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ARTICLE

Semantic information boosts the acquisition of a novel grammatical system in different presentation formats

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Abstract
Designing effective language learning settings requires an understanding of the processes taking place in language learning and the way they interact. One important issue concerns the interaction between meaning and grammar. A number of studies have shown a beneficial effect of semantics in grammar learning. What is unclear, however, is how far this effect may be influenced by the presentation formats of the semantic content. In two experiments, participants performed rule search tasks on Latin sentences. In Experiment 1, we presented semantic information in the form of naturalistic photographs, whereas in Experiment 2, the semantic information was implemented by quasi-translations. The control groups did not receive any semantic information. Learning performance was assessed by a grammaticality-judgment task combined with a source-attributions task. In both experiments, participants in the with-semantics group outperformed the respective control groups. Yet, only in Experiment 1, participants report having more explicit than implicit knowledge. We argue that semantic information boosts the acquisition of grammatical structures regardless of the presentation format. Furthermore, we suggest that, consistent with multimedia learning theories, the pictorial presentation format of Experiment 1 helped to use working memory capacity efficiently, which may have led to the generation of more explicit knowledge.

Keywords: grammar; Latin; second language acquisition; semantics

1. Introduction

When learning a language, learners face a multitude of challenges on the way from a firstly receptive role towards being able to use the language actively. They need to segment words out of a stream of sounds, remember in which positions in the sentence a word can occur, and generalise over various exemplars in order to identify

grammatical categories (see, for example, Gómez & Gerken, 2000; Rebuschat et al., 2021). This involves noticing the common features between different elements of the language and keeping track of the statistical contingencies to finally abstract grammatical regularities (Romberg & Saffran, 2010). Thus, the acquisition of the grammatical system is a highly demanding sub-task. For instance, when hearing a sentence like 'Sagana stolidum dilaudat', someone who does not know Latin would need to identify the borders of the single words, try to discover which words are nouns, which one is the verb, and in which number each of them occurs, to be able to learn the grammatical system. Of course, one could not answer these questions based on a single sentence; one would at least need to compare several sentences to each other. Would it not also be helpful in this learning process to know the meaning of the sentence?

In this example, it already becomes clear that, for natural languages, the grammatical system does not occur in isolation but is only one of the interwoven components that determine a language. Semantic content is separate from – yet closely connected to – the grammatical system. In his words-and-rules-theory, Pinker (2011) claimed that irregular verbs are learned like vocabulary, whereas morphologically regular endings are treated as grammatical rules. Although this theory has been questioned, it demonstrates how closely related grammatical phenomena, such as inflectional morphology and the lexical system (which contains word meanings) are in natural languages.

When teaching children or adults a foreign language, the situation differs from a natural language learning situation because the interaction with the language is somewhat controlled, and the aim is for the learners to reach a certain level of proficiency. Such language teaching settings thus provide the advantage that they can be shaped to provide optimal learning conditions, for instance, by designing instruction and learning materials. One important question relates to the interplay of grammar and meaning. Does meaning help in acquiring a novel grammatical system, or should grammar rather be taught in isolation? Both approaches may have certain advantages: it may be beneficial to imitate natural language learning as closely as possible in the teaching setting, and this would suggest integrating meaning and grammar in teaching a language. On the other hand, it might be helpful for learners to reduce the complexity of the learning material by teaching them vocabulary and grammar separately.

There is an ongoing discussion about the interplay of form and meaning in language learning in second language acquisition (SLA) research. The main question of interest is whether, during the acquisition of a novel language, the focus should be on meaning or form(s) (Ellis, 2001). Using the focus-on-meaning approach, the learner is immersed in the language without explicit instruction about the grammatical structure. In this approach, it is expected that the learner acquires the grammatical features incidentally. In contrast, in the focus-on-forms approach, the learner acquires the grammatical structures in relative isolation and with no particular focus on the meaning. A third approach, focus-on-form, mediates between those two approaches, and although its name is similar to the focus-on-forms approach, the suggested procedure is quite different. In the focus-on-form approach, learners are presented with the language in communicative contexts, and – from time to time – grammatical structures are highlighted when they arise (Long, 1991). It has been suggested that, under certain circumstances, meaning-based approaches that also direct attention to form are more promising than exclusive approaches (Lightbown & Spada, 2013;

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Spada, 2014), while others found form(s)-based approaches (regardless of whether meaning is included) to be most beneficial (Norris & Ortega, 2000). However, it has to be noted that focus-on-forms teaching can also include meaning, even if it is not the focus of this approach. Another question of interest in this context concerns the role of attention. It has been shown that learners can acquire sensitivity to the grammatical structures even when their attention is not directed to forms and the corresponding meanings (Leung & Williams, 2012; Marsden et al., 2013), while other studies suggest that directing learners' attention to form-meaning connections is more, or at least as, beneficial (Kasprowicz & Marsden, 2017; Marsden, 2006). In sum, the studies discussed above suggest that the mapping of form and meaning plays an important role in the acquisition of a novel grammar.

In contrast to research in the tradition of SLA – that typically investigates language learning from an applied educational perspective, focusing on the question of how real-life language learning can be improved – studies in artificial grammar learning (AGL) have addressed the question from a perspective that puts a strong focus on the cognitive processes underlying language learning. Several AGL studies have addressed whether meaning promotes the acquisition of grammatical structures by presenting semantic information in different formats and with varying degrees of abstraction. Van den Bos and Poletiek (2015) presented their participants with sentences of an artificial grammar (consisting of letter strings) combined with a semantic reference field. (A semantic reference field in this context can be understood as elements that contain meaning and that learners can refer to when acquiring the grammatical system.) Van den Bos and Poletiek (2015) implemented meaning in their study by presenting pictures of train waggons of different shapes and colors. In the with-semantics condition, participants were asked to decode the connections between the letter strings and the trains (decide which train was described by which letter string). In contrast, in the without-semantics condition, participants were asked to memorise the letter strings. The authors assessed learning performance by presenting participants with a grammaticality judgment task. They found a beneficial effect of semantic information on the acquisition of the grammatical target structures in the one grammar (of two) with lower complexity. Furthermore, the authors aimed to investigate what kind of knowledge the participants had acquired. Thus, they combined the grammaticality judgment task with confidence ratings to measure participants' awareness of the grammatical structures. Interestingly, participants reported mainly conscious knowledge when they were given the sentences together with a semantic reference field. In contrast, in the condition without a semantic reference field, participants' knowledge was mainly unconscious. The authors argued that a semantic reference field may increase the salience of the relevant grammatical structures, as certain structures (trains and chunks of letters) always have to be decoded together, and thereby guide the learners' attention to the relevant aspects of the linguistic input.

