Title
Non-Native Language Processing Engages Mental Imagery

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 28(28)

ISSN
1069-7977

Authors
Wheeler, Kathryn B.
Stojanovic, Diana

Publication Date
2006

Peer reviewed

Non-Native Language Processing Engages Mental Imagery

Kathryn B. Wheeler (katrev21@aol.com)
Diana Stojanovic (stojanov@hawaii.edu)
Department of Linguistics, 569 Moore Hall, 1890 East West Road,
Honolulu, HI 96822 USA

Abstract

The theory of simulation semantics (Bergen & Chang 2005) posits that understanding language, in part, requires activation of mental imagery. This allows understanders to mentally re-create the scene or event to facilitate understanding and prepare for situated action (Glenberg & Kashak 2002). The idea that understanding action language relies on neural circuitry involved in action execution is supported by a cross-modal matching method introduced by Bergen et al. (2003), which demonstrated that specific effectors (hand, mouth, foot) are critical to the motor imagery involved in language understanding. Previous studies, however, have focused exclusively on adult native speakers, which leaves open the question of how language-driven imagery develops during language acquisition. The current study investigates whether non-native English speakers engage in mental simulation during language processing. We used an image-verb forced-choice matching task, where an image and verb depict different actions using either the same effector (e.g. *grab* and *push*) or different effectors (e.g. *grab* and *lick*). As in previous work with native speakers, response times were significantly longer when the two actions used the same effector. Moreover, subjects showed a correlation between stimulus comprehension accuracy and the size of the simulation effect. This suggests that non-native speakers not only perform mental imagery like native speakers but do so increasingly as their linguistic competency improves.

Keywords: Motor imagery, simulation semantics, motor representation, L2 acquisition

Introduction

A theory of cognition based on mental simulation has increasingly received both neurophysiological and behavioral support from a wide range of sources – psychology, neuroscience, artificial intelligence, and linguistics. Beginning with the breakthrough discovery of "mirror neurons" that become active in the motor cortex of rhesus monkeys during both action execution and action observation (Gallese et al., 1996; Rizzolatti et al., 1996), research has exploded exploring similar overlapping structures in humans that are involved in comprehension, interpretation, and memory of perceptual and motor information (Lotze et al. 1999; Porro et al., 1996; Gallese et al., 1996; Nyberg et al., 2001; Wheeler et al., 2000).

It has been previously shown that the motor cortex is somatotopically arranged such that sections are devoted to specific effectors, such as mouth, arm, or leg (Buccino et al., 2001). Ehrsson et al. (2003) give evidence that this somatotopic division holds true during exclusively imagined activity as well, showing that actions need not be overt to induce effector-specific localized neural activation.

Complementing a burgeoning theory of meaning that relies on the embodiment of language, Pulvermuller et al. (2001) have shown that motor structures are selectively active when understanding and producing verbs describing actions performed with specific effectors. Further, Tettamanti et al. (ms.) found that even passive listening to sentences describing motion by three main effectors -- mouth, hand, leg -- activated different motor regions. In other words, in processing action language, an understander relies upon the same cognitive structures involved in performing actions, in effect running a mental simulation of what it would be like to perform the action.

This idea of mental simulation also supports a view of understanding as embodied, where the world is perceived and interpreted based on the way the body interacts with it (Zwaan, 1999; Feldman & Narayanan, 2003). It is intuitive to think the systems underlying tangible (perceptual, motor) experiences, being our most immediate and concrete connection to the world, would serve to facilitate other kinds of cognitive behaviors, like language comprehension and memory. Behavioral evidence of visual and motor imagery during language processing shows that understanders rely on mental imagery to interpret language about visual scenes (Kosslyn et al., 2001; Zwaan et al., 2002) or actions (Glenberg & Kashak 2000). In other words, running an internal re-creation of the scene or event facilitates understanding and responding to linguistic input.

In order to address the degree of specificity involved in the mental simulation of action language, Bergen et al. (2003) used a forced-choice matching task to see whether subjects would show greater response latency when a picture and verb depicted different actions using the same effector (mouth, hand, or leg) than when they depicted different actions using different effectors. As predicted, subjects indeed responded more quickly to mismatches when the implied effectors were different, which indicated that there was additional processing load when the same cognitive structure was required to process two competing inputs. This result was reinforced by a follow-up study by Narayan et al. (2004), which replicated this experiment with a lexical matching task.

