Body in Mind: How Gestures Empower Foreign Language Learning

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ABSTRACT—It has previously been demonstrated that enactment (i.e., performing representative gestures during encoding) enhances memory for concrete words, in particular action words. Here, we investigate the impact of enactment on abstract word learning in a foreign language. We further ask if learning novel words with gestures facilitates sentence production. In a within-subjects paradigm, participants first learned 32 abstract sentences from an artificial corpus conforming with Italian phonotactics. Sixteen sentences were encoded audiovisually. Another set of 16 sentences was also encoded audiovisually, but, in addition, each single word was accompanied by a symbolic gesture. Participants were trained for 6 days. Memory performance was assessed daily using different tests. The overall results support the prediction that learners have better memory for words encoded with gestures. In a transfer test, participants produced new sentences with the words they had acquired. Items encoded through gestures were used more frequently, demonstrating their enhanced accessibility in memory. The results are interpreted in terms of embodied cognition. Implications for teaching and learning are suggested.

In the early eighties, initial laboratory evidence was obtained demonstrating that if verbal phrases for action are encoded by self-performed representational actions, their retrieval is better than if the verbal information is only heard or read. Engelkamp and Krumnacker called the effect of an action on memory the "enactment effect" (Engelkamp & Krumnacker, 1980). Further research demonstrated that enacting verbal material improves its accessibility in memory. It was shown that in free recall tests, enacted items "popped out" of the mind without effort (Zimmer, Helstrup, & Engelkamp, 2000). More recently, the issue of high accessibility was investigated by Masumoto and colleagues with a reaction time experiment (Masumoto et al., 2006). They found enhanced speed of recognition for enacted action phrases compared to action phrases encoded audiovisually. Spranger and colleagues worked on action phrases and administered immediate and delayed free recall tests to younger and older adults. The results demonstrated the high accessibility of enacted items in both age groups and in both tests (Spranger, Schatz, & Knopf, 2008). In brief, experimental evidence from the last three decades has shown that encoding through enactment compared with audiovisual encoding provides manifold advantages: Verbal information is retrieved in better quantity, it is accessed faster and more accurately and it decays more slowly.

Different theoretical explanations have been provided for the enactment effect. It was suggested that it is driven by a motor trace in memory, which is created through the physical action accompanying the word (Engelkamp & Zimmer, 1984, 1985). Evidence in support of the motor trace theory has come from brain imaging experiments in recent years. In fact, it has been demonstrated that if a self-performed action accompanies a word, its neural representation contains a motor component (Eschen et al., 2007; Macedonia, Muller, & Friederici, 2011; Masumoto et al., 2006; Nilsson, 2000).

Motor imagery (i.e., a kinetic representation of the word's semantics created through the action) was also identified as the crucial factor leading to enactment (Saltz & Donnenwerthnolan, 1981). Brain imaging experiments have revealed evidence of underlying representations of kinetic images connected to the word's semantics. If semantically incongruent or unrelated gestures are produced synchronously with words, mechanisms of cognitive control denoting disturbance become active.

In a recent Stroop-like EEG study, Kelly and colleagues showed participants videos in which an actress/actor spoke and performed gestures on common actions like "cut" and

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"drink" in Japanese. If the gestures were incongruent to the words, a larger N400 was elicited. This neural correlate is an event-related brain potential denoting semantic relations (Kelly, Creigh, & Bartolotti, 2009). Similarly, in an fMRI study by Macedonia and colleagues, participants learnt a set of novel words by accompanying them with congruent gestures, and another set of novel words with incongruent gestures. Here, incongruence between word semantics and gestures activated a network for cognitive control (Macedonia et al., 2011) similar to networks elicited in Stroop tasks (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004).

In contrast to motor imagery, others hold that enactment leads to a complex representation of the word comprising different sensory and motor components. Complexity—not only the motor component—enhances the word's storage in memory (Bäckman & Nilsson, 1984, 1985; Bäckman, Nilsson, & Chalom, 1986). It is true that by adding a gesture to a word, its representation is enriched by a number of modalities and is therefore more complex. Its representation is thus deeper than for a word that is only read and heard (Klimesch, 1994; Shams & Seitz, 2008). Further factors eliciting the enactment effect and thus deeper semantic processing have been identified as self-involvement and enhanced attention during gesture production (Knopf, 1992; Kormi-Nouri, 1995, 2000). Studies have also demonstrated that attention modulates learning if subjects produce an action while uttering a word (Knudsen, 2007; Muzzio, Kentros, & Kandel, 2009).

Altogether, these studies show the existence of an inextricable link between language and gesture. It should be noted that the theoretical positions discussed above do not mutually exclude each other. Instead, they highlight different aspects of the same phenomenon. Single aspects might seem predominant because they are predominant in a particular experimental design.

ENACTMENT AND FOREIGN LANGUAGE LEARNING

Although total physical response (Asher, 1969) paved a way toward enactment of foreign languages and in the last three decades, it has been proven that enacting words leads to better memorization and faster retrieval, no pedagogical theory considers enactment as a strategy to enhance foreign language learning. Interdisciplinary research on gestures in foreign language teaching and learning has mainly focused on spontaneous gestures produced by teachers and learners (Gullberg, 2008; Gullberg & Indefrey, 2006; Gullberg & McCafferty, 2008). Teachers tend to pantomime, to give signs of evaluation and to stress prosody by gesturing (Lazaraton, 2004; McCafferty & Stam, 2008). On the other side of the desk, learners use their hands when searching for words or when communicating in the foreign language (Gregersen, Olivares-Cuhat, & Storm, 2009).

However, to our knowledge, only a few studies have investigated the effect on memory of gestures performed by learners when encoding foreign language. Seminal work was done by Quinn-Allen (1995), who taught university students 10 French expressions. Following on from this, Macedonia cued young adults to learn 36 items (nouns, adjectives, verbs, and prepositions) in Tessetisch, an artificial corpus conforming with Italian phonotactic rules (Macedonia, 2003). A similar approach has been used to teach English nouns to French children (Tellier, 2008) and Japanese action verbs to university students (Kelly, McDevitt, & Esch, 2009). More recently, Macedonia trained participants on 92 concrete nouns in Vimmi, a novel artificial corpus based on Italian phonotactics (Macedonia et al., 2011). Altogether, these studies show better memory retrieval through enactment for foreign language words and phrases.

The explanations the authors of these studies provide for the memory enhancement have different focuses. Macedonia (2003) explained the superior memory performance found for words encoded through enactment in terms of the Connectivity Model of Semantic Processing (Klimesch, 1994). This model deals with the question of how complex semantic codes are represented, searched, and retrieved in long-term memory. According to this model, the use of a gesture paired with the word would enrich the representation of the word by creating a complex representation, a deep code. A deep code is better retrieved and decays more slowly. In her study, Tellier related superior memory performance to encoding depth due to multimodality (Tellier, 2008). Kelly and colleagues connected better retrieval of enacted items with deeper encoding: they related it to an embodied mental image of the word's semantics. In their recent experiment, Macedonia and colleagues also supported the view of a mental image of the word provided by the gesture matching with an internal representation of the word's semantics (Macedonia et al., 2011).

Without a doubt, these studies have opened new perspectives toward a practical application of enactment in foreign language teaching and learning. However, it is important to address some issues that might have influenced the results and therefore could be improved.

In some of the above-mentioned studies, the use of a natural language for experimental purposes can be a source of confound. A substantial portion of English words consists of French words stemming from the Norman Conquest. Vocabulary common to both languages facilitates (also unconscious) association for English subjects learning French and for French subjects learning English. Thus, in the studies by Quinn-Allen (1995) and Tellier (2008), it is difficult to discern whether the gesture or an association facilitates the memorization of a word. Likewise, natural languages, like Japanese, that are not easily associable for English-speaking subjects show characteristics like unfamiliar sound combinations or syllabic tautologies. These may influence memory performance because of their phonetic and/or orthographic peculiarity. In fact, it has been demonstrated that bizarreness has an impact on memory (Engelkamp, Zimmer, & Biegelmann, 1993).

Furthermore, natural languages cannot be controlled for item length. The debate about the relationship between word length and memorization is still ongoing, and opinions related to this issue are contradictory. It is plausible that word length affects recall, with short words being better recalled than long ones (Baddeley, 2003; Baddeley, Thompson, & Buchanan, 1975). Note, however, that the data available on this topic are related to experiments investigating the memory span in the participants' mother tongue and they cannot be transposed automatically into the foreign language. When unfamiliar phoneme strings are memorized, not only length but also the novelty factor due to phonemic peculiarity may have an extra impact on memory (Hunt & Worthen, 2006). However, there is evidence that short words are also kept in memory better in a foreign language (Baddeley, 2003; Baddeley et al., 1975). Nevertheless, there is a need to clarify this issue and more research is necessary to understand whether the length itself or the phonotactics of a short word cause its easier memorization (Jalbert, Neath, Bireta, & Surprenant, 2011). The use of an artificial corpus rules out the possible confounds addressed above. On the other hand, it has to be admitted that an artificial corpus might affect the motivation of learners.

Another factor that was not always controlled for in the past is the familiarity of the words used in experiments. Infrequent words are more likely to be memorized than familiar everyday words (Chee, Westphal, Goh, Graham, & Song, 2003; Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002). Similarly, idiomatic expressions and metaphors are likely to be favored because of the bizarre images they often provide (Hamilton & Rajaram, 2001; Peterson & Mulligan, 2010).