Like van den Bos and Poletiek (2015), Franck et al. (2016) also presented their participants with a semantic referent field consisting of abstract geometric shapes. In their study, the objects moved. The authors compared participants' performance in this experimental setup with another condition in which other participants received only phonological or prosodic cues for acquiring long-distance agreement relations but no semantic information. Participants learned the grammatical target structures successfully in all conditions, and the induction of rules to more complex sentences was facilitated in the with semantics conditions as compared to that in which only phonological or prosodic cues had been given. Thus, these studies suggest that

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semantic information, at least when presented in a pictorial format, is beneficial for the acquisition of grammatical structures.

In other studies, participants seemed to benefit from semantic information even when not presented in a pictorial format. For instance, Fedor et al. (2012) presented their participants with artificial sentences containing either actual Hungarian words or non-words. Thus, semantic information was not presented separately in a pictorial format but was inherent in the materials in the with-semantics condition because the meaning of the vocabulary was known to the learners in this condition. The sentences were combined according to centre-embedded recursion rules (according to which one sentence is embedded in another, a phenomenon that also occurs in natural languages) and presented using a 'starting small paradigm' (from simple to more complex sentences). The authors found that learners with natural vocabulary, which also contained semantic relationships between the words, outperformed those with fictive pseudowords.

However, not all studies have found a semantic benefit. Öttl et al. (2017) used naturalistic learning materials, namely fictive characters performing various actions and auditorily presented sentences describing these actions. In the initial phase, participants in the with-semantics condition acquired the vocabulary; this was followed by the grammar learning phase (for both groups). Öttl et al. (2017) conducted two consecutive experiments in which they varied the salience of the semantic reference field during the learning phase. In Experiment 2, they kept the language exposure of both experimental groups constant to rule out a possible familiarity effect. However, a beneficial effect of semantic information was observed in neither experiment. Based on previous studies that did not control language exposure but did find a semantic benefit effect, Öttl et al. (2017) proposed familiarity with the language material as a possible alternative explanation.

Another question that should be addressed is whether the staged procedure implemented by previous studies (consecutive learning of vocabulary and syntax) is necessary to allow learners to acquire a novel grammatical system. It might also be insightful to not artificially reduce complexity, as this may be a factor that facilitates learning by providing useful hints for the learner (Öttl et al., 2017) and gives them the opportunity to carry out their own learning strategies with respect to their individual preferences and requirements. Learners typically acquire vocabulary and syntax first (Rebuschat et al., 2021), but this does not mean they ignore other features, like inflectional morphology. As meaning and grammar are closely connected, it might unnecessarily interrupt the natural learning process if their acquisition is separated into two different tasks. This may be especially so if morpho-syntax is investigated, as in the present study, rather than syntax, like in previous studies. Van den Bos et al. (2012) showed that adding a semantic reference field boosts the learning of probabilistic non-adjacent dependencies, which can be compared with the learning of morpho-syntax in natural languages. The authors used no staged paradigm but presented the learners with visually enhanced material over the exposure phase. In contrast, Fedor et al. (2012) used a staged paradigm but still found a semantic benefit. However, as the present study aims to bridge a gap between artificial and natural language learning research, we decided to use an immersion rather than a staged paradigm.

Taken together, evidence from SLA and AGL research suggests that learners of a novel grammatical system benefit from knowing the semantic content of a sentence. However, language familiarity may have been a moderating factor in some studies.

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We address this in the present study, which we locate between AGL and SLA research. We sought to investigate a question that is relevant for real-life teaching settings using the natural language Latin but aimed at doing so using a highly controlled laboratory paradigm inspired by AGL tasks. The paradigm we used aims to produce a language learning situation that imitates natural language immersion while allowing us to control certain language features (as with artificial languages).

Using artificial learning materials has some crucial advantages. In AGL, several factors relevant to language learning, such as word frequency or length, can be controlled. Furthermore, previous language exposure and possible incidental learning can be ruled out. Another advantage is that the experimental materials can be designed in a way that is precisely tailored to the requirements of the research question. Therefore, it is possible to present the grammatical structures of interest with a higher frequency than they would occur in natural language learning. At the same time, however, this may lead to an exaggeration of these structures, which may, in turn, trigger different processes than those involved in natural language learning. This constitutes a disadvantage of using artificial languages to study language learning. It has been pointed out that data from AGL studies may be more comparable to natural language learning data if the artificial grammar imitates natural language grammar more closely (e.g. de Vries et al., 2012). These studies point to the possibility that some findings of AGL studies may not be as informative concerning natural language learning as initially thought. It may be that the results of these studies cannot be applied to natural language learning on a one-to-one basis. For these reasons, we chose Latin as the experimental language in our study, as it perfectly combines the advantages of artificial and natural languages. It is a natural language (and thus sure to possess a valid and learnable grammatical system) but is no longer spoken. Therefore, previous incidental learning does not pose a problem, although caution about possible familiarity with other Romance languages is required. As Latin is taught in many grammar schools in Germany, we ensured that learners had no previous knowledge of Latin in our experiment. Furthermore, Latin is a language rich in morphological variation, and it thus provides an ideal methodological paradigm to teach learners certain grammatical phenomena in relative isolation without the need for any previous language exposure.

