to-fact" past constructions than simply reading (processing) the sentences without feedback. Again, however, the explicit feedback was most effective in producing learning. The facilitative impact of negative feedback on L2 grammar learning evident in these studies has been more broadly established in meta-analyses that have shown the superiority of providing negative feedback over less explicit (Norris & Ortega, 2000) or no error-focused feedback (Russell & Spada, 2006). Furthermore, the theoretical mechanism of feedback on learning has generally been thought of in terms of comparing the learner's current L2 representations with those in the input, based on the feedback (Carroll & Swain, 1993; Rosa & Leow, 2004; Tomasello & Herron, 1989). Thus, feedback is assumed to help convert input into intake at some level of awareness.

Cognitive neuroscientific evidence for awareness

The relationship between awareness and learning is complex, and evidence for both learner awareness and learning outcomes may be expected to be as well. Likewise, evidence for the effect of the one on the other is sensitive to a range of developmental, linguistic, cognitive, and task factors. As such, the tools used to date provide only a coarse-grained view of the underlying processes. While the use of *online* measures as represented in the concurrent verbal report technique provide the required focus on the underlying cognitive processes, more sophisticated tools are now available that will allow a more rigorous, millisecond-scale investigation of this domain. We will focus here on the use of event-related potentials (ERPs), which are a class of neurophysiological indices that hold significant promise for examining the potential role of awareness in learning. As we will discuss, ERPs can be used to both gauge the degree to which an L2 learner consciously or unconsciously detects a specific grammatical violation in real time (Rossi, Gugler, Friederici, & Hahne, 2006; Tokowicz & MacWhinney, 2005) and the degree to which the learner is aware of having committed an error in real time (Endrass, Reuter, & Kathmann, 2007; Ganushchak & Schiller, 2009; Gehring, Goss, Coles, Meyer, & Donchin, 1993).

ERPs provide online indicators of linguistic processing on a millisecond time scale. ERPs are electroencephalogram (EEG) signals (brain waves) that have been averaged over trials sharing the same experimental conditions and time-locked (i.e., matched) to specific events (e.g., stimulus or response onset). Specific ERPs have been shown to be reliably associated with specific processing functions. Of particular interest here, three ERP waveforms, the LAN, the N400, and the P600, have been shown to be associated with syntactic processing. The LAN is an early left anterior negatively deflected waveform that peaks roughly 300 ms after stimulus presentation, the N400 is a negatively deflected waveform that peaks at roughly 400 ms after stimulus presentation, and the P600 is a positively deflected waveform that peaks roughly 600 ms after stimulus presentation. The LAN appears to be automatic and is associated with detecting morphosyntactic violations (Rossi et al., 2006), though it is not always found, even in native speakers (Tanner et al., 2012). The N400 is also relatively automatic and is generally associated with semantic processing difficulty (Kutas & Hillyard, 1983; West & Holcomb, 2002) but is also associated with morphosyntactic processing difficulty in less linguistically proficient individuals (McLaughlin et al., 2010; Moreno, Rodríguez-Fornells, & Laine, 2008; Tanner et al., 2012). The P600 is more controlled and is associated with syntactic processing difficulty, such as when encountering an ungrammatical constituent in a sentence (Davidson & Indefrey, 2008; McLaughlin et al., 2010; Rossi et al., 2006).

A cross-sectional study by Rossi and colleagues showed that the LAN and P600 indicated developmental changes in L2 learners of German and Italian (Rossi et al., 2006). See Figure 1 for results for German learners. Specifically, when encountering ungrammatical items in a grammaticality judgment task (GJT), low-proficiency L2 learners did not produce the LAN and produced delayed P600s as shown on the right side of the figure, whereas both the high-proficiency learners on the left and native speakers, not shown, produced similar LANs and P600s. These ERP results were also consistent with the grammaticality judgments, which were less accurate for the beginning L2 learners than the advanced learners and native speakers. Thus, ERPs provide an online measure of L2 learners' awareness of grammatical violations prior to making any overt response. In sum, these ERPs are evidence of the purest sort of grammatical competence in the L2 that one can hope to measure, are objectively measurable, and do not require introspection. As a caution, though, it should also be noted that individual differences in L2 ERP performance between L2 learners and relative to the L1 baseline can be considerable (Morgan-Short et al., 2010; Tanner et al., 2012). Specifically, it has been shown repeatedly that L2 learners who are initially learning that an L2 structure is ungrammatical will often show an N400 to it but that with time, as their learning progresses, they switch to showing a P600 (McLaughlin et al., 2010; Tanner et al., 2012). This transition, then, between N400 to P600 to L2 grammatical violations is a measure of learning. But if the ERPs of learners showing N400s are averaged with learners showing P600s, the result will mask both patterns (Tanner et al., 2012). This potential problem requires careful attention when interpreting ERP outcomes.