In her recent paper, Tellier addresses the issue concerning the impact of enactment on different word classes (Tellier, 2008). Studies conducted up to now have mainly investigated memory for action verbs and are not automatically generalizable to other word classes. It is conceivable that enactment works better on an action verb than on an abstract noun, with the action verb intrinsically containing a gestural component in its representation (Boulenger, Hauk, & Pulvermuller, 2009; Hauk, Johnsrude, & Pulvermuller, 2004). There might also be differences within the same word class, for instance, between concrete and abstract nouns, as a concrete noun is richer in its sensorial representation than its abstract counterpart (Barsalou, Kyle, Barbey, & Wilson, 2003). Thus, it is necessary to elucidate the impact of enactment on concrete and abstract items as well as the differences occurring between different word classes.

In summary, the studies described here show that language and gesture are an integrated system. Gestures have an impact on verbal memory for words and action phrases not only in the mother tongue of the participants, but also if subjects learn verbal items in foreign and laboratory languages. In the literature, the explanations for the superior memory performance have ranged from multimodal complexity, hence depth of encoding, a motor trace in memory, motor imagery and enhanced attention due to self-involvement. However, there is a need to improve the experimental corpora in multiple ways and to control for intrinsic factors that might have influenced results in the studies conducted to date. Moreover, no study has yet investigated the effect of gesture on memory for abstract words (e.g., for words like adverbs) that usually do not have a culturally well-established gestural component. The effects of enactment on language production have also not yet been tested. If the present study proves that enactment also enhances memory for abstract words and enacted words are used more often in the production of new sentences, it will demonstrate that using enactment is a valid tool that can be applied in pedagogical contexts to empower foreign language learning.

THE PRESENT STUDY

Taking the above considerations into account, the present study aims to elucidate the following issues:

1. By using a controlled artificial corpus of abstract sentences, we intend to replicate the results of previous experiments by comparing the memory recall of words that have been encoded audiovisually with words that have been encoded by enactment. We predict superior memory performance for encoding through enactment.
2. Research aiming to make predictions on foreign language learning must take into account the fact that learners rarely acquire vocabulary as isolated items. Rather, learners are presented with dialogues and texts, embedding sentences and words. Thus, in order to transpose knowledge deriving from experimental evidence into pedagogy, it is necessary, at least to some extent, to reproduce the encoding conditions present during instruction. Here, participants learn words embedded in the context of sentences. We predict that in the context of sentences, enacted words are also better retrieved than words encoded audiovisually. If the data confirm this prediction, enactment can be considered a suitable encoding strategy in language teaching, with its efficiency not limited to isolated single items or to particular word classes.
3. We want to clarify the relationship between memorization and word class. Considering studies on the acquisition of grammatical categories, (Gentner & Boerman, 2009; Gentner & Boroditsky, 2009), we predict that, within the same training procedure, nouns will be better recalled than verbs, and verbs better memorized than adverbs.

Moreover, we expect that concrete nouns will show better memory results than abstract ones.

4. Vocabulary acquisition is a first step in language learning. Learners need vocabulary to make active use of a language and produce their own communicative acts. In foreign language education, the validity of a learning strategy is closely connected with the transferability of learned words into the production of sentences, specifically of new sentences (Pavicic-Takac, 2008). Here, we test if enacted items are used more frequently in the construction of new sentences than words encoded audiovisually. If this is the case, this would provide evidence for their better accessibility in memory. We predict that enacted words will be used more often in the production of new sentences and thus are more easily accessible.

METHOD

Participants

Twenty German-speaking subjects (mean age 21.14, *SD* 2.53, 12 females, 8 males) participated in the experiment. They were recruited from the Institute's database and were paid for their participation. No subject had any known hearing deficits or neurological disorders. Before the experiment, each volunteer gave written informed consent to participate.

Materials

The training material comprised 32 transitive sentences in *Vimmi*, which is an artificial corpus created for experimental purposes (Tables 1, 2 and the corresponding translation into English in Table 3). We opted for an artificial corpus in order to rule out possible associations with participants' previous knowledge and also factors present in natural languages that might influence single word learning. Within words, these factors can be peculiarities in their phonotactics, word length, and frequency of occurrence. Other features characterizing natural languages are syntactic structures and idiomatic expressions. Our sentences all had the same syntactic structure and contained no idiomatic expressions. As there may also be differences in attitudes toward natural languages and hence variation in individual participants' motivation to learn a particular language, we opted for a nonexistent laboratory language. We are well aware of the fact that the results deriving from our study cannot be fully transferred to foreign language learning. However, we see these methodological restrictions as necessary to isolate memory performance in word learning from language learning, which is a largely more complex task.

Each of the 32 sentences of the artificial corpus comprised 4 grammatical elements: subject, verb, adverb, and object. The nouns for the subjects were assigned concrete meanings indicating actors, such as *director* and *musician*. The remaining

Table 1
Vimmi Sentences Used for the Training

	Subject	*Verb*	*Adverb*	*Object*
1	nelosi	otu	tioda	sigule
2	gelori	lefa	itru	lifawo
3	miruwe	ifra	kadu	bekoni
4	lutepa	kori	dalo	gubame
5	gepesa	lari	roike	pirumo
6	mebeti	fadro	liwe	giketa
7	atesi	repo	figru	magosa
8	lofisu	fegla	ipe	uladi
9	serawo	dupi	toage	nabita
10	botufe	redu	foki	giwupo
11	siroba	dawu	ragi	mesako
12	wugezi	poagu	dero	motila
13	suneri	zobu	oga	elebo
14	mewima	ipri	tidu	dafipo
15	guriwe	ziso	egi	puneri
16	bifalu	rifa	kizo	pokute
17	afugi	bepa	teku	wefino
18	getuna	kuato	bani	utike
19	pamagu	luko	bofe	dizela
20	gokasu	iblo	kiore	pefita
21	asemo	toze	bilu	gaboki
22	wasute	lapo	teni	mofibu
23	maloti	koga	owe	denalu
24	dubeki	lozu	tawo	fremeda
25	sokitu	igro	doza	muladi
26	nibesa	kelo	zade	fradonu
27	dotewe	zuko	fubli	boruda
28	batewo	dife	Zega	migedu
29	lamube	rowu	Nagri	gasima
30	nalefa	buto	Idre	gorefu
31	wiboda	baku	Ozi	fapoge
32	nowitu	kune	Tari	munopa

Note. Sentences 1–16 were encoded through enactment, sentences 17–32 were encoded audiovisually.

words were abstract. For example, among the verbs there were *accept* and *plan*, among the adverbs *thereafter* and *already*, and among the abstract nouns *recommendation* and *warning*. Participants were informed that they would take part in a language learning experiment. However, they were not told which language they were learning. The SVO sentences were therefore accepted as well formed even if they did not contain definite articles, for example Vimmi *siroba ragi dawu mesako*; English *(the) clerk administrates basically (the) property*.

The artificial corpus *Vimmi* was generated by using a script in Perl, a programming language for text manipulation (Hammond, 2003). Words were constructed conforming with Italian phonotactics. Thereafter, they were adjusted in order to avoid tautological occurrence of syllables, frequency of consonants and vowels, appearance of strings sounding unusual to German-speaking subjects, associations with words from European languages taught at school in Germany (English, French, Italian, Spanish, and Latin) and with

Table 2
Translation into German of the Vimmi Sentences Used for the Training

	Subject	*F*	*Verb*	*F*	*Adverb*	*F*	*Object*	*F*	*F-average*
1	Wissenschaftler	9	vertritt	11	zunächst	7	Theorie	11	38
2	Designer	11	gestaltet	10	häufig	9	Stil	10	40
3	Arbeitslose	10	kritisiert	9	massiv	10	Wohlstand	12	41
4	Autofahrer	9	ignoriert	12	derzeit	7	Warnung	11	39
5	Techniker	11	untersucht	10	künftig	7	Struktur	11	39
6	Gast	9	akzeptiert	10	anschließend	9	Empfehlung	11	39
7	König	10	erteilt	11	genau	7	Befehl	12	40
8	Musiker	10	pflegt	12	ebenso	8	Tradition	10	40
9	Freund	9	stabilisiert	12	vielleicht	8	Partnerschaft	10	39
10	Patient	11	bezweifelt	12	inzwischen	7	Therapie	11	41
11	Beamte	10	verwaltet	12	grundsätzlich	9	Besitz	10	41
12	Polizist	11	liebt	11	allein	7	Disziplin	11	40
13	Architekt	11	ermöglicht	10	dadurch	9	Wiederaufbau	10	40
14	Richterin	11	vermutet	10	meist	8	Unschuld	12	41
15	Produzent	9	entdeckt	9	regelmäßig	9	Talent	11	38
16	Profi	11	registriert	10	sofort	8	Unterschied	10	39
17	Schneider	10	verändert	10	daraufhin	9	Vorlage	10	39
18	Bauer	11	erhöht	9	demnach	9	Bestand	11	40
19	Botschafter	11	vernachlässigt	12	völlig	8	Pflicht	10	41
20	Reporter	11	beschreibt	10	eher	7	Tendenz	11	39
21	Pilot	11	genießt	11	wirklich	7	Aussicht	10	39
22	Verbraucher	11	wählt	11	manchmal	9	Alternative	10	41
23	Leiterin	11	bestimmt	9	öffentlich	9	Maßnahme	10	39
24	Sportler	10	kennt	9	lediglich	8	Übung	12	39
25	Maler	10	berechnet	12	weniger	7	Aufwand	11	40
26	Radfahrer	11	erregt	12	besonders	7	Aufmerksamkeit	10	40
27	Intendant	11	verspricht	10	oft	7	Sensation	12	40
28	Pfarrer	11	sammelt	12	gleich	7	Spende	10	40
29	Mediziner	10	beobachtet	10	sonst	8	Effekt	11	39
30	Kollege	10	schätzt	10	zusätzlich	9	Verständnis	10	39
31	Ministerin	10	wünscht	11	schließlich	8	Korrektur	12	41
32	Künstlerin	11	erwägt	11	deshalb	7	Absage	10	39
									39.68

Note. Sentences 1–16 were encoded through enactment, sentences 17–32 were encoded audiovisually. The table shows the frequency (*F*) score of the single item as well as the average of frequencies for the whole sentence.

common proper nouns comprising names of products available on the German market.