In addition to these methodological considerations that make Latin an ideal language for studying language learning in the laboratory, we feel there are other advantages to investigating language learning with Latin. To date, most language learning studies using natural languages have addressed modern or artificial languages. Evidence is lacking for the teaching of ancient languages, namely Greek and Latin. They provide a basis for many modern European languages and open the door to a deeper understanding of European history and culture. They are, therefore, of general educational interest. We thus consider it important to add studies examining the acquisition of Latin to the literature on language learning. To our knowledge, only a few language learning studies have used Latin as the experimental language (Cintrón-Valentín & Ellis, 2015; Sanz et al., 2009; Stafford et al., 2012).

In the present study, we hypothesise that semantic information facilitates the acquisition of a novel grammar. By presenting learners of both experimental groups with the same amount of input material, we aimed to keep language familiarity constant, an issue raised in previous studies (Öttl et al., 2017). Furthermore, by this approach, we attempted to imitate a natural language learning situation in which learners experience immersion into the language without previous vocabulary training.

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2. Experiment 1

In this experiment, we aimed to investigate the hypothesis that semantic information facilitates the acquisition of a novel grammatical system, in this case, Latin morpho-syntax (subject and object endings).

2.1. Methods

2.1.1. Participants

Eighty-two participants took part in the experiment in exchange for financial reimbursement or course credit. They were native speakers of German. Contrary to the exclusion criteria, six participants indicated at the end of the experiment that they had prior knowledge of one of the following languages: Latin, Italian, Spanish, or Portuguese. We excluded two of these six participants (one each in each experimental condition) with knowledge of Latin from the analyses. Speakers of the other Romance languages were retained because we wanted to be parsimonious with exclusions and because it is unclear whether the knowledge of those languages results in an advantage (or even a disadvantage, by interfering with the Latin sentences). Thus, 80 participants were included in the analyses (age: M = 23.2, range 19–40 years, 57 female).

2.1.2. Stimulus material

We used simple Latin sentences consisting of subject, object, and predicate as stimulus material. Participants learned the composition of singular and plural subjects, objects and predicates. Latin possesses a case marking system by which the endings of the words are marked according to the cases, singular and plural and various tenses (Table 1). In the present study, we used only present tense sentences. The words from which the sentences were composed were chosen from a set of four different trisyllabic nouns and four verbs (also trisyllabic in the inflected form). Examples of the nouns and verbs are shown in Table 2.

The nouns were presented in subject and object functions. The subjects were presented in plural, whereas the objects occurred only in singular, to reduce the morphological richness naturally existing in Latin and to give participants a better chance of acquiring the congruency between subject and predicate endings. Co-occurrence of words, singular/plural and word position (subject-object-verb/object-subject-verb) were counterbalanced across the sentences, resulting in 192 sentences (see Table 3 for examples of possible sentences).

Of these sentences, 176 were used in the learning phase of the experiment. The remaining 16 were used in the testing phase, along with another 16 ungrammatical sentences. These ungrammatical items each contained one violation of a grammatical

Table 1. Endings of the Latin nouns and verbs. Two nouns were feminine and from the a-declination and two were masculine and from the o-declination. The verbs belonged to the a- and e- conjugation, respectively (Table 2)

	Nouns subject		Nouns object		
	Feminine	Masculine	Feminine	Masculine	Verbs
Singular	-a	-us	-am	-um	-t
Plural	-ae	-i	-	-	-nt

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Table 2. Examples of nouns and verbs from every declination and conjugation used in the experiment. Nouns are shown in nominative form, verbs in infinitive form

Nouns				Verbs		
Latin	Meaning	Gender	Declination	Latin	Meaning	Conjugation
Sagana	witch	feminine	a	dilaudare	to praise	a
Colona	farmer	feminine	a	adlevare	to comfort	a
coquus	cook	masculine	o	perterrere	to scare	e
stolidus	clown	masculine	o	inridere	to laugh at	e

Table 3. Examples of Latin sentences. Endings are printed in bold for clarification. In the experiment, the endings were not bold

Word Order	Gender (subj)	Number (subj)	Gender (obj)	Example
SOV	feminine	Singular	masculine	Sagan**a** coqu**um** inride**t**.
OSV	feminine	Plural	masculine	Stolid**um** colon**ae** perterren**t**.
SOV	masculine	Singular	feminine	Coqu**us** colon**am** dilaud**at**.
OSV	masculine	Plural	feminine	Sagan**am** stolid**i** adlevan**t**.

Table 4. Types of violations in the ungrammatical sentences of the grammaticality judgment task. The violations are printed in bold. Correct forms of, for instance, sentence 1 would be: 'Coquus stolidum inridet' or 'Coqui stolidum inridentt'

Description	Type of violation	Example
subject singular, verb plural	Subject-verb congruency	Coqu**us** stolidum inride**nt**.
subject plural, verb singular	Subject-verb congruency	Sagan**ae** colonam dilaud**at**.
two subjects	Each synatic function once	Stolid**us** colona perterret.
two objects	Each synatic function once	Sagan**am** coqu**um** adlevant.

rule. Four sentences were constructed for each of four violation types: two forms of subject-predicate congruency violation (subject singular, verb plural or subject plural, verb singular) and two forms of grammatical role violation (two subjects, no object or two objects, no subject). Examples are presented in Table 4. Across all testing sentences, all words were presented with the same frequencies and equally often in subject and object function.

The meaning of the sentences was implemented by naturalistic photographs. Four men and four women were dressed as the respective characters, which resulted in two persons each portraying one character. We also varied how the different actions were portrayed (e.g. regarding the costumes) and the positions of agent and patient in the picture to imitate natural variation with different exemplars of a category (Figure 1).