While the connection between language and motor simulation has been established, there remains an important dimension that has yet to be explored. Thus far studies have been conducted almost exclusively on subjects in their native languages, yet the majority of the world is multilingual making it important to address the issue of second language processing. This study seeks to answer two key questions related to non-native simulation. The first is simply whether non-native speakers are performing mental imagery (simulation) during language comprehension. Non-native speakers develop native-like competence over time and we explain this development of L2 processing from a controlled to an automatic process by way of McLaughlin's (1987) information processing theory. Automatic processes do not restrict attention and can be done in parallel, implying a faster performance. We predict that simulation is a key element to "native-like" processing, and that L2 learners gradually change their processing strategy from "translation of L1 into L2", which is a controlled, attention-demanding process, to "simulation", a fast, attention-free, automatic process used by native speakers. We argue that simulation is a key element to "native-like" processing, as it is computationally more efficient than an approach based on language understanding by "translation from L1". Non-native simulation in language learners can be secondarily informative by offering insights into L1 acquisition since it can rely on comparisons between adult speakers and learners to shed light on the developmental aspects of simulation.

The second question of non-native simulation we address is whether learning a second language involves not only acquiring proficiency in the formal structures of the language (syntax, phonology, semantic relations), but also gaining the ability to process linguistic meaning like native speakers do. Specifically, when learning a non-native language, we want to know if speakers increasingly engage tools like mental simulation when understanding, just like a native speaker.

The basis for the interference effect hypothesized in this task is mutual inhibition. In order to maximize functionality, similar neural structures at given levels need to mutually inhibit each other, which means that the more similar the information they encode, the greater the mutual competition. In other words, when one neural region is required to simultaneously evaluate two competing pieces of information, processing time is increased for both inputs. In terms of the experiment, subjects presented with two different actions should be slower to distinguish them when the two actions involve the same effector than when they use different effectors. This interference indicates that subjects are not simply observing general properties of the image and the verb, but actually performing a mental simulation of the actions and what they entail.

Simulation is built on experience with the world and is, therefore, a tool that must necessarily develop and improve along with increased experience. As language skills improve in connection with simulation, proficiency could be directly related to the degree of mental simulation being performed by an understander. In order to look at this potential relationship, a vocabulary test – a measure frequently used to determine proficiency – was conducted after the main experiment. We predicted that if proficiency and simulation are related, higher vocabulary scores will correlate with stronger simulation interaction effects.

Method

The work reported below is, to our knowledge, the first departure from the existing work on mental simulation to provide evidence on whether non-native speakers of a language engage in mental simulation for understanding. This research, drawing on the method from Bergen et al. (2003), demonstrates that non-native English speakers show simulation effects like those of native English speakers.

Subjects performed a forced-choice task, deciding whether an image and a verb depicted the same action. Critically, when the actions were different, the body part involved in the action (mouth, arm, or leg) was either the same or different. If the non-native speakers are in fact performing mental imagery in understanding, then when the actions are different, response times should be longer when the involved effector is the same than when it is different.

There were two dimensions of variation which were not directly controlled between subjects in this experiment: native language and English proficiency. The latter is not only difficult to control, but also to define. Subjects were drawn from a variety of native language groups and were proficient enough to enroll in mainstream classes at the University of Hawai'i Manoa[1]. In order to have an independent measure of ability across subjects[2], we included a vocabulary test at the end of the experiment to determine whether subjects' vocabulary – one measure of proficiency – correlated with their degree of motor simulation.

Subjects

One subject was excluded for performing the task with less than eighty percent accuracy. The remaining 39 subjects were analyzed (25 women), ranging in age from 18 to 49 years with a mean age of 26.8. All subjects were right-handed, non-native speakers of English enrolled in mainstream classes at the University of Hawai'i Manoa who participated in exchange for either course credit or five dollars. Subjects self-reported total years of studying English from 2 to 29 years with a mean length of study around 14 years.

Materials

The picture-verb stimulus pairs were taken from Bergen et al. (2003) with a written verb and a stick-figure drawing depicting an action. Each picture and verb action used one of three effectors: mouth, hand, or foot. Pairs were in one of three conditions (Table 1): matching (picture and verb depict the same action), non-matching, different effector (picture and verb depict different actions using different effectors), and non-matching, same effector (picture and verb depict different actions using the same effector). There were 48 picture-verb pairs per half (24 matching; 12 non-

[1] This requires a minimum TOEFL composite score of 173 (computer), 61 (internet), or 500 (paper).