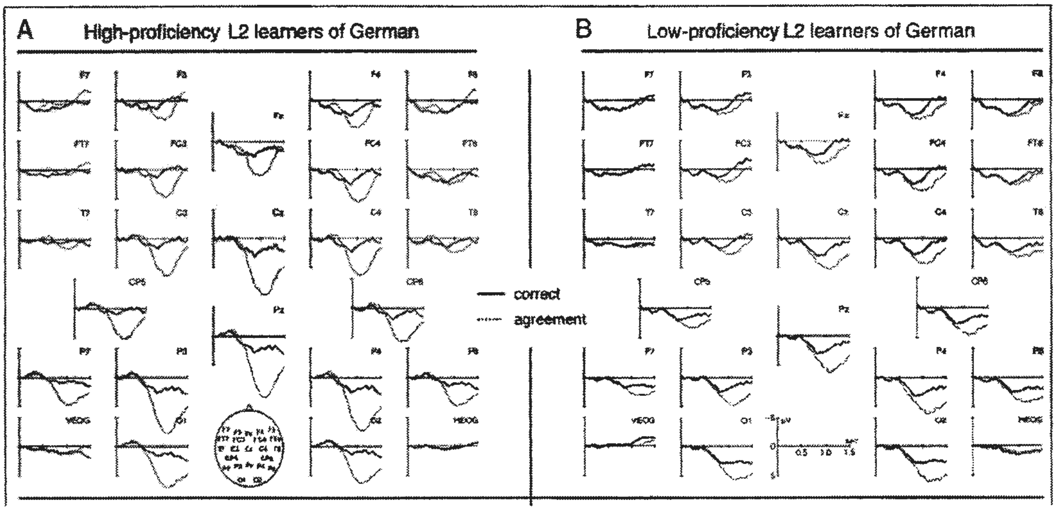


Figure 1. Adapted from Rossi et al. (2006).[1] Grand average ERPs at 25 electrode locations for (A) 16 high-proficiency learners and (B) 19 low-proficiency learners of German in a grammaticality judgment task. ERPs are shown for sentences having incorrect agreement (*agreement*) versus sentences that are correct (*correct*), with waveforms relative to verb onset (0 msec) up to 1500 msec later. The 25 electrode locations include F(frontal), C (central), T (temporal), P (parietal), and O (occipital) locations, each with numbered subscripts. In this figure, negative voltage is plotted upward.

The Rossi et al. (2006) study showed cross-sectionally that ERPs were related to the accuracy results of a GJT. Their findings are consistent with other studies, both cross-sectional (Tanner et al., 2012) and longitudinal (McLaughlin et al., 2010; Morgan-Short et al., 2010; Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006) showing that L2 learners' P600 amplitudes are highly correlated with their GJT sensitivity. This suggests, then, that the P600 may be an online measure of L2 learners' awareness of grammatical violations.