2.1.3. Conditions

Half of the participants were randomly assigned to the experimental condition (with semantics) and half to the control condition (without semantics). We presented participants of both groups with Latin sentences in written format. Participants in the with-semantics condition additionally saw pictures depicting the meaning of the sentences.

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Figure 1. Example of the photographs presented. The matching Latin sentence in this case is 'Stolidi saganam derident' ('The clowns laugh at the witch').

2.1.4. Experimental setup and apparatus

The sentences appeared in black characters on a grey background. The sentences were presented in the middle of the screen in the control condition. In contrast, in the experimental condition, the pictures appeared centrally, with the sentences slightly above them (to ensure participants paid attention to the pictures). In the testing phase, participants responded to grammatical sentences by pressing the 'k'-key ('korrekt' ['correct']) and to ungrammatical sentences by pressing the 'f'-key ('falsch' ['incorrect']). The experiment was implemented with e-prime (Version 2.0) on Lenovo ThinkPad notebooks.

2.1.5. Procedure

The experiment consisted of a learning phase and a testing phase. The total duration of the experiment was about 50 minutes.

Learning Phase. In the learning phase, participants performed a rule-search task. They were instructed to read the sentences carefully and to try to identify the rules for constructing them. They received no further information about the type of the rules they were searching for. In the with-semantics condition, participants were also told that the pictures depicted the meaning of the sentences. The sentences were presented in the learning phase for eight seconds each. The learner could not interrupt the presentation. The sentences were presented in eight blocks with 22 trials each. After each block, participants could take a self-paced break. After approximately every 10th trial on average, participants were instructed to indicate whether a certain word had been part of the previous sentence to maintain their attention. The target words varied with respect to the position in which they occurred in the sentence, the word class, and whether they occurred in exactly the same morphological form. In every block, between one and three questions were asked. The word had actually occurred in the previous sentence in half the cases.

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Testing Phase. After the learning phase, participants completed a grammaticality judgment task. They were asked to decide whether a sentence was correct or false according to the previously learned rules. They responded to 16 grammatical[1] and 16 ungrammatical sentences. In order to gain more insight into the kind of knowledge that participants had acquired, we asked them to indicate the source of their knowledge after each trial. Brief explanations of the respective categories (guess, intuition, recollection, rule knowledge) had been given to them in the main introduction to the experiment. In addition, participants were asked to indicate how much they had enjoyed participating in the experiment and how much effort they had made. Both variables were assessed by means of a 5-point Likert scale.

2.2. Results

Data analysis was carried out with RStudio (Version 0.98.1062).

In the grammaticality judgment task, the percentage of correct answers served as a measure of learning performance. For the source attribution task, we calculated the percentage of answers in each category in comparison to the absolute number of answers.

2.2.1. Grammaticality judgment task

Mean learning performance in the two groups of participants is depicted in Figure 2. As a measure of absolute learning performance, we calculated one-sided *t*-tests comparing the learning scores to the 50% chance level. Both groups acquired some sensitivity to the novel grammar. The frequency of correct answers was above the 50% chance level in both the without semantics condition ($t(39) = 3.17$, $p = 0.001$) and the with-semantics-condition ($t(39) = 6.38$, $p < 0.001$). To compare the two conditions, we calculated a binomial logistic regression. We observed a significant difference in

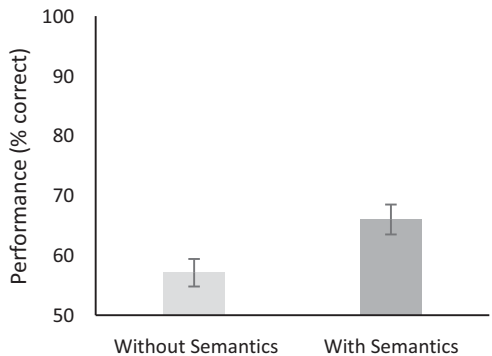

Figure 2. Learning performance in Experiment 1. Mean performance represents the percentage of correct answers. Error bars represent standard deviations.

[1]For the first 40 participants, two sentences had to be excluded from the analyses because one had accidentally already been shown in the learning phase, and one contained a typing error.

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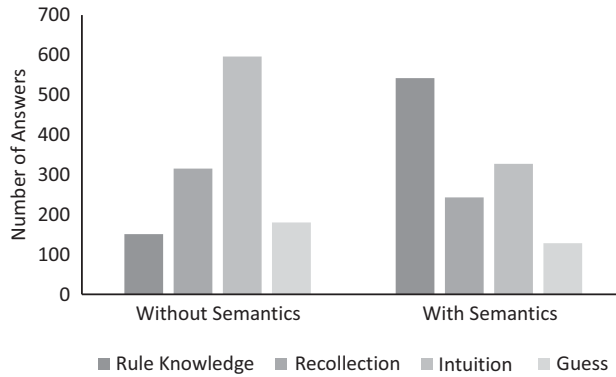

Figure 3. Source attributions as indicated by learners after each grammaticality judgment trial in total numbers per category.

learning performance, with better learning in the with-semantics than in the without-semantics condition $z = 4.500$, $p < 0.001$, OR = 1.452 (95% CI: 1.235, 1.709).

2.2.2. Source attributions

After each trial, participants indicated the basis of their decision (rule knowledge, recollection, intuition, and guess). We compared the distribution of answers in each category using a χ^2-test of statistical independence. The results showed that the distributions of answers in the with-semantics and without-semantics groups were statistically dependent ($\chi^2(3) = 317.07$, $p < 0.001$). Participants in the with-semantics group reported more cases of rule knowledge, whereas participants in the without-semantics group relied more on intuition (see Figure 3 for the number of answers in each condition).

However, the numbers reported in each category do not necessarily indicate whether participants acquired explicit knowledge. Therefore, the accuracies in the respective categories were analysed. As suggested by Dienes and Scott (2005), we assumed explicit knowledge when participants reported 'rule knowledge' or 'recollection' and implicit knowledge when participants reported 'intuition' or 'guess'. The respective two categories were analysed together using logistic regression. Results suggest a higher accuracy in the explicit categories than the implicit ones, $z = 5.503$, $p < 0.001$, OR = 1.580 (95% CI: 1.343, 1.860). Therefore, it can be concluded that learners in the with-semantics condition reported more explicit knowledge that their answers in these categories were more accurate.