The items were also controlled for their length in Vimmi. Nouns consisted of three syllables, verbs, and adverbs were disyllabic. The items were controlled for their frequency, that is, concept familiarity of occurrence (Allen & Hulme, 2006), in their German translation. For this purpose, we used the “Wortschatzportal” of the University of Leipzig (http://wortschatz.uni-leipzig.de). Frequencies of occurrence are listed next to the words in Table 2. The corpus used for training comprised 118 novel vocabulary items in Vimmi and their corresponding translations into German (Table 2).

For each item to be learned within the sentence, the training stimulus consisted of four components: the video, the Vimmi audio file, the word written in Vimmi, and its translation into German. The 118 words were recorded and cut into 118 single audio files, with files having a length of approximately 1 s. For each item, a video clip was recorded with an average duration of 4 s. When creating the videos, the experimenter worked with three research assistants who controlled the gestures for their duration and their distribution in space. A maximum radius of displacement of 50 cm from the standby position was permitted. This was done to control for gestural complexity and to avoid gestures that, through temporal difference or spatial complexity, might have become peculiar and therefore better memorized. The facial expression of the actress performing the gestures was neutral. She avoided producing any movements with her eyes or her mouth that might have added information to the gesture and enriched the representation of the word. We opted for the neutral expression in order to not introduce the factor face, which could have created a confound (i.e., the learning effect being not attributable only to the gesture itself but also to the facial expression). Moreover, some words—like *innocence*—would have had a facial connotation per se, but many other—like

Table 3
Translation into English of the Sentences Used for the Training (Not Used in the Experiment)

	Subject	*Adverb*	*Verb*	*Object*
1	(The) scientist	first	argues (for)	(the) theory
2	(The)designer	frequently	shapes	(the) style
3	(The) unemployed	massively	criticizes	(the) wealth
4	(The)driver	presently	ignores	(the) warning
5	(The) technician	in the future	inspects	(the) structure
6	(The) guest	thereafter	accepts	(the)recommendation
7	(The) king	accurately	gives	(the) command
8	(The) musician	alike	takes care (of)	(the) tradition
9	(The) friend	possibly	stabilizes	(the) partnership
10	(The) patient	(in the) meanwhile	questions	(the) therapy
11	(The) clerk	basically	administrates	(the) property
12	(The) policeman	only	loves	(the) discipline
13	(The) architect	thereby	enables	(the) reconstruction
14	(The) judge	mostly	presumes	(the) innocence
15	(The) producer	regularly	discovers	(the) talent
16	(The) professional	immediately	assesses	(the) difference
17	(The) dressmaker	hereupon	changes	(the) pattern
18	(The) farmer	thereafter	increases	(the) inventory
19	(The) ambassador	completely	neglects	(the) duty
20	(The) reporter	rather	describes	(the) tendency
21	(The) pilot	really	enjoys	(the) view
22	(The) consumer	sometimes	chooses	(the) alternative
23	(The) director	officially	determines	(the) procedure
24	(The) sportsman	exclusively	knows	(the) exercise
25	(The) painter	to a lesser extent	charges	(the) effort
26	(The) biker	particularly	attracts	(the) attention
27	(The) artistic director	often	promises	(the) sensation
28	(The) priest	equally	collects	(the) donation
29	(The) doctor	otherwise	observes	(the) effect
30	(The) colleague	appreciates	additionally	(the) understanding
31	(The) minister	Wishes	finally	(the) correction
32	(The) artist	presumably	considers	(the) cancellation

Note. Sentences 1–16 were encoded through enactment, sentences 17–32 were encoded audiovisually. Note that in English, some items are bound prepositions or consist of several words. However, this is not the case for German.

thereby— not. Thus, in order to not favor the memorization of particular words, we kept the actress' face neutral.

The single gestures mirrored some feature of the semantics of the word that was arbitrarily chosen by the experimenter from a range of possibilities discussed in the team. For instance, for the verb *to ignore*, the actress turned her head and made a disparaging gesture with her right hand (Figure 1a). The items were enriched with a plausible sensory motor connotation suitable for German speakers. However, our claim was not of a cultural nature (i.e., pairing culturally accepted gestures with words in order to improve memorization). Here, in a more "mechanical" way, we wanted to enrich the word with sensorimotor information in order to enhance memorability in words that per se have little or no sensorimotor connotation and are not phonetically associable with words in languages known to the subjects.

The 32 sentences were randomly distributed in two training conditions, an audiovisual (16 sentences) and an enactment condition (16 sentences). All participants trained the 32 sentences: 16 in the audiovisual and 16 in the enactment condition. The purpose of the two training conditions was to investigate how memory performance for verbal information is enhanced through enactment. Furthermore, we also wanted to determine if factors such as word category (noun, verb, and adverb) and concreteness (concrete and abstract nouns) also influence memory performance.

In condition 1, audiovisual training (AV), participants saw the word written in Vimmi and heard it. After 0.5 s, its translation into German appeared on the screen. Synchronously, a video with a still image of the actress appeared on the screen (Figure 1a). The audio file for the word was played again. Participants were cued to repeat the word they had previously seen and heard aloud.

In condition 2, enactment (EN), participants saw the word written in Vimmi and heard it. After 0.5 s, its translation in German appeared on the screen. Synchronously, a video with the actress performing a symbolic gesture related to the word appeared on the screen (Figure 1b). The start of the Vimmi

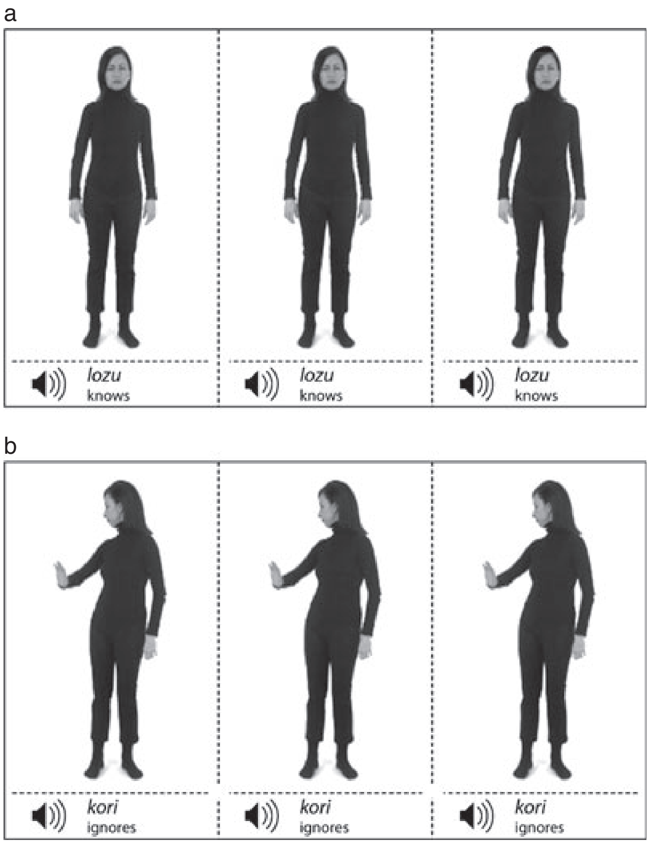

Fig. 1. Video screen shots illustrating the two training conditions. (a) In the audiovisual (AV) condition, participants were cued to read and listen to the Vimmi word and to repeat it. The picture shows the still image used. Note that the actress performs no gesture. (b) In the enactment (EN) condition, participants were instructed to read and listen to the Vimmi word and to repeat it and to perform the gesture while saying the word. The picture shows a symbolic gesture used for the encoding condition through enactment. The actress mimics the word to ignore, Vimmi kori, by turning her head to the right and making a disparaging gesture with her right hand and arm. Note that the facial expression is kept neutral.

audio file was separately timed for each item and coincided with the start of the movement in the video. Participants were cued to repeat (i.e., to read aloud) the word they had previously read and heard, and to accurately imitate the gesture shown in the video.

Training Procedure

Participants were informed that the experiment was on foreign language learning and that the goal of the training was to remember as many words as possible. Participants were informed that their performance would be assessed daily through different kinds of written tests. Two research assistants monitored all parts of training and testing. They made sure that participants attended to the stimuli and performed the training without omitting any part of it (word repetition or gesture imitation).

The training lasted 3 h daily. The 32 sentences were subdivided into 4 blocks of 8 sentences each, in which the two training conditions were alternated daily. After each training block, a break of 5 min followed. During the training, each sentence first appeared on the screen in Vimmi, followed by its translation into German. Thereafter, each item was presented separately according to the training condition it belonged to, that is, AV or EN. Each sentence was repeated item by item four times every day. The software used for the training was Presentation (version 12) by Neurobehavioral Systems, Albany, CA.