Given the above results, the skeptical reader might ask why one should go to the trouble of measuring ERPs if they tell us little more than the GJT task itself, except perhaps indicating which particular word is ungrammatical (based on the time-locked ERP response to it)? Put another way, it would seem far simpler and cheaper to simply ask L2 learners to, say, circle the ungrammatical words in each test sentence, in addition to making the standard binary grammaticality judgment. However, not all ERP studies of L2 learners carrying out a GJT have shown ERPs to correlate with conscious behavioral measures. Tokowicz and MacWhinney (2005) and McLaughlin, Osterhout, and Kim (2004) both found ERPs showing implicit knowledge of the L2, which the learners were unable to demonstrate explicitly. Specifically, the studies found P600s in response to morphosyntactic violations (Tokowicz & MacWhinney, 2005) or P400s in response to lexical violations (McLaughlin et al., 2004), which were not reflected in sensitivity on a grammaticality judgment task or a word/non-word judgment task respectively. Thus, assuming

1 Rossi, S., Gugler, M. F., Friederici, A. D., & Hahne, A. (2006). The impact of proficiency on syntactic second-language processing of German and Italian: Evidence from event related potentials. *Journal of Cognitive Neuroscience*, *18*, 2030–2048. MIT Press Journals. Reprinted by permission of MIT Press Journals. © 2006 Massachusetts Institute of Technology.

that sensitivity in the GJT and word/non-word tasks reflected learners' conscious awareness, the ERPs indicated implicit knowledge of which learners were unaware.[2]

Therefore, using ERPs together with behavioral responses (such as sensitivity in a GJT) allow us to distinguish four logically possible combinations of L2 grammatical violation processing and awareness, as shown in Table 1. Note that one combination would not plausibly occur: (–) Processing of violation and (+) Awareness—a learner could not plausibly be aware of the violation upon reading it without processing the violation as such. However, the other three logical possibilities are of great interest. As discussed above, there is clear evidence of processing of L2 violations, as shown by ERPs, both with and without awareness, as indicated by L2 judgment task sensitivity or the lack thereof. And, of course, prior to any learning of the L2 structures, there is a lack of either processing of the violation as such and naturally no awareness of it as being a violation. This serves as a critically important baseline condition to compare the other two combinations of interest.

Table 1. Combinations of L2 violation processing and violation awareness, and associated outcomes for ERPs and L2 judgment task sensitivity (with example references)

	(+) awareness of violation	**(–) awareness of violation**
(+) processing of violation	(+) ERPs & (+) L2 JT sensitivity (McLaughlin et al., 2010; Morgan-Short et al., 2010; Rossi et al., 2006; Tanner et al., 2012)	(+) ERPs & (–) L2 JT sensitivity (McLaughlin et al., 2004; Tokowicz & MacWhinney, 2005)
(–) processing of violation	*(–) ERPs & (+) L2 JT sensitivity (*This would not plausibly occur)	(–) ERPs & (–) L2 JT sensitivity (Davidson & Indefrey, 2008; McLaughlin et al., 2004; McLaughlin et al., 2010)

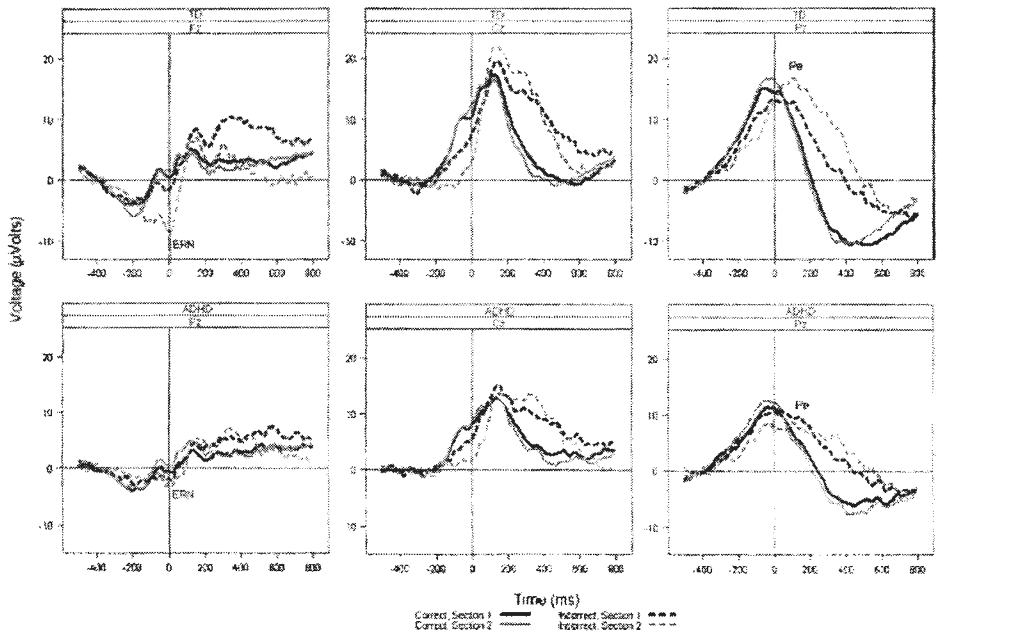
note. (+)=present; (–)=absent; ERPs=event-related potentials to an L2 violation; L2 JT=L2 judgment task (e.g., grammaticality judgment, or word/non-word judgment)