2.2.3. Fun and effort

In order to assess other factors that might have influenced the learning process, we asked participants to indicate how much fun they had experienced and how much effort they had made when completing the tasks. We assessed each of these measures on a 5-point Likert scale. (The values were not recorded for one participant due to a technical problem.) Because of the unequal group sizes, we used a Welch test, taking into account possible unequal variances. There were no significant differences between the two groups concerning effort ($t(77) = 0.22$, $p = 0.826$). There was a

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Table 5. Mean fun and effort scores in Experiment 1, separate for the with- and without-semantics condition

	Without semantics	With semantics
Effort	3.58 ± 0.81	3.62 ± 0.81
Fun	2.63 ± 1.10	3.10 ± 1.12

tendency towards participants in the with-semantics group reporting more fun than those in the without-semantics group, but this difference was not statistically significant ($t(77) = 1.91$, $p = 0.060$). The results are shown in Table 5.

2.3. Discussion

In this experiment, we investigated whether semantic information benefits the acquisition of a novel grammatical system, in this case Latin morpho-syntax. We implemented the semantic information using photographs depicting scenes involving two or three characters. The results suggest that semantic information facilitated the acquisition of the novel grammar. Participants in both the experimental and control conditions developed some sensitivity to the grammatical rules, but participants in the with-semantics condition outperformed those who had not seen pictures. Analyses of the reported source attributions revealed that participants in the with-semantics condition reported more rule knowledge. In contrast, those in the without-semantics group based a large proportion of their answers on intuition. Having semantic information available during the learning phase thus seems to foster the acquisition of more explicit knowledge. Participants in the with-semantics group tended to enjoy the experiment more than participants who did not have semantic information available. Therefore, it is unclear whether performance differences between the two groups might be partly due to differences in fun. Furthermore, the question arises of what role the pictorial format of the semantic information played in the success of the with-semantics group. It is conceivable that it was not the semantic content that led to their higher performance but rather the pictorial presentation format. The additional presentation of the pictures may lead to a multimedia effect when information is presented in different formats, in this case, verbal and pictorial. According to Paivio's (1990) dual coding theory, incoming information is stored in a verbal and pictorial format. As both formats are available during information retrieval, this dual coding is expected to increase memory performance. A second approach that might explain an increased performance when pictorial information is also available is Baddeley and Hitch's (1994) working memory model. According to this model, working memory comprises different elements that fulfil distinct tasks, including the visuo-spatial sketchpad and the phonological loop. Using different elements should lead to an increased memory performance, as there is no overload of only one element. In our experiment, it might well be that using a combination of visual and verbal information led to an unloading of the phonological loop, which could free up cognitive resources to identify explicit grammatical rules. Mayer (2005) proposed that learning with information in multiple formats is an active process that requires tasks like selecting the relevant information and integrating the single elements into a consistent representation. These tasks may well prove advantageous for the learning process. Selecting

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information from different sources and integrating it into one mental representation is assumed to result in a more easily retrieved representation (Scheiter et al., 2017). In addition, according to the cognitive theory of multimedia learning (Mayer, 2005), combining different presentation formats can help to use working memory capacity more efficiently to build meaningful associations. Thus, it does not seem implausible that learning processes in the with-semantics group were partly due to information being presented in different formats.

For these reasons, we conducted a second experiment in which we changed the presentation format. Instead of pictures, we presented participants with translations of the single elements of the sentences in a propositional-like format. Thus, we presented participants with the meaning of the subject character, the object character, and the action performed by them. If the semantic benefit observed in the previous experiment reflected a multimedia effect, then we should not see a semantic benefit in Experiment 2. If, however, the benefit in the with-semantics group was indeed due to having available semantic information, then we should see a similar benefit in Experiment 2.

3. Experiment 2

3.1. Methods

As in Experiment 1, the aim of Experiment 2 was to investigate the hypothesis that semantic information facilitates the acquisition of a novel grammatical system, in this case Latin morpho-syntax (subject and object endings). In this study, we tested whether the effect in Experiment 1 was due to the semantic content itself rather than the pictorial nature of the semantic information.

3.1.1. Participants

To ensure we met our target of 80 participants (age: $M = 23.95$, range = 19–63, gender: 57 female), we tested 85 participants. We excluded three from the analyses because of technical problems, one because his native language was not German, and one because he had already participated in Experiment 1.

3.1.2. Stimulus material

The Latin sentences we used were identical to those in Experiment 1. However, the with-semantics group was not presented with pictures to provide them with the meaning of the sentences (as in Experiment 1), but with sentence meaning in a propositional-like format (relation, agent, patient). For instance, for the sentence, 'The witches comfort the clown', the with-semantics group was presented with the following information: 'relation: to comfort, agent: witches, patient: clown'. This served two purposes: first, we imitated the with-semantics condition of the previous experiment without using a pictorial format, and second, we aimed at an experimental setting that provided semantics information in a less fun and motivating way than in Experiment 1. It should be noted that in the with-semantics condition of this experiment, participants had information available about the agent, patient, and the relation (as in Experiment 1) but did not see the exact wording of the sentences. Exact wording would have provided further information (e.g. information concerning the active or passive voice of the sentences).

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3.1.3. Procedure

The procedure was the same as in Experiment 1.

3.2. Results

3.2.1. Grammaticality judgment task

Mean learning performance in the two groups of participants is depicted in Figure 4. As in Experiment 1, both groups showed some sensitivity to the novel grammar (without-semantics condition: $t(39) = 4.53$, $p < 0.001$; with-semantics condition: $t(39) = 6.34$, $p < 0.001$). In addition, the with-semantics group again outperformed the without-semantics group: $z = 3.823$, $p < 0.001$, OR = 1.372 (95% CI: 1.167, 1.613).