Tests and Results

Memory performance was assessed daily starting from day 2. Before starting the training, participants had to perform a free and thereafter a cued recall task. Items were considered correct if their spelling corresponded 100% to the word spelling provided during training. Correct items were given the score 1. All other items were considered wrong and given a score of 0. Partial correctness was not considered at any time of testing. From day 4 through day 6, in addition to the memory tests, a written production task assessed the production of new sentences created with the inventory of trained words.

Free Recall Test (Figure 2a, b)

Participants were given an empty sheet. They were instructed to write as many items as possible in both languages. Items could be loose (i.e., only German or only Vimmi) or matched (i.e., Vimmi and German). The free recall test lasted 15 min. The results of a free recall test indicate a first memorization step of vocabulary. Therefore, the result of the free recall test can to some extent be considered as initial knowledge that is necessary to access semantics in the language, roughly understand what other people say and to produce access level communication.

Results: Free Recall German and Vimmi. In German, recall of items that had been encoded through enactment was superior over the entire training period (Figure 2a). A repeated measures ANOVA with the factors training (AV and EN) and time (day 1 until day 6) confirmed this observation, $F(1,19) = 12.29$, $p < .01$.

The diagram in Figure 2b shows that in Vimmi recall, the superiority of enactment over audiovisual learning only emerges on day 3. The ANOVA did not yield a significant effect for the entire period of training. Separate t tests for daily performance found a significant difference in recall of items encoded through enactment for days 3 and 6, showing a clear trend.

The difference between the results of the free recall test in German and those in Vimmi indicated that it was necessary to

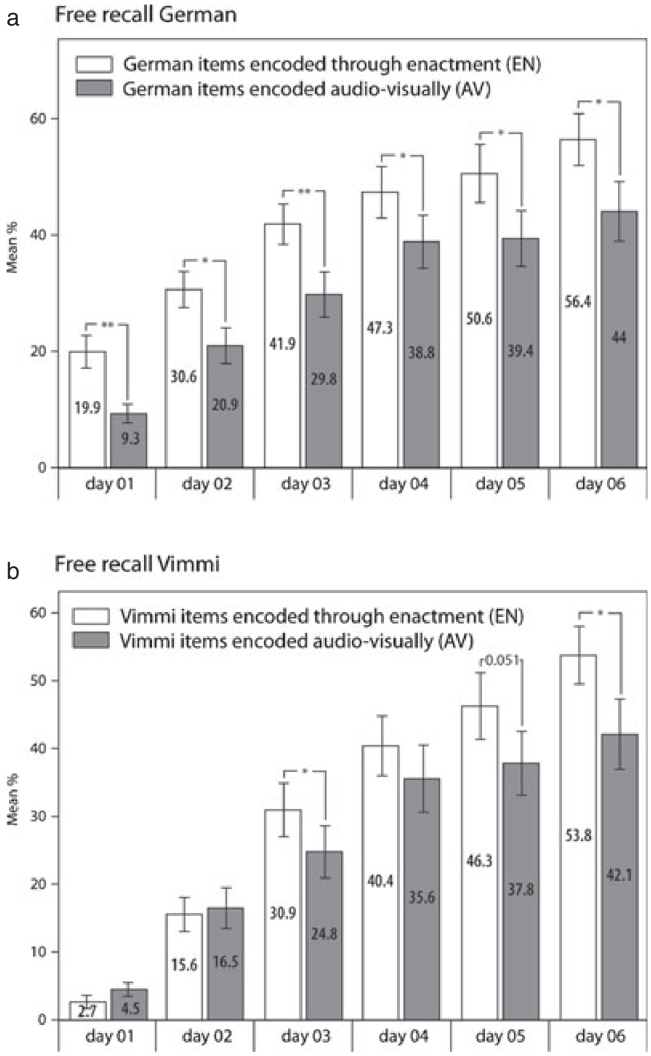

Fig. 2. (a) Training results for the free recall test in German, days 1–6. Words encoded through enactment are significantly superior in retrieval at all time points. (b) Training results for the free recall test in Vimmi, days 1–6. Words encoded through enactment are better retrieved at all time points. However, difference reaches significance only and days 3 and 5. Figure error bars represent ±1 *SE*. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$ in all illustrations in this article.

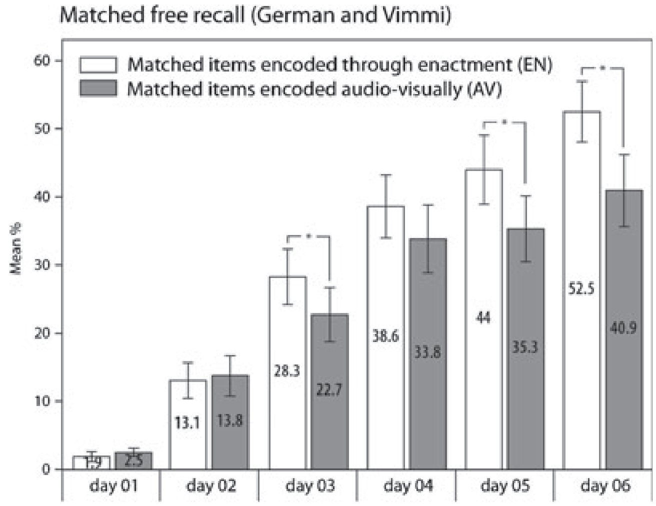

Fig. 3. Training results for the matched free recall test, days 1–6. Words encoded through enactment are better retrieved at all time points. Significance is only reached on days 3, 5, and 6. This test mirrors the capacity to retrieve acquired verbal information needed to access the lexical inventory necessary for active communication. Learners can connect the word in the foreign language with the correspondent word in their mother tongue and easily switch from one language into the other.

inspect the test material more closely. We found that participants had filled in their test sheets with a large number of items. However, many of them were affected by spelling mistakes (e.g., wrong or missing letter(s) as in X for Y). Considering that the orthography rules of Vimmi are the same as those of German, the participants' mother language, we assume that mistakes reflect tuning processes into the phonematics of the novel language more than orthography errors.

Matched Free Recall Test (Figure 3a, b)

Again, participants were given an empty sheet. They were instructed to write as many items as possible in both languages. Items could only be matched (i.e., only German and Vimmi or Vimmi and German). The matched free recall test lasted 15 min. Free recall can be considered a good measure of verbal memory, whereas the matched free recall test indicates the specific skill necessary to access vocabulary from one language to the other and vice versa. Matched free recall indicates that learners succeeded in establishing the connection between their mother tongue and the target language.

Results. The repeated measures ANOVA with the factors training (AV and EN) and time (day 1 until day 6) showed that training through EN nearly reached significance, $F(1,19) = 4.39$, $p < .05$. Superior recall for enacted items was found, however, on days 3, 5, and 6 as illustrated in the graph (Figure 3). Altogether, the mean training results summarized in Figure 3 suggest a superiority of enactment encoded items from day 3 on, similar to the Vimmi only free recall results.

Cued Recall Test (Figure 4a, b)

Participants were given a randomized list of the 118 trained items to be translated from German into Vimmi (duration 10 min) and then after a break of 5 min, another randomized list of the same words to be translated from Vimmi into German (duration 10 min), with the instructions to translate the items from one language into the other. The order of the translation from one into the other language alternated daily.

Results. The ANOVA with the within-subject factors time (day 1 to day 6) and training (EN and AV) yielded significant results in both translation directions, from German into Vimmi and from Vimmi into German, $F(1,19) = 13.16$, $p < .01$ and $F(1,19) = 8.42$, $p < .1$, respectively.

The training procedure had an impact on performance, which was consistent over time, as indicated by the significant interaction between time and training, both for the translation from German into Vimmi, $F(5,95) = 12.05$, $p < .001$, and for the translation from Vimmi into German, $F(5,95) = 7.76$, $p < .001$.

Interestingly, in both translation directions, significant differences in training started appearing from day 3 (Figure 4a, b), as already found for the Vimmi free recall condition. It seems that enactment needs time to produce effects on memory. This is in line with findings in motor learning that report longer times for motor encoding to produce results, possibly due to consolidation processes after practice (Baraduc, Lang, Rothwell, & Wolpert, 2004; Shadmehr & Holcomb, 1997). However, this is a somewhat speculative interpretation and further research is needed. Altogether, in the cued recall task, participants progressed with time; from day 3 they benefited from using the gestures, and were better at translating from the foreign language into their mother tongue than vice versa.

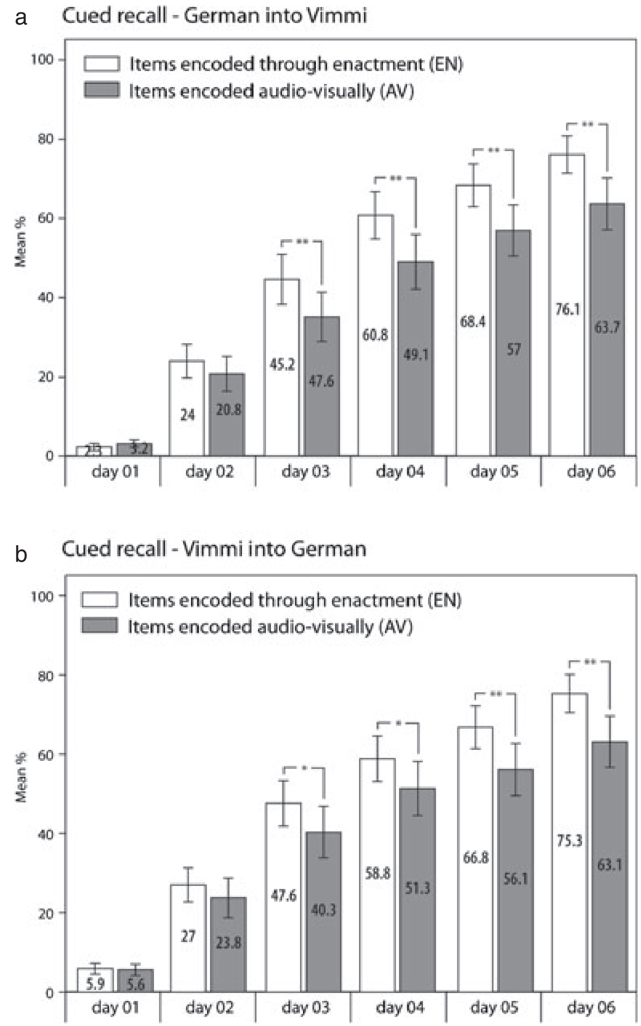

Fig. 4. (a) Training results for the cued recall tests from German into Vimmi and (b) vice versa for days 1–6. Words encoded through enactment are better retrieved in both translation directions. Superior results are produced for the translation into the mother tongue, considered to be the easier task. Significant differences start from day 3 in both translation directions.