ERPs can also be associated with processing of one's own performance errors in, for example, a GJT (Davidson & Indefrey, 2008). We argue that awareness of one's GJT performance errors should indicate awareness in Schmidt's terms. Specifically, knowing that one's GJT response was an error implies that a) one has a representation of the target language structure in question; b) one has a representation of the structure in the stimulus sentence about which one made a grammaticality judgment, and c) in the case of a "miss" in the grammaticality judgment (i.e., a response of "grammatical" when one should have responded "ungrammatical"), one has consciously detected a difference between the two, just after making a response.

Of particular importance are two well-known ERPs—the error-related negativity (Ne) (Gehring et al., 1993) and the error positivity (Pe) (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). The Ne has been intensively studied over the last two decades and is known to be produced roughly 80–100 ms after an error has been committed, to increase in amplitude as a greater emphasis is put on task accuracy, and to be associated with efforts at error recovery (Gehring et al., 1993). However, more recent research has shown that while many errors are associated with the Ne, only errors for which the subject shows awareness

2 An even stronger argument along these lines would be to aggregate the ERP data not only on whether the L2 structure was grammatical or not, but also based on whether the grammaticality judgment responses were correct or not. If the same native-like P600s were found on ungrammatical sentence trials that were responded to as "ungrammatical" or "grammatical," it would most clearly show the disconnect between implicit processing and awareness (Tanner et al., 2012).

produce the Pe (e.g., Endrass et al., 2007; Nieuwenhuis et al., 2001). In particular, the late Pe, which occurs ~600 ms after the response, is most clearly associated with error awareness (e.g., by making a second response indicating that their first response was an error) and subsequent error compensation (i.e., self-correcting) (Endrass et al., 2007). Thus, the Ne and Pe together allow us to distinguish between unconscious and conscious error processing.



Response-locked ERPs. ERP waveforms time locked to the response (0 ms) are depicted at Fz, Cz and Pz for the informative condition. For both the first and second sections of the task separate waveforms are shown for correct and incorrect responses.

Figure 2. Adapted from Groen et al. (2008).[3] Grand average ERPs, for correct and incorrect responses in a probabilistic learning task, both early in learning (Section 1) and later in learning (Section 2), by typically developing children (TD) and children with unmedicated ADHD. Waveforms are relative to the time of response (0 ms) and range from −400 msec before to 800 msec after. Waveforms are plotted for three electrode locations, Fz (frontal), Cz (central), and Pz (parietal). "ERN" is another name for Ne, and "Pe" is Pe. In this figure, negative voltage is plotted downward.

Other research by Groen and colleagues has compared the roles of individual differences in attentional capabilities and the effects of learning on error awareness as indicated by the Ne and Pe (Groen et al., 2008). Their study compared children with unmedicated ADHD with typically developing children and found that those with unmedicated ADHD showed a trend toward smaller Ne waveforms and significantly smaller Pe waveforms, indicating a clear lack of explicit awareness of their errors (compare the 1st and 2nd rows of Figure 2). Of critical importance for the study of learning, Groen et al. had the children perform a probabilistic learning task

3 Reprinted from *Clinical Neurophysiology, 119*, Groen, Y., Wijers, A. A., Mulder, L. J. M., Waggeveld, B., Minderaa, R. B., & Althaus, M., Error and feedback processing in children with ADHD and children with autistic spectrum disorder: An EEG event-related potential study. Copyright (2008), with permission from Elsevier.

and showed that the typically developing children learned more and showed larger Ne and Pe waveforms, indicating greater awareness of their response errors, as learning progressed. This is shown in Figure 2 by a comparison of the gray broken lines for errors in section 2 with the black broken lines for errors in section 1, particularly in the left column for the Pz electrode location, which is over parietal areas, and is known to produce stronger Pe waveforms (Endrass, Klawohn, Preuss, & Kathmann, 2012; Endrass et al., 2007). Conversely, the children with unmedicated ADHD learned less and showed less development of awareness of when they committed response errors, as shown by the corresponding comparisons in the bottom row of Figure 2.