3.2.2. Source attributions

As in Experiment 1, we asked participants to report the basis of their decision after each trial. We compared the distributions of answers in each category using a χ^2-test of statistical independence. The results showed that the distributions of answers in the with-semantics and without-semantics conditions were statistically independent ($\chi^2(3) = 6.12$, $p = 0.106$), indicating that differences in the distributions are due to random variation (see Figure 5).

As in Experiment 1, we used binomial logistic regression to analyse the accuracy rates in the implicit and explicit categories. Results suggest a higher accuracy for answers in the explicit than implicit source categories: $z = 4.902$, $p < 0.001$, OR = 1.500 (95% CI: 1.276, 1.765). Therefore, learners in the with-semantics condition showed higher accuracies, and the accuracies were higher for the explicit sources. However, as learners in the with-semantics condition did not report more cases of explicit knowledge, it cannot be said that they acquired more explicit knowledge than the without-semantics group.

3.2.3. Fun and effort

We assessed the participants' fun and effort while completing the task. Two-tailed *t*-test showed no significant differences between the two groups regarding effort

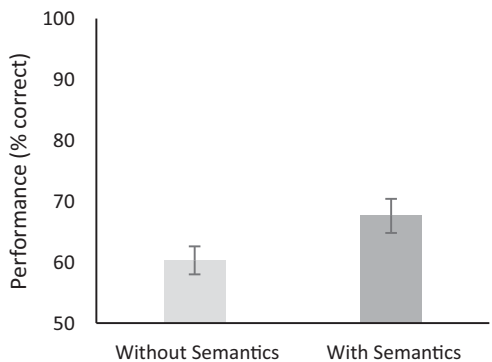

Figure 4. Learning performance in Experiment 2. Mean performance represents the percentage of correct answers. Error bars represent standard deviations.

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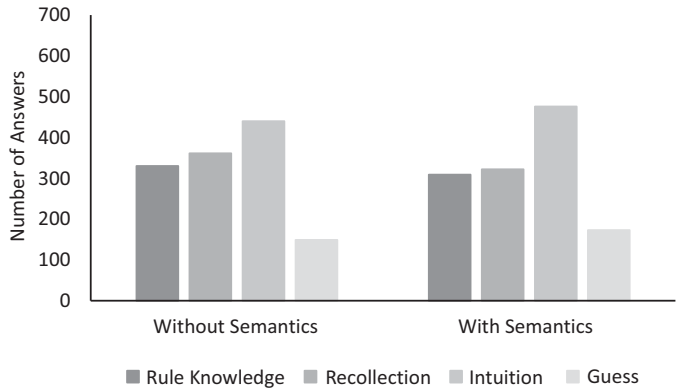

Figure 5. Source attributions as indicated by learners after each grammaticality judgment trial, in total numbers per category.

($t(78) = 0.94$, $p = 0.349$) or fun ($t(78) = 1.22$, $p = 0.225$). The results are shown in Table 6.

3.2.4. Between experiment comparison

To compare the participants' learning performance in the two experiments, we calculated a logistic regression with the factors 'experiment' and 'with/without semantics'. The means and standard deviations can be seen in Table 7.

The results showed a significant effect for 'with/without semantics', $z = 4.500$, $p < 0.001$, OR = 1.452 (95% CI: 1.235, 1.709), and no effect for 'Experiment', $z = 1.605$, $p = 0.109$, OR = 1.139 (95% CI: 0.972, 1.335). Furthermore, there was no significant interaction between the two factors, $z = -0.489$, $p = 0.625$, OR = 0.944 (95% CI: 0.751, 1.188).

Combining both experiments, it can be seen that the frequencies of participants that could classify a very high percentage correctly varied between the with-semantics and the without-semantics conditions (Figure 6).

Table 6. Mean fun and effort scores in Experiment 2, separate for the with- and without-semantics condition

	Without semantics	With semantics
Effort	3.70 ± 0.69	3.85 ± 0.74
Fun	2.90 ± 1.06	3.20 ± 1.14

Table 7. Overview over the mean performances (percentage of correct answers) and standard deviations separately for both experiments and experimental groups

	Experiment 1 (photos)	Experiment 2 (relations)
With semantics	66.01 ± 2.51	67.58 ± 2.77
Without semantics	57.15 ± 2.26	60.31 ± 2.27

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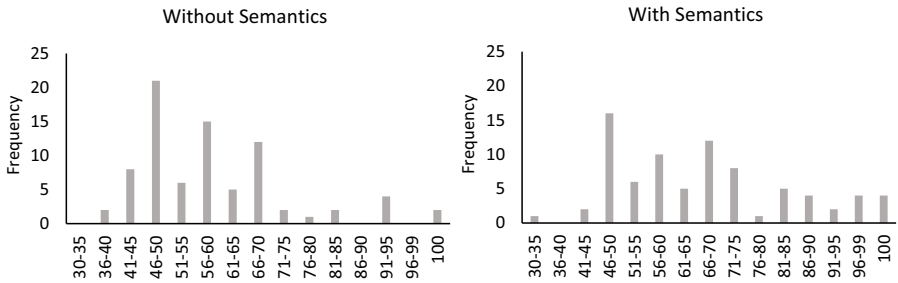

Figure 6. Accuracy distributions across both experiments, separately for with- and without-semantics conditions. For clarity, data are presented in categories of 5% steps.

3.3. Discussion

In Experiment 2, we investigated whether a semantic benefit would also be evident when presented in a different format, namely with quasi-translations instead of pictures in the with-semantics condition. We thereby aimed to test whether the learning benefits observed in Experiment 1 were indeed due to the availability of semantic information itself and did not merely reflect a multimedia effect. The findings of Experiment 2 confirmed the results of Experiment 1. Participants in the with-semantics condition showed a better learning performance than those who learned without semantic information, even though the semantic information was not presented in a pictorial format. We can, therefore, rule out the possibility that the benefit observed in Experiment 1 reflected a multimedia effect. Furthermore, participants reported no differences concerning fun and effort in this experiment, allowing us to rule out the possibility that between-condition differences in Experiment 1 were due to differences in fun or effort.