Written Production Test (Figure 5a, b)

After the free and the cued recall tests, participants were given an empty sheet. They were instructed to write as many new sentences in Vimmi as possible using the words they had previously learned and to provide translations of the sentences in German. Participants were explicitly instructed to avoid the reproduction of canonical sentences they had trained and, instead, to create new sentences with plausible semantic content.

Only meaningful sentences in which Vimmi and German matched completely and which contained a minimum of three words were considered for statistical evaluation.

Results. Although participants were instructed to produce new sentences with the inventory of learned items, they also reproduced the canonical sentences. Interestingly, as shown in the graph (Figure 5a), the reproduction of canonical sentences stagnated over time. However, even if learning did not increase over time, participants reproduced sentences with more items (thus sentences) that had been encoded through enactment, $F(1,19) = 4.46$, $p < .05$.

In contrast, in the production of new sentences (Figure 5b), the ANOVA with the factors time (days 3–6) and training (AV and EN) yielded significant results, respectively $F(2,38) = 9.16$, $p < .005$ and $F(1,19) = 18.78$, $p < .001$. On this measurement, participants also improved their memory performance over time and made greater use of enacted than audiovisually learned words. Interestingly, not only the quantity but also the significance between enacted and audiovisually learned words used in the production of sentences increased in time. This seems to reflect and confirm the tendency that there is a benefit in enactment with a certain shift in time present in other measurements in this experiment.

Item Analyses

We were interested in the impact different word categories and training have on memory performance. We hypothesized a ranking in recall, with concrete nouns scoring better than abstract nouns, nouns scoring better than verbs,

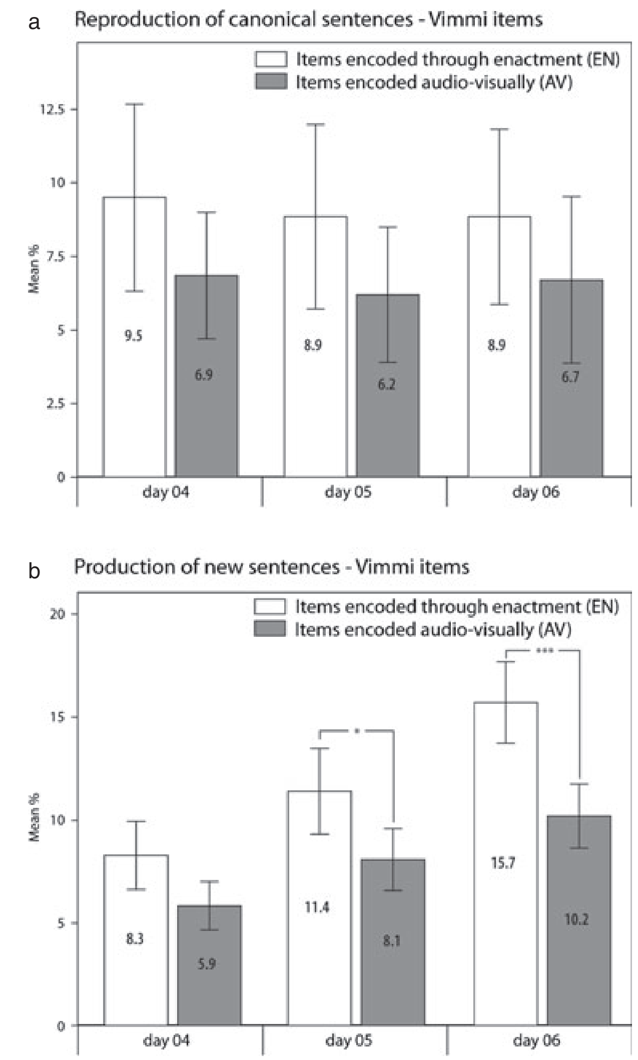

Fig. 5. Words used in the reproduction of canonical sentences (days 4–6). (a) In the reproduction of canonical sentences, the number of sentences and thus of words stagnates from day 4 to day 6. The daily difference between items encoded through enactment or audiovisually does not reach significance. (b) In contrast, in the production of new sentences, the number of words used increased daily. The use of enacted items was favored and increased in time significantly.

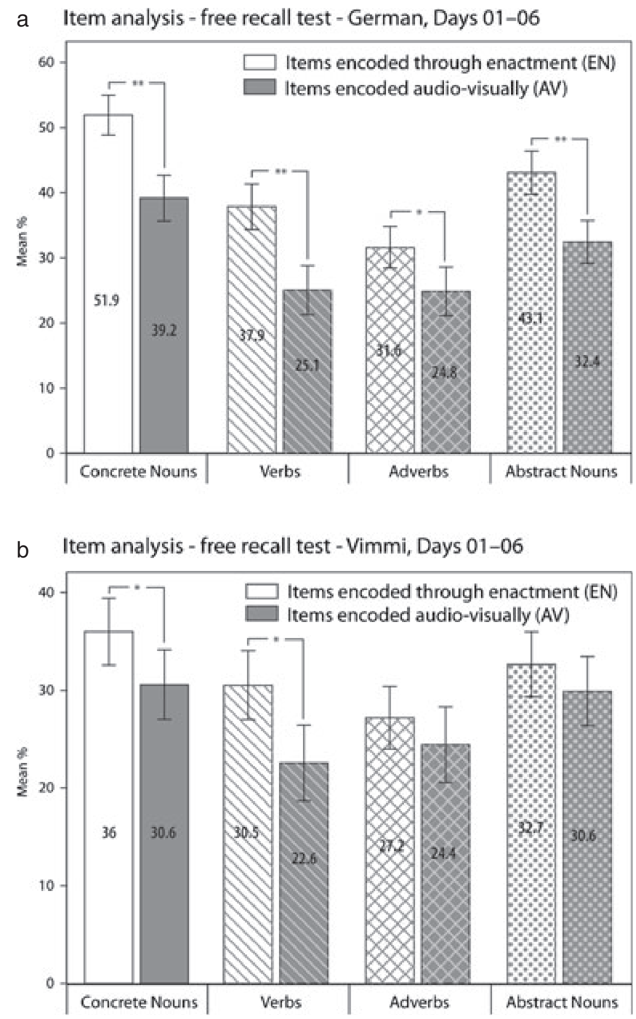

Fig. 6. Item analysis in free recall for (a) German and (b) Vimmi, days 1–6. In both languages, concrete nouns score best, followed by abstract nouns, verbs and adverbs. Enacted items are better retrieved than items encoded audiovisually. In contrast to other word classes, in the case of adverbs, the training condition does not play a significant role in either language.

and verbs better than adverbs. Within the same word category, we assumed that enacted words are better retrieved than words learned audiovisually. We performed repeated measures ANOVAs considering the within-subject factors word category (CN = concrete nouns, V = verbs, ADV = adverbs, and AN = abstract nouns) and training (AV and EN). The results of the item analyses are listed below.

Free Recall German and Vimmi (Figure 6a, b)

Results. For German words (Figure 6a), the factors word category and training were both significant, $F(3,57) = 20.60$, $p < .001$ and $F(1,19) = 33.37$, $p < .001$, respectively. Similarly, we found a significant interaction between word category and training, $F(3,57) = 5.87$, $p < .01$.

In Vimmi (Figure 6b), the factor word category was significant, $F(3,57) = 13.49$, $p < .001$, whereas the factor training only significantly affected concrete nouns and verbs.

Matched Free Recall (Figure 7)

Results. When participants combined the word in Vimmi with its correspondent in the mother tongue (Figure 7), the factor word category was significant, $F(3,57) = 17.67$, $p < .001$. The factor training nearly reached significance. We also found an interaction between word category and training, $F(3,57) = 3.12$, $p < .05$.

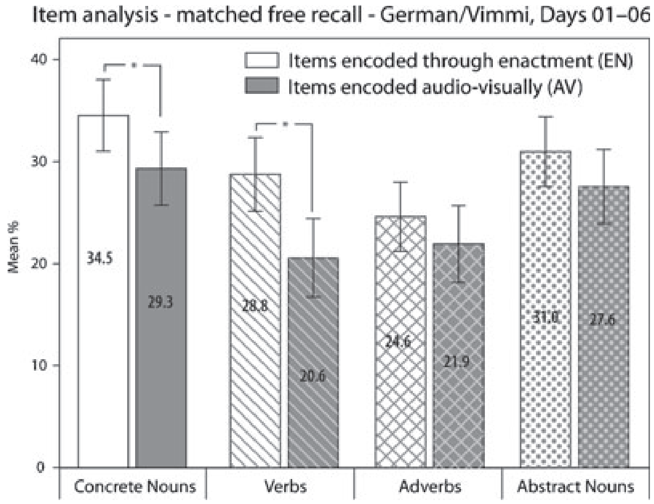

Fig. 7. Item analysis in the matched free recall test, days 1–6. In this test, participants recalled both languages, German and Vimmi, correctly linked with each other. Again, we find the ranking concrete nouns, abstract nouns, verbs, and adverbs. Also in this item analysis, enactment produces better results. However, the difference is not significant for all word classes.