These results are important for our current discussion for several reasons. First, they show that a person's assumed attentional capabilities are positively correlated with their degree of awareness of their response errors (as indicated by the amplitude of their Pe). Second, such awareness seems to be correlated with how much is learned. Third, at a methodological level, the results provide a neurophysiological correlate of online learning in terms of increasing amplitude of the Pe when errors are made. And, indeed, studies with L2 learners have found large Ne waveforms when making L2 speech errors (Ganushchak & Schiller, 2009) or L2 GJT errors (Davidson & Indefrey, 2008).

In sum, by measuring the above ERPs, we can track L2 learners' moment-by-moment implicit and explicit processing of L2 structural violations (i.e., with and without awareness) and their implicit and explicit processing of their own performance errors (i.e., with and without awareness). In doing so, we can provide a profile of developing L2 structural knowledge and learners' awareness. Specifically, such ERP data indicate whether there is movement of the learners' interlanguage towards the target language, even when the learner is not yet aware of it. Likewise, we can determine whether this movement includes intermediate steps in which the learner's error responses are initially not processed as such, when the learner knows nothing of the structure, but gradually change to being implicitly processed, and then explicitly processed (with awareness).

GJT data is particularly suited to this undertaking. The ability to focus on the processing of target linguistic features while performing a discrete yes/no judgment task provides the degree of task control needed for collecting and interpreting ERP results. Although the sensitivity of binary GJT responses to gradient grammatical rules has been questioned (e.g., Schütze, 1996), the fact remains that most structures lend themselves to categorical judgments as to whether a sentence is grammatical or ungrammatical. Furthermore, recent evidence suggests a close correspondence in performance between binary and gradient grammaticality judgments across sentences that differ in the degree of agreement among native speakers (e.g., Bader & Haussler, 2010). While acknowledging the potential limitations, we also believe the GJT provides an important window on linguistic processing.

Key questions for further research

Recent developments in the cognitive neuroscience of L2 learning offer better methods and evidence for investigating whether awareness is necessary or only facilitative of L2 learning. Such studies provide rigorous, implicit, online, neurophysiological measures of L2 structural processing and learning. Together with standard behavioral measures of sensitivity to such structures and learning, one can address the following research questions:

- Is it possible to learn L2 grammatical structures without awareness?
- Does awareness facilitate learning L2 grammatical structures?
- How does implicit and explicit error feedback influence awareness of L2 grammatical structures and L2 learning?

How do we research awareness? Online processing and post-processing performance

Let us consider the minimal experimental design that one would need to address the research questions above. One would need to examine learning within a short time frame such that one could see the processes of turning input into intake as they unfold in real time. A good way to do this would be to use both behavior in a GJT and one's implicit measures of awareness via ERPs as dependent measures. Such a study would likely use a pretest/posttest design, with experimental treatment in the middle, to measure learning. In order to quickly examine learning, one could provide feedback to the GJT on every trial during the experimental treatment, thus allowing the learner to compare their representations of the target language rules/patterns with those in the input. The feedback could be either explicit or implicit (a la Rosa & Leow, 2004). We would expect that learning would vary as a function of the type of feedback, with explicit feedback producing quicker learning. Ideally, feedback would be given via an automated computer-assisted instruction program (e.g., Rosa & Leow, 2004) in order to ensure that it is given in exactly the same ways to all participants.

A spread of proficiency levels is also important. One would ideally include subjects from three levels: lower L2 proficiency, higher L2 proficiency, and a native speaker control group. Having the two L2 proficiency levels would allow one to see if the effects of the feedback were stronger for one proficiency level than another. However, with sufficient pilot testing, one could eliminate one or the other proficiency level. The native speaker control group would be absolutely necessary, however, to provide baseline data to compare with the L2 learners and would only take the pretest and posttest, or, assuming that performance would be at ceiling, could take the test only once.