In contrast to Experiment 1, the analyses of the source attributions in Experiment 2 showed no differences in the response behaviour of participants of the two groups. It seems that the semantic categories presented in Experiment 2 were insufficient to induce as high a proportion of explicit rule knowledge as observed in Experiment 1. Analysis of the accuracy ratings revealed that learners in the with-semantics condition showed higher accuracies and that the accuracies were higher for the explicit sources. However, as learners in the with-semantics condition did not report more cases of explicit knowledge, it cannot be said that they acquired more explicit knowledge overall than the without-semantics group. This finding could be related to the fact that the task in Experiment 2 was probably more difficult than in Experiment 1. The meaning of the sentences had to be decoded first and probably was not as salient at first sight as in Experiment 1. This may have reduced the cognitive capacity for building explicit knowledge. Furthermore, as mentioned above, Mayer's (2005) cognitive theory of multimedia learning would indicate that presenting materials in different formats (Experiment 1) as compared to a single format (Experiment 2) can help to use working memory capacity more efficiently and thus foster learning. Consequently, the increased amount of available working memory capacity may have been used by the participants in the with-semantics group of Experiment 1 to build up more explicit knowledge, for instance, by abstracting over the single exemplars and identifying rules.

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4. General discussion

Learning a novel grammar requires abstraction over concrete exemplars that are part of a complex language system. In natural language learning settings, meaning and grammar are closely interconnected. Several AGL studies have aimed at disentangling the interdependence between these two language components. Many of these have shown a beneficial effect of a semantic reference field in learning new grammatical structures (Fedor et al., 2012; Franck et al., 2016; Van den Bos & Poletiek, 2015). Inspired by these studies, we investigated the role of semantic information in learning the morpho syntax of the natural language Latin. The semantic information was implemented in two different formats. In Experiment 1, participants were presented with photographs depicting the meaning of the sentences, whereas in Experiment 2, participants saw quasi-translations in a propositional-like format (meanings of subject, object, and predicate). Thereby, we aimed to test the hypothesis that a beneficial effect of the pictures in Experiment 1 was not merely a multimedia effect induced by the pictorial presentation format but that the semantic content of the materials influenced the learning process. In both experiments, we used a rule-search paradigm in which we asked participants to identify the rules underlying correct sentences of Latin. Afterwards, participants completed a grammaticality judgment task that allowed us to assess their grammatical knowledge. In addition, participants indicated the basis on which they had decided, the effort they had made during learning, and how much they had enjoyed the task.

The results suggest that semantic information did facilitate the acquisition of the novel grammatical system and that it did so regardless of the format in which the semantic information was presented. This finding aligns with AGL studies that show a semantic benefit for the learning of novel grammatical structures in different presentation formats (e.g. Fedor et al., 2012; Franck et al., 2016; Van den Bos & Poletiek, 2015). These studies used semantic reference fields in different presentation formats, including coloured geometrical shapes, fictive pictorial characters, and non-pictorial material.

One aim of the present study was to keep familiarity with the novel language constant –not done in some of the previous studies (e.g. Fedor et al., 2012; see Öttl et al., 2017) – by using an immersion-like setting to imitate natural language learning situations. The results of our study suggest that the semantic benefit is evident even when controlling for language familiarity. This raises the question of why Öttl et al. (2017), who also controlled for language familiarity, did not find a beneficial effect of semantics. One reason might be that the language material they used was not close enough to natural language material, impeding the acquisition of the grammatical rules. This explanation is in line with the study by Franck et al. (2016), who found a semantic benefit compared to only prosodic cues. Although they used an artificial language, it closely imitated a natural language by focusing on grammatical agreement and implementing cues – like pauses and singular/plural – which can also be found in natural languages. It may be that, in natural languages, semantic information plays an even more significant role as it relates to naturalistic concepts (in our case, figures and actions). Furthermore, our data suggest that strategies that are meant to facilitate the acquisition of the novel language for the learner – that have been used in previous studies like pre-training or starting small (Franck et al., 2016; Öttl et al., 2017) – are not needed for learners to acquire the rules of a novel grammar. The immersion-like setting, which was oriented in natural language learning situations where the learner

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does not receive any instruction, may even have provided helpful cues to map the semantic information to the sentences from the outset and thus acquire meaning and grammar simultaneously.

It should be reflected in more detail what exactly was learned by the participants in the respective conditions. Learners in the without-semantics condition were presented with co-occurring forms from which they could extract rules using cross-situational statistics. Strictly speaking, one might argue that these are not morphosyntactic and thus grammatical rules, as they do not contain information about the grammatical reference categories. They could instead be seen as abstract patterns that can be learned simply with sensitivity to co-occurring features. However, on the contrary, it can also be argued that using statistical information to identify rules is also one of the first steps of grammar acquisition and, thus, a prerequisite for language learning. Yet, language learning is more than the acquisition of abstract patterns; namely, it includes meaning. What kind of learning benefit does the learner thus receive when meaning is added to the grammar learning setting? First, it may be the opportunity to assign meaningful roles to the given words. This may help learners to structure a sentence (e.g. by paying attention to a specific grammatical category) before they try to disentangle the rules of the whole sentence. Second, it may allow learners to make a connection to their own real-life experiences. If the words are already filled with meaning, there is no need to find ways to deal with abstract categories, which may come in with a mnemonic advantage. In this context, it also needs to be considered what role is played by the linguistic imprint – the native language. Learners in the present study were native speakers of German, which comprises gender, case, and verbal agreement, like Latin. It would be interesting to investigate a possible semantic benefit with native speakers of other languages with entirely different grammatical systems, such as Chinese.