[2] Exact TOEFL scores were not collected from each subject but this could be a potentially meaningful correlation for future studies.

matching, same effector; 12 non-matching, different effector) for a total of 96 stimuli. Subjects saw each picture in two conditions: once in the matching and once in either of the non-matching conditions (half same and half different effector). Subjects were randomly assigned to do one of two experiment versions with the three conditions and effectors counter-balanced so that no subject saw the same item in both of the non-matching conditions.

No verbs from the original study were excluded although at least two were questionable with regard to the rate of familiarity among even advanced non-native language learners. In order to preserve the original design, these items were included with the assumption that outlying items would be excluded prior to analysis. Only correct responses were analyzed.

Table 1: Verbs in the three conditions with the image *kick*.

	Image
Matching verb	'Kick'
Non-matching, same effector	'Run'
Non-matching, diff. effector	'Drink'

Procedure

Subjects performed a matching task where they decided if the depicted action and described action were the same, and pressed either the "k" key labeled YES or the "d" key labeled NO to indicate their decision. They were verbally instructed to keep one finger from each hand over each key throughout the experiment. A training session preceded the main experiment.

Each trial went as follows. A fixation cross appeared center-screen for 1000 ms, followed by the picture for 1000 ms, a visual mask for 450 ms, a 50 ms pause, and finally the verb appeared center-screen and remained until the subject pressed either the YES or NO button.

When subjects completed the main experiment, they were then asked to answer a few easy questions and given the following instructions: "You will see an action verb. Please decide what body part the action uses: mouth, hand/arm, foot/leg. For example, "jump" uses the foot/leg."

They were asked to respond by pressing buttons labeled MOUTH, HAND, and FOOT. We included both words for the hand/arm area and the foot/leg area to ensure subjects demonstrated a general awareness of the region used for the verb rather than requiring strict specificity. Since the vocabulary test was intended to gauge subjects' understanding of the verbs as they might be simulated, we wanted the decisions to correlate with effector areas involved in visual or motor imagery. Response accuracy was measured.

Results

As expected, some vocabulary items were unfamiliar, which resulted in the exclusion of nine items prior to analysis due to a mean accuracy rate of less than eighty percent on the main experiment. Excluded verbs came relatively evenly from each of the effector groups (three mouth, two hand, and four foot). For each subject, outlying response times (RTs) were replaced with the RT 2.5 standard deviations from that subject's mean RT.

A main effect of match versus non-match was marginally significant, $F_1(1,39)=3.83$; $p=.058$.

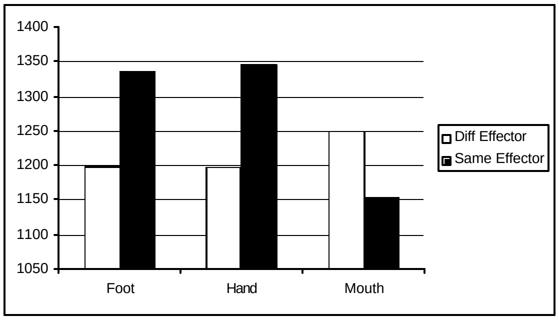
Table 2: Mean Response Times for the three conditions

Condition	Mean (msec)	Std.Dev. (msec)
Matching	1197.753	419.391
Non-match, Different Effector	1215.955	434.2224
Non-match, Same Effector	1283.625	384.6534

The critical interaction we were interested in was between the non-matching conditions only. A repeated measures analysis of variance showed the predicted interaction effect to be significant: $F_1(1,39)=5.502$; $p<.05$. The items analysis was not significant ($F_2(1,39)=.804$; $p=.376$), so we investigated the items effects by effector. A two-way analysis with effector and non-match condition as independent variables was highly significant: $F_1(1,39)=10.632$; $p<.001$. In two-way analyses with pairs of effectors, foot and hand verbs did not behave statistically differently from each other ($F_1(1,39)=.054$; $p=.817$), but mouth verbs were found to act differently from the other two effectors (Fig 1): mouth and hand, $F_1(1,39)=11.075$; $p<.005$; mouth and foot, $F_1(1,39)=17.159$; $p=.000$.

Figure 1: Mean subject Response Times (msec) in non-matching conditions by effector with means table.