The dependent variables would include the accuracy of the grammaticality judgment responses, as well as the reaction times for the responses (because when people are aware they have committed an error, their responses tend to be slower on the following trial than when they are unaware of having committed an error) (Endrass et al., 2007). Importantly, EEG data would be collected throughout the experiment, including the pretest and posttest. One would analyze this data in terms of ERPs that are time-locked to two specific events: 1) the onset of the ungrammatical word in each GJT sentence and 2) the subject's manual response ("grammatical" or "ungrammatical") for that sentence. The logical outcomes for the responses and ERPs to grammatical and ungrammatical stimuli are set out in the tree diagram shown in Figure 3.

Of particular interest would be the ERPs and responses to ungrammatical stimuli (the right half of the tree diagram in Figure 3). For the first event, the onset of the first ungrammatical word, one could determine whether or not the subject shows the LAN, N400, or P600 ERPs, indicating whether the ungrammaticality has been processed and to what level (since N400s indicate shallow processing of an ungrammatical item) (McLaughlin et al., 2010). As discussed in Table 1, at the earliest stage before learning anything about the L2 structure, learners should show no processing of an L2 violation (e.g., no P600) nor any awareness of it as a violation (e.g., no sensitivity in the GJT). Furthermore, after learning, they should show both processing of the violation (e.g., a strong P600) and awareness of it (sensitivity in the GJT). The interesting question is how often one finds cases of implicit, unaware processing of the violation (i.e., a strong P600 but no sensitivity in the GJT). In addition, one can ask whether implicit processing of the violation is optionally an intermediate stage of learning that occurs prior to full awareness. Additionally, we could ask how the provision of implicit versus explicit feedback influences the implicit versus explicit processing of the violations.

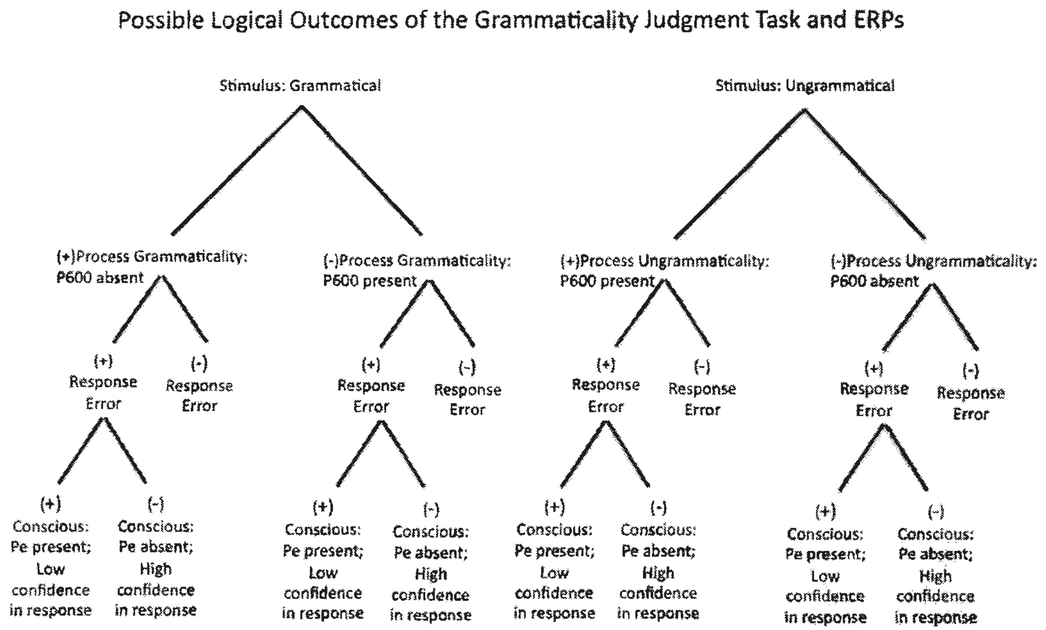


Figure 3. Possible logical outcomes for grammatical and ungrammatical sentences in a grammaticality judgment task. Outcomes include ERPs and overt responses. (+)=present, (–)=absent. P600=the P600 ERP waveform, associated with processing of syntactic violations. Pe=the Pe ERP waveform, associated with consciousness of oneself having committed an error.