Cued Recall Tests (Figure 8a, b)

Results. In the translation from German to Vimmi (Figure 8a), both factors were significant; word category, $F(3,15) = 16.16$, $p < .001$, and training, $F(1,5) = 12.14$, $p < .05$. Furthermore, we found an interaction between both factors, $F(3,15) = 8.25$, $p < .01$.

In the translation from Vimmi into German (Figure 8b), word category and training were significant, $F(3,15) = 24.69$, $p < .001$ and $F(1,5) = 14.2$, $p < .05$, respectively. We again obtained an interaction between word category and training, $F(3,15) = 8.57, p < .01$.

All Tests Averaged (Figure 9)

More generally, by averaging over all tests and time points as illustrated in Figure 9, we found that concrete nouns are best memorized, followed by verbs, abstract nouns, and adverbs.

Here, the ANOVA with the factors word category and training yielded significant results for both factors, with $F(3,15) = 7.71, p < .01$ and $F(1,5) = 52.47, p < .01$, respectively. An interaction between training and word category was also present, $F(3,15) = 3.74$, $p < .05$.

Sentence Production (Figure 10)

Results. The item analysis for the written production of new sentences (Figure 10) in the time window days 4–6 revealed that both the factors training and word category were significant, $F(1,19) = 20.28$, $p < .001$ and $F(3,57) = 6.24$, $p < .01$, respectively.

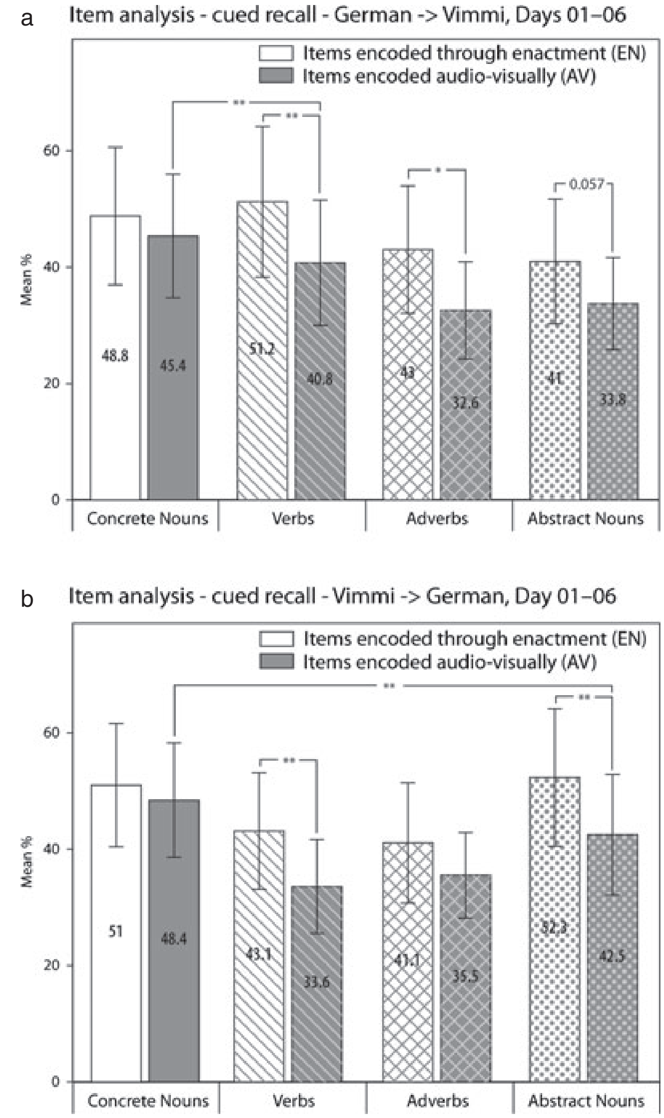

Fig. 8. Item analysis in cued recall for German into Vimmi (a) and Vimmi into German (b) averaged over days 1–6. We find the ranking of recall as previously described: concrete nouns are followed by abstract nouns, verbs, and adverbs. Interestingly, in the translation direction from German into Vimmi (7a), the difference between concrete and abstract nouns disappears in the enactment condition but remains for words encoded audio visually.

DISCUSSION

The following findings of the study can be highlighted:

Memory Performance

We predicted superior memory performance for encoding through enactment. For this purpose, participants learned an artificial corpus of abstract sentences. Participants were tested with different assessment modalities and at different stages of the training process. Our results clearly show

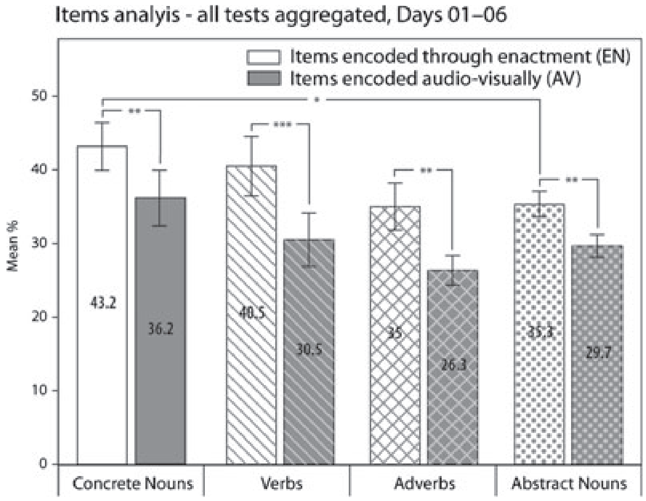

Fig. 9. Item analysis, averaged over all tests (i.e., free recall German, Vimmi, matched free recall, cued recall from German into Vimmi and vice versa, and new sentence production) and days. Note that in this measurement, adverbs also significantly show an advantage for training through enactment.

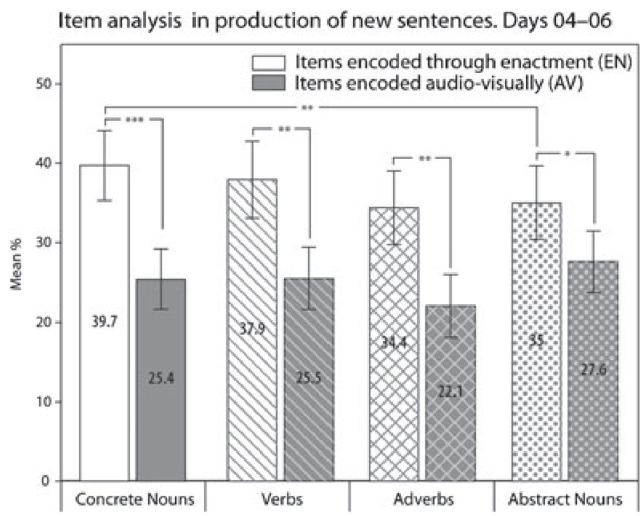

Fig. 10. Item analysis in the new sentence production for days 4–6. When producing new sentences, participants used significantly more items encoded through enactment. The difference was not only present for the traditional items favored by enactment like concrete and abstract nouns, but also for verbs and most interestingly for adverbs. These data suggest that enactment makes items more accessible in memory and leads to enhanced sentence production, thus to enhanced learning of foreign languages.

that learning through enactment in addition to audiovisual encoding, enhances memory performance. This is in line with previous studies on the effect of enactment on single items and expressions and extends it to items learned in the context of sentences of a controlled foreign language artificial corpus. We interpret our result in the light of the theories on enactment that we identified in the introduction. According to these theories, better memory through enactment relies on multimodal encoding, on complexity in the word's representation induced by the gesture and therefore on enhanced depth of processing.

Although some participants questioned the training and asserted that enacting would "disturb" them, enacting proved to induce superior memory performance. The reason why foreign language training benefits from enactment is possibly related to the fact that the brain performs perception in a multimodal way (Calvert, Campbell, & Brammer, 2000; Calvert, Spence, & Stein, 2004). While older theories described perception as modular, with its different modalities operating independently as separate processes, experimental evidence in the last decade has demonstrated that the brain does not work in isolated circuits. Instead, information is processed in highly interconnected functional networks (Ghazanfar & Schroeder, 2006) in which interactions between modalities occur throughout processing (Cappe, Rouiller, & Barone, 2009). In other words, enactment enhances verbal learning in a foreign language because it provides multimodal and sensorimotor information necessary for optimal information processing.

Of course, our experimental design cannot unequivocally clarify if the enhancement comes because participants saw or because they saw and performed the gestures. We assume that it is performing the gesture that leads to better memory based on the literature. This is derived from the fact that the question of whether observation of another person performing the gesture or performing it oneself is the factor leading to memory enhancement was addressed in the beginning of enactment research. In an early experiment by Engelkamp and Zimmer, subjects learned items by watching the experimenter performing the action (experimenter-performed task, EPT) and by performing the actions themselves (subject-performed task, SPT): SPT memory was better than EPT memory (Engelkamp & Zimmer, 1983). The SPT effect was also documented if the item lists were long and if—within the list—encoding conditions were mixed (Engelkamp & Zimmer, 1997). However, we note that an experimental design comparing memory performance on novel items of an artificial corpus learned through audiovisual encoding, gesture observation, and gesture performance would provide stronger evidence for our position.