The two experiments of the present study compared two visual formats of presenting semantic information, a pictorial and a non-pictorial one. Although we observed no difference in the learning performances of the two experimental groups, the analyses of the source attributions hint at differences in the kind of knowledge that learners acquire with each of the presentation formats. The analysis of the subjective source attributions in Experiment 1 revealed that the experimental group (with photos) gave most of their answers in the rule knowledge category. In all the other conditions of both experiments, participants mainly reported intuition as the source of their decision. Dienes and Scott (2005) distinguish the sources of 'rule knowledge' and 'recollection' as based on explicit knowledge, whereas 'intuition' and 'guess' are considered implicit knowledge. According to this classification, it can be argued that participants gained a relatively substantial amount of explicit knowledge in the with-semantics condition. In contrast, we neither observed a gain of explicit knowledge in the control conditions of both experiments nor in the experimental condition using a propositional-like presentation of the semantic content in Experiment 2. This finding might be because the with-semantics condition of Experiment 1 may have provided more effective learning circumstances. If this is true, one possible explanation might be that the pictorial-verbal presentation format helped to use working memory capacity more efficiently, as claimed by the cognitive theory of multimedia learning (Mayer, 2005). Thus, learners may have used their cognitive resources to establish more explicit knowledge, resulting in a higher rate of correct answers due to rule knowledge.

As pointed out previously, it can be assumed that abstraction is a crucial process involved in learning a new grammatical system. According to this view, it may seem

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counterintuitive that the condition in which the semantic information was presented in a very concrete pictorial format led to more explicitly perceived knowledge about the grammatical rules, while the more abstract propositional-like format did not. However, the pictorial format provided the advantage of making all the relevant features salient at once. It is possible that in this format, decoding the meaning according to the given categories (subject – object – verb) before abstracting morphosyntactic rules is easier due to the increased salience of the co-occurring elements as compared to the quasi-translations in Experiment 2. As we presented the stimuli for the same amount of time in both conditions, it seems possible that this time was insufficient for explicitly forming rules in the with-semantics condition of Experiment 2. This finding is in line with the explanation that Van den Bos and Poletiek (2015) provided for their finding that semantic information boosts grammar learning. They argued that semantic information in their experiment facilitated the learning process by increasing the salience of the relevant grammatical structures. They also showed that participants who had a semantic reference field available were aware of their knowledge, whereas participants in the memorise condition were not. Taking a closer look at the source attributions, learners' answers in both experiments were more correct when reporting explicit knowledge. However, the proportions of explicit knowledge reported by the with-semantics group were higher than the control group only in Experiment 1. This finding might be explained by a potential qualitative difference in the nature of the knowledge that was acquired in the two experiments: while in Experiment 1, building form-meaning connections, learners in Experiment 2 may have used mere form-level distributional statistics to build (rather abstract) rules, which may have been more difficult than also having meaning available.

In addition to the learning performance and the source of participants' knowledge, we assessed their effort and how much they enjoyed the experiment. We thereby aimed to gain more insight into possible mediating factors that might influence learning performance. Overall, no differences in fun and effort were reported by participants in the two groups. However, comparing the with- and without-semantics groups in Experiment 1, we observed a tendency in the direction that participants in the with-semantics condition enjoyed the experiment more. This perhaps points to the pictures being more motivating and engaging, but we cannot be sure that this finding is attributable to the character of the pictures themselves or to the increased feeling of competence during learning. It seems possible that the properties of the pictorial presentation format were more suitable to foster the learning of the target structures, resulting in an increased feeling of success and, consequently, a higher level of fun. Nonetheless, as the level of fun between the two experimental groups did not differ significantly in either experiment, this finding should not be overestimated.

In educational contexts, the temporal stability of the acquired knowledge is crucial. Successful learning relates to knowledge that is retained some time afterwards. It would thus be relevant to investigate the long-term effects of grammar learning with different formats of meaning implementation. Studies have shown that in learning mathematical concepts, cognitive activation, which can be described as the cognitive effort invested during learning, improves learning outcomes (Lipowsky et al., 2009). If semantic information at least partly accounts for an increased cognitive activation and, therefore, deeper elaboration of the learning materials, we

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expect this effect to hold over a more extended period. In this context, it would also be interesting to investigate whether there are differences regarding the level of the beneficial germane cognitive load between the two presentation formats (meaning of syntactic roles vs pictures, cf. Sweller et al., 2011), which would lead one to expect more significant learning gains. It might be possible that the pictures increase levels of germane cognitive load by presenting all relevant information at once.

In all groups, some participants answered correctly in all (or nearly all) the questions, while others did not perform at levels above chance. However, the proportion of learners who reached high accuracies was larger in the with-semantics groups. Therefore, it seems that the absence or presence of semantic information can contribute to explaining the differences in the learning of grammatical rules, but not exhaustively. It would thus be enlightening to investigate individual learner characteristics that may account for the performance differences (Ruiz et al., 2018, 2021; Tagarelli et al., 2016; Walker et al., 2020). For instance, it is feasible that factors like verbal memory, visual memory, or working memory at least partly account for learning success. Shedding light on these differences could provide a basis for establishing adaptive learning environments tailored to the specific needs of the individual learner.

5. Conclusions

The present study provides evidence for the beneficial effect of semantic information in acquiring a novel grammatical system, in this case, Latin morpho-syntax, regardless of the format in which the semantic information was presented (pictures or quasi-translations). The subjective source attributions showed an increased level of explicit rule knowledge compared to the control condition only in the with-semantics condition with pictures but not in the with-semantics conditions with propositions. Thus, the presentation may have influenced the explicitness of the knowledge that participants acquired, but not their learning performance.

Data availability statement. Data and analysis scripts are publicly available under the following link: https://osf.io/fsuqa/

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Competing interest. The authors declare to have no competing interests.

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