For the second event, the subject's overt response ("grammatical" or "ungrammatical"), one could determine whether the subject shows either an Ne or Pe when making a GJT error. To help identify the Pe, we would also have learners rate their confidence in each grammaticality judgment. There are three logical possibilities for what we might observe: 1) neither an Ne nor a Pe, indicating no processing of the error; 2) an Ne but no Pe, indicating implicit processing of the error, without awareness; or 3) both an Ne and a Pe, indicating full awareness of having committed an error. (Note that all of this is prior to receiving feedback on the response.) As with the online ERP responses to the L2 violation discussed above, a key question is whether implicit processing of one's response errors (Ne without Pe) is an optional intermediate stage of learning that occurs prior to full awareness of one's errors (Ne and Pe). Alternatively, the learning progression could bypass the implicit error processing stage. One hypothesis is that when given only implicit error feedback, error processing progresses more slowly and includes the intermediate implicit error processing stage, whereas when given explicit error feedback, learners may jump straight from no processing of their response errors (neither Ne nor Pe) to full awareness of them (showing both an Ne and Pe). Finally, an interesting question is whether those learners who show robust Pe waveforms to their own errors, namely awareness of their errors, learn more quickly and make fewer errors than those learners who show only the Ne, indicating implicit, unaware error processing.

Davidson and Indefrey (2008) embodies key elements of our ideal study, though with some important differences, especially with regard to the feedback condition. In their study they found rapid learning of a target grammatical structure (in L2 German by L1 Dutch speakers). At pretest they showed neither sensitivity in the GJT nor a P600 (or LAN) to the ungrammatical items. However, over the course of the single session experiment, they showed learning (increased sensitivity in the GJT) and the development of a P600 to the ungrammatical items. Thus, learning was shown, and it was associated with conscious processing of the grammatical violations. In addition, they found no Ne or Pe responses to the learners' errors at pretest but strong Ne- and Pe-like waveforms during training, and to a lesser degree, during the posttest a week later. The error-related waveforms were found to be strongest for those who showed the greatest increase in sensitivity in the GJT. Furthermore, this relationship remained after a regression analysis had accounted for learners' L2 proficiency. This result is important because it suggests that increased processing of one's errors was associated with increased learning. However, because it was a correlational finding, we do not know the direction of causation (i.e., whether increased processing of one's errors caused greater learning or whether greater learning caused greater processing of one's errors or if a third factor caused both).

The Davidson and Indefrey (2008) experiment is an excellent example of the type of study we believe is needed to investigate the role of awareness in L2 learning. Nevertheless, there were several aspects of the study that limit the conclusions that can be drawn concerning the nature of the learning outcomes observed. There was no evidence of unconscious learning, since the increases in both the P600 and Ne were associated with increases in GJT sensitivity. As such, the Davidson and Indefrey (2008) study provides evidence of awareness being positively associated with L2 learning but does not rule out the potential role of unconscious learning. Specifically, just because a study shows no evidence of unconscious learning does not prove that unconscious learning is impossible. (Absence of evidence is not evidence of absence.) Indeed, we have already cited ERP evidence of implicit learning—processing of violations without accompanying conscious GJT sensitivity (McLaughlin et al., 2004; Tokowicz & MacWhinney, 2005)—namely, learning without awareness. Furthermore, those studies only add to the available literature showing implicit learning. Schmidt's (1990, 1995) theory posits that understanding is not necessary and admits implicit learning as an example of learning without understanding. However, if we also accept Truscott and Sharwood Smith's (2011) argument that we cannot meaningfully distinguish between noticing and understanding, then we may conclude that awareness is not necessary for L2 learning. This is consistent with the evidence shown by McLaughlin et al. (2004) and Tokowicz and MacWhinney (2005).