Memorability and Concreteness

On the basis of previous research, our prediction concerning memory performance for word category (i.e., that nouns are better recalled than verbs and verbs are better recalled than adverbs) was also confirmed by the data. The ranking suggests that memorability is related to concreteness of the items. In fact, the average performance of all tests (Figure 9) shows that nouns were memorized best, followed by verbs, abstract nouns, and adverbs ranked last. Interestingly, the division of the class noun into concrete and abstract nouns provided further evidence of the relationship between concreteness and memory retrieval: Concrete nouns remained in first position whereas abstract nouns ranked behind verbs, just before the adverbs, and did not differ significantly from them. The fact that mimesis is a component of communication might explain why concrete words benefit most from gestures (McCafferty, 2008). Also, the connection between memorability and concreteness can be interpreted in terms of theories of embodied cognition (Barsalou, 2008; Glenberg, 1997; Taylor, Lev-Ari, & Zwaan, 2008). According to these theories, cognition interfaces with perception and action. These theories ground the meaning of linguistic units in perceptual experience in interaction with the world. In recent years, the focus of research has been on embodiment through “referential motor resonance” (Fischer & Zwaan, 2008). It was demonstrated that simply listening to action words induces activity in motor brain areas (Pulvermuller, 2005). Furthermore, words are somatotopically mapped into the topography of motor cortices with a high degree of precision (D’Ausilio et al., 2009). Not only listening to words but also silent reading of words activates brain areas related to action. Hauk and colleagues demonstrated that the word *kick* activates areas in the motor strip that are also active when subjects move their feet (Hauk et al., 2004). This study further showed that word processing in motor areas is fine-grained. In fact, *pick* and *lick* induced changes in blood flow in regions controlling movements of hand and tongue. Similarly, silent reading of idioms with arm- and leg-related action words induces activity in brain regions controlling those body parts (Boulenger et al. 2009). Considering that idiomatic expressions are to a certain degree semantically opaque, it is remarkable how embodiment grounds a word’s semantics. Interestingly, embodiment not only maps action into cognition; rather it also records and integrates any sensorial experience into higher cognitive processes. Thereby, any perception can be a part of a complex representation of a word, like, for example, *odor*. In an fMRI study by Gonzáles and colleagues, it was enough for the subjects to read the word *cinnamon* in order to evoke brain responses in olfactory areas (González et al., 2006).

When considering different degrees of embodiment among linguistic units, a phrase like *cut the bread* is more grounded in action than a phrase like *consider the issue*. In the former case, the person has performed the action thousands of times in her/his life by making a sequence of movements and a number of sensorial experiences connected with the food. Because of the sensorial experiences concrete concepts allow, their linguistic representation is richer than those of abstract concepts, their degree of embodiment is higher and their memorability is better. Thus, it is conceivable that concrete nouns are better recalled than abstract nouns. Interestingly, in the cued recall item analysis, the word category for which use of enactment makes the least difference is concrete nouns. We presume that concrete words already “contain” an embodied connotation that might compensate for the lack of a gesture in the audiovisual condition. In other words, concrete words are per se richer in sensorimotor information, this enrichment having being possibly created during first language acquisition and through experience in everyday life.

In our data, verbs were the second category in the overall ranking. We reason that if a verb is abstract, like *enjoy* or *appreciate*, even if it does not produce a visible movement or a gesture, it still contains an idea of action—of an actor doing something. Thus, we speculate that an abstract verb might also be embodied to a certain degree and therefore it might take advantage of enactment.

In the case of abstract nouns, especially those not derived from a verb and not containing any action in their semantic core representation, like *innocence*, for example, embodiment might function differently. Thinking of *innocence* opens associative windows, for example, to children and/or to somebody expressing her/his innocence by shrugging her/his shoulders. The action of shrugging one’s shoulders can become the embodied component of *innocence*. Thus, words that are not overtly embodied like *cut* can also be grounded in perception and action by means of the association they allow. In other words, the degree of embodiment, hence concreteness and therefore memorability, might not only be connected to intrinsic sensorimotor components present in the representation of the word itself, but also to the sensorimotor components of associable words present in its semantic field. Because items such as *therefore* and *rather* cannot be grounded intrinsically in the body or easily allow associations in their semantic fields, adverbs rank last in our list. They have few chances to form sensorimotor associations, their embodiment is poor, hence their memorability low.

However, as our study shows, adverbs also have a chance to be better memorized in foreign language learning. The results confirmed the prediction that within the same category, enactment leads to superior memory performance as the graph (Figure 9) demonstrates. As shown, this also holds for adverbs, the word class we described as having the smallest potential to benefit from embodiment.

In the light of the above considerations, our data suggest that enactment produces two effects on memory for the words under investigation. First, enactment strengthens the connections to embodied features of the word contained in its core semantic representation, or to associated items. Second, enactment can construct an embodied representation, which was not originally present, from scratch. Consider a gesture for the word *rather*. It is evident that *rather* cannot be illustrated by a representational gesture. Thus, in order to embody it, the gesture must be arbitrary. Such a gesture has a symbolic value for the linguistic items it accompanies. When the symbolic gesture is performed, a sequence of movements is produced. They enrich the word's representation and possibly leave a motor trace in the representation of the word, in this case an adverb. From this perspective, enactment can be considered as a tool that can potentially embody any kind of verbal information and mechanically enhance its memorability. The finding that not only concrete words but also abstract items are better memorized if enacted is central to our experiment. However, only future neuroscientific research will be able to effectively demonstrate whether enactment changes the neural representation of an abstract word by adding a sensorimotor component, in this case a motor trace as suggested by Engelkamp in early years (Engelkamp & Krumnacker, 1980).

Enacting Sentences

Our results have confirmed the prediction that not only single words in a foreign language but also words presented in sequences—here, simple transitive sentences—can be enacted. Besides proving that enactment of whole sentences is feasible, we showed that enactment is a powerful tool not only for single item encoding but also for text encoding. If further research can also demonstrate the superiority of enactment in texts containing inflectional morphology and consisting of different syntactic structures, a rethinking about audiovisual encoding will be needed. In fact, in the last two decades, mainly audiovisual strategies, such as listening and comprehension activities, have been employed in foreign language instruction.

Enhanced Language Production

Beyond the effect on memory retrieval for concrete and abstract words encoded in the context of sentences, the main contribution of this study was to explore how enactment affects the accessibility of memorized words. We demonstrated that enacted items were recruited significantly more often when participants produced new sentences. Our findings not only provide additional evidence of better accessibility of enacted items but also prove that enactment enhances foreign language production and therefore use.

CONCLUSION

If adding a gesture to a word in a foreign language is a key to better storage and slower decay, teaching and learning should take this into account. The possibilities are enticing: Teachers could present new texts by connecting non-associable words with gestures and cueing students to repeat them. Learners could forsake their archaic vocabulary lists and instead invent and perform their own actions accompanying new items, either individually or in sentences. Indeed, similar suggestions have previously been made in foreign language teaching literature describing the superiority of this learning strategy (Macedonia, 1999), yet beyond anecdotal evidence, experimental evidence was lacking. This study shows that enactment, a fascinating phenomenon of embodied cognition, enhances memory not only for concrete but also for abstract words. Within the abstract words, enactment significantly enhances memory for items of different grammatical classes, including adverbs, which scarcely contain an embodied component. Furthermore, this study has shown that enactment leads to enhanced language production. On the base of previous studies and of our results, we conclude that enactment can be considered as a tool empowering foreign language instruction and learning.

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REFERENCES

Allen, R., & Hulme, C. (2006). Speech and language processing mechanisms in verbal serial recall. *Journal of Memory and Language*, *55*(1), 64–88.

Asher, J. J. (1969). Total physical response technique of learning. *Journal of Special Education*, *3*, 253–262.

Bäckman, L., & Nilsson, L. G. (1984). Aging effects in free recall: An exception to the rule. *Human Learning: Journal of Practical Research & Applications*, *3*(1), 53–69.

Bäckman, L., & Nilsson, L. G. (1985). Prerequisites for lack of age differences in memory performance. *Experimental Aging Research*, *11*, 67–73.

Bäckman, L., Nilsson, L. G., & Chalom, D. (1986). New evidence on the nature of the encoding of action events. *Memory and Cognition*, *14*, 339–346.

Baddeley, A. (2003). Working memory and language: an overview. *Journal of Communication Disorders*, *36*, 189–208.

Baddeley, A., Thompson, N., & Buchanan, M. (1975). Word length and the structure of memory. . *Journal of Verbal Learning & Verbal Behavior*, *14*, 575–589.

Baraduc, P., Lang, N., Rothwell, J. C., & Wolpert, D. M. (2004). Consolidation of dynamic motor learning is not disrupted by rTMS of primary motor cortex. *Current Biology*, *14*, 252–256.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Barsalou, L. W., Kyle, S. W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, *7*(2), 84–91.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychology Review*, *108*, 624–652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in Cognitive Sciences*, *8*, 539–546.

Boulenger, V., Hauk, O., & Pulvermuller, F. (2009). Grasping ideas with the motor system: Semantic somatotopy in idiom comprehension. *Cerebral Cortex*, *19*, 1905–1914.

Calvert, G., Spence, C., & Stein, B. E. (2004). *The handbook of multisensory processes.* Cambridge, MA: MIT Press.

Calvert, G. A., Campbell, R., & Brammer, M. J. (2000). Evidence from functional magnetic resonance imaging of crossmodal binding in the human heteromodal cortex. *Current Biology*, *10*, 649–657.

Cappe, C., Rouiller, E. M., & Barone, P. (2009). Multisensory anatomical pathways. *Hearing Research*, *258*(1–2), 28–36.

Chee, M. W., Westphal, C., Goh, J., Graham, S., & Song, A. W. (2003). Word frequency and subsequent memory effects studied using event-related fMRI. *NeuroImage*, *20*, 1042–1051.

D'Ausilio, A., Pulvermüller, F., Salmas, P., Bufalari, I., Begliomini, C., & Fadiga, L. (2009). The motor somatotopy of speech perception. *Current Biology*, *19*, 381–385.

Engelkamp, J., & Krumnacker, H. (1980). Imaginale und motorische Prozesse beim Behalten verbalen Materials. *Zeitschrift für experimentelle und angewandte Psychologie*, *27*, 511–533.

Engelkamp, J., & Zimmer, H. (1983). Zum Einfluß von Wahrnehmen und Tun auf das Behalten von Verb-Objekt-Phrasen. *Sprache & Kognition*, 117–127.

Engelkamp, J., & Zimmer, H. D. (1984). Motor program information as a separable memory unit. *Psychological Research*, *46*(3), 283–299.

Engelkamp, J., & Zimmer, H. D. (1985). Motor programs and their relation to semantic memory. *German Journal of Psychology*, *9*(3), 239–254.

Engelkamp, J., & Zimmer, H. D. (1997). Sensory factors in memory for subject-performed tasks. *Acta Psychologica*, *96*(1–2), 43–60.

Engelkamp, J., Zimmer, H. D., & Biegelmann, U. E. (1993). Bizarreness effects in verbal tasks and subject-performed tasks. *European Journal of Cognitive Psychology*, *5*, 393–415.

Eschen, A., Freeman, J., Dietrich, T., Martin, M., Ellis, J., Martin, E., et al. (2007). Motor brain regions are involved in the encoding of delayed intentions: A fMRI study. *International Journal of Psychophysiology*, *64*, 259–268.

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology*, *61*, 825–850.

Gentner, D., & Boerman, M. (2009). Why some spatial semantic categories are harder to learn than others. In E. L. J. Guo, S. Ervin-Tripp, N. Budwig, S. Özçaliskan, & K. Nakamura (Eds.), *Crosslinguistic approaches to the psychology of language: Research in the tradition of Dan Isaac Slobin* (pp. 465–480). New York: Erlbaum.

Gentner, D., & Boroditsky, L. (2009). Early acquisition of nouns and verbs: Evidence from Navajo. In V. Gathercole (Ed.), *Routes to language: Studies in honor of Melissa Bowerman.* New York: Taylor & Francis.

Ghazanfar, A. A., & Schroeder, C. E. (2006). Is neocortex essentially multisensory? *Trends in Cognitive Sciences*, *10*, 278–285.

Glenberg, A. M. (1997). What memory is for: Creating meaning in the service of action—Author's response. *Behavioral and Brain Sciences*, *20*(1), 1–19.

González, J., Barros-Loscertales, A., Pulvermüller, F., Meseguer, V., Sanjuán, A., Belloch, V., et al. (2006). Reading cinnamon activates olfactory brain regions. *NeuroImage*, *32*, 906–912.

Gregersen, T., Olivares-Cuhat, G., & Storm, J. (2009). An examination of L1 and L2 gesture use: What role does proficiency play. *The Modern Language Journal*, *93*, 195–208.

Gullberg, M. (2008). Gestures and second language acquisition. In P. Robinson (Ed.), *Handbook of cognitive linguistics and second language acquisition* (pp. 276–305). London: Routledge.

Gullberg, M., & Indefrey, P. (2006). *The cognitive neuroscience of second language acquisition.* Malden, MA and Oxford, UK: Blackwell.

Gullberg, M., & McCafferty, S. G. (2008). Introduction to gesture and SLA: Toward an integrated approach. *Studies in Second Language Acquisition*, *30*, 133–146.

Hamilton, M., & Rajaram, S. (2001). The concreteness effect in implicit and explicit memory tests. *Journal of Memory and Language*, *44*(1), 96–117.

Hammond, M. (2003). *Programming for linguists: Perl for language researchers.* Malden, MA and Oxford, UK: Blackwell.

Hauk, O., Johnsrude, I., & Pulvermuller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, *41*, 301–307.

Hunt, R. R., & Worthen, J. B. (2006). *Distinctiveness and memory.* New York and Oxford, UK: Oxford University Press.

Jalbert, A., Neath, I., Bireta, T. J., & Surprenant, A. M. (2011). *When does length cause the word length effect? Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*, 338–353.

Kelly, S. D., Creigh, P., & Bartolotti, J. (2009). Integrating speech and iconic gestures in a stroop-like task: Evidence for automatic processing. *Journal of Cognitive Neuroscience*, *22*(4), 683–694.

Kelly, S. D., McDevitt, T., & Esch, M. (2009). Brief training with co-speech gesture lends a hand to word learning in a foreign language. *Language and Cognitive Processes*, *24*, 313–334.

Klimesch, W. (1994). *The structure of long-term memory: a connectivity model of semantic processing.* Hillsdale, NJ: Erlbaum.

Knopf, M. (1992). Gedächtnis für Handlungen. Funktionsweise und Entwicklung. Unpublished post-doctoral thesis, University of Heidelberg, Heidelberg, Germany.

Knudsen, E. I. (2007). Fundamental components of attention. *Annual Review of Neuroscience*, *30*, 57–78.

Kormi-Nouri, R. (1995). The nature of memory for action events: An episodic integration view. *European Journal of Cognitive Psychology*, *7*(4), 337–363.

Kormi-Nouri, R. (2000). The role of movement and object in action memory. *International Journal of Psychology*, *35*, 132–132.

Lazaraton, A. (2004). Gesture and speech in the vocabulary explanations of one ESL teacher: A microanalytic inquiry. *Language Learning*, *54*(1), 79–117.

Macedonia, M. (1999). *Sinn-voll Fremdsprachen unterrichten.* Linz, Austria: Veritas-Cornelsen.

Macedonia, M. (2003). *Voice Movement Icons. Sensomotorische Encodierungsstrategie zur Steigerung der quantitativen und qualitativen Lerneffizienz bei Fremdsprachen.* PhD Thesis, Universität Salzburg, Salzburg, Germany.

Macedonia, M., Müller, K., & Friederici, A. D. (2011). The impact of iconic gestures on foreign language word learning and its neural substrate. *Human Brain Mapping*, *32*, 982–998.

Masumoto, K., Yamaguchi, M., Sutani, K., Tsuneto, S., Fujita, A., & Tonoike, M. (2006). Reactivation of physical motor information in the memory of action events. *Brain Res*, *1101*, 102–109.

McCafferty, S. G. (2008). Mimesis and second language acquisition: A sociocultural perspective. *Studies in Second Language Acquisition*, *30*, 147–167.

McCafferty, S. G., & Stam, G. (2008). *Gesture : second language acquisition and classroom research.* London: Routledge.

Muzzio, I. A., Kentros, C., & Kandel, E. (2009). What is remembered? Role of attention on the encoding and retrieval of hippocampal representations. *The Journal of Physiology*, *587*, 2837–2854.

Nilsson, L. G. (2000). Remembering actions and words. In F. I. M. Craik & E. Tulving (Eds.), *The Oxford handbook of memory* (pp. 137–148). Oxford, UK: Oxford University Press.

Pavicic-Takac, V. (2008). *Vocabulary learning strategies and foreign language acquisition.* Clevedon, UK and Buffalo, NY: Multilingual Matters.

Peterson, D., & Mulligan, N. (2010). Enactment and retrieval. *Memory & Cognition*, *38*, 233–243.

Pulvermuller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience*, *6*, 576–582.

Quinn-Allen, L. (1995). The effects of emblematic gestures on the development and access of mental representations of french expressions. *The Modern Language Journal*, *79*, 521–529.

Roodenrys, S., Hulme, C., Lethbridge, A., Hinton, M., & Nimmo, L. M. (2002). Word-frequency and phonological-neighborhood effects on verbal short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 1019–1034.

Saltz, E., & Donnenwerthnolan, S. (1981). Does motoric imagery facilitate memory for sentences—A selective interference test. *Journal of Verbal Learning and Verbal Behavior*, *20*, 322–332.

Shadmehr, R., & Holcomb, H. H. (1997). Neural correlates of motor memory consolidation. *Science*, *277*, 821–825.

Shams, L., & Seitz, A. R. (2008). Benefits of multisensory learning. *Trends in Cognitive Sciences*, *12*, 411–417.

Spranger, T., Schatz, T. R., & Knopf, M. (2008). Does action make you faster? A retrieval-based approach to investigating the origins of the enactment effect. *Scandinavian Journal of Psychology*, *49*(6), 487–495.

Taylor, L. J., Lev-Ari, S., & Zwaan, R. A. (2008). Inferences about action engage action systems. *Brain and Language*, *107*(1), 62–67.

Tellier, M. (2008). The effect of gestures on second language memorisation by young children. *Gesture*, *8*, 219–235.

Zimmer, H. D., Helstrup, T., & Engelkamp, J. (2000). Pop-out into memory: A retrieval mechanism that is enhanced with the recall of subject-performed tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*, *26*(3), 658–670.