Thus, the data from Davidson and Indefrey (2008) can be said to most clearly support the facilitative role of awareness in error processing, particularly as indicated by the fact that the Ne and Pe were strongly positively correlated with increases in GJT sensitivity. However, even here, the data is naggingly equivocal. Specifically, Davidson and Indefrey's (2008) Pe, which is associated with conscious processing of one's errors, was abnormally early, occurring roughly 150 ms after an erroneous response, whereas the Pe usually occurs at roughly 600 ms after the error. Indeed, it is the later Pe that is most closely associated with consciousness (Endrass et al., 2007). The lack of a clear Pe means that learners' error processing waveforms in Davidson and Indefrey's (2008) study cannot be definitively associated with awareness of errors. Interestingly, Ganuschak et al. (2009) also failed to report Pe waveforms in their study of L2 ERPs to speech errors but did report strong Ne waveforms. Whether normal Pe waveforms are found in L2 learners is clearly an issue that begs for careful investigation in further such studies.

As noted earlier, Davidson and Indefrey (2008) did not manipulate the type of feedback (explicit vs. implicit) that was provided. This might have produced differential levels of awareness of both violations and learner response errors, and differential learning outcomes.

The behavioral data thus far suggest that explicit feedback is more effective for learning than implicit feedback (Carroll & Swain, 1993; Rosa & Leow, 2004). This suggests at least a facilitative role for awareness for L2 learning, on the assumption that explicit error negative feedback engages the learner's awareness. Nevertheless, L2 learning studies combining both types of error feedback with ERP recordings are needed to more precisely determine the relationships between a) the two types of feedback, b) learners' conscious error processing (Pe & Ne) and unconscious error processing (Ne without Pe), and c) learners' gains in GJT sensitivity (i.e., turning input into intake).

Finally, future research along the lines suggested here should benefit from doing trial-level analyses of their ERP data using multi-level modeling (Zayas, Greenwald, & Osterhout, 2011). Such analyses would allow one to determine the effects of, say, P600 amplitude on a given trial on subsequent GJT accuracy, or the effect of Pe amplitude on a given trial on trial accuracy on the following trial. In this way we can begin to truly understand the role of awareness on single trials on L2 learning.

Summary and conclusion

We have sketched out a line of research that we believe can answer important questions raised by Schmidt's theory of the role of awareness in L2 learning that have not yet been adequately addressed. Specifically, by measuring changes in L2 learners' ERPs over the course of many trials, both during the processing of target grammatical structures and immediately after making response errors, it is possible to determine the degree to which L2 learning occurs without conscious awareness within the time frame of a single experiment. Similarly, one can also determine the degree to which explicit feedback, conscious awareness of grammaticality, and conscious awareness of one's response errors facilitate L2 learning. Importantly, such questions are now beginning to be addressed using robust physiological measures capable of showing both conscious and unconscious processing of input and one's responses to it (Davidson, 2010).

So where does this leave Schmidt's original formulations? As we note, it is probably impossible to distinguish between noticing and understanding as originally proposed, largely due to difficulties in conceptualizing and operationalizing each relative to the other. Schmidt has previously argued that awareness at the level of noticing is necessary for learning, while awareness at the level of understanding is not, because of the role that implicit (unaware) learning can play in our conscious understanding. However, consistent with more recent discussions by Schmidt (2012), it seems to us that awareness, at whichever level one wants to define it, is best understood as *facilitative* of learning. It seems that the effect of awareness on learning operates more in terms of a continuum (more or less learning) than a dichotomy (no or some learning).

In our discussion of an approach to studying the relationship between awareness and L2 learning, we have deliberately left out specific details such as the target L2, the particular grammatical structures to be tested, etc. Such details are of course critical to the success of any such study. However, our purpose in this paper is to draw attention to what we believe is a useful approach to studying the role of awareness in L2 learning and the logic behind it. Indeed, in the words of Greenwald (2012), "there is nothing so theoretical as a good method." That is, in science it is often the case that long-standing theoretical debates are only settled when an appropriate method is developed to test between competing hypotheses. We believe that the methods discussed here will be able to do just that with regard to the debate on the role of awareness in L2 learning—a debate that Dick Schmidt has played a seminal role in shaping.

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