	Diff Effector	Same Effector
Foot	1198	1337
Hand	1198	1347
Mouth	1249	1155



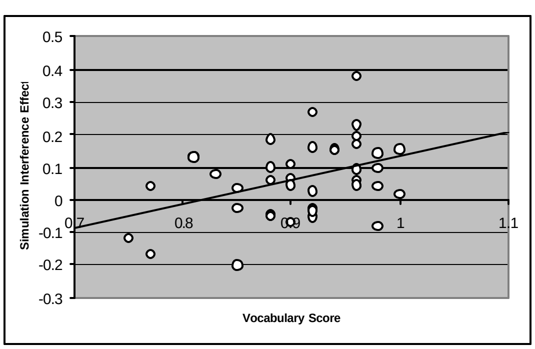
Response latency was longer overall as compared to Bergen et al. (2003) as seen in Table 3.

Table 3: Means table comparing reaction times (msec) per condition in the current study and Bergen et al. (2003).

	Bergen et al. study	Current study
Match	740.57	1197.753
Non-match, Different Effector	750.93	1215.955
Non-match, Same effector	798.54	1283.625

Turning now to the vocabulary test, speakers performed well overall (accuracy rate between 0.75 and 1 with a median score of 0.92). We performed a regression analysis correlating the vocabulary test results for each subject with the size of their simulation interaction effect. This latter statistic was calculated as the difference for each subject between the mean RT in the non-matching same-effector condition and the non-matching different-effector condition. Thus, larger simulation interaction effect sizes, reflecting greater degrees of interference, were expected to correlate positively with accuracy on the vocabulary test. The better the subject's understanding of the target vocabulary, the more mental simulation they should be performing. As predicted, the interference effect size correlated positively with increased language proficiency: $\beta = -9.75$, $t(39) = 26$, $p < .001$ (Fig. 2).

Figure 2: Regression analysis correlating vocabulary test accuracy with simulation interaction effect over subjects



Discussion of Effector Differences

In the non-matching conditions, subjects were faster to respond when both the image and verb used the mouth (same-effector condition). This effect is in direct opposition to the foot and hand verbs and was not reportedly present in the results of Bergen et al. (2003).

One possible explanation for this discrepancy between verbs using the foot or hand and those using the mouth could be the presence of overt or covert subvocalization by subjects. The idea of subvocal rehearsal has been linked to production, auditory working memory (the phonological loop), prosodic disambiguation (Slowiaczek & Clifton, 1980; Smith et al., 1995; Pich, 2000) and comprehension (Watkins et al., 2003; Watkins & Paus 2004), making it an important tool for language processing in both native and non-native speakers (Matsunaga, 2001). Since this task involved the comparison of two actions, the latter being linguistically represented, it would not be surprising if our non-native subjects relied heavily on subvocal rehearsal to both recall and compare the actions. If this were the case, neural structures associated with speech production and the vocal articulators would be covertly activated during the presentation of stimuli, and would thus be primed before the matching decision needed to be made. Contrary to the interference that occurs in the other effectors due to concurrent processing as they compare the actions, subvocalization on this account activates speech production regions of motor cortex before any additional processing is necessary. When mouth-specific motor structures are re-activated during imagery generation, priming will yield faster access to the representations of mouth actions and language. In other words, when the action depicted by a picture or described by a verb uses the mouth, the subject is primed to then simulate a mouth action due to subvocal activation of those motor structures.

Discussion of Results

It was not surprising that the non-native speakers had overall longer response times than the native speakers studied by Bergen et al. (2003), and the main effects were successfully replicated here. In the critical non-matching conditions, responses were slower when the two different actions used the same effector (e.g. *jump* and *kick*); an effect that has been argued to derive from mutual inhibition between competing neural structures that are active when the subject must simultaneously process related inputs.

The interesting difference in the results of this study is that the speakers were all advanced non-native learners and, although overall reaction times were longer, the same interference effect proved to be statistically significant. Since non-native speakers showed native-like simulation effects, certain conclusions can be drawn about language learning and imagery. Specifically, the regression analysis showed that the more vocabulary subjects were familiar with, the stronger their simulation (interaction) effect was, which suggests that there is an identifiable correlation between understanding more fully (which may tie in to proficiency) and simulation. We can conclude that these non-native speakers are relying on motor imagery for understanding in a similar way to native speakers.

Discussion of Vocabulary Test

This interaction tells us that the more experimental verbs the subject knew, the bigger the interaction effect, which can be interpreted as an indication that the more knowledgeable they were on this language task (potentially correlating with more general proficiency), the more simulation they performed. This suggests that learners may progressively develop the ability to recruit neural circuitry to perform mental simulation when understanding language. In other words, as non-native speakers become more competent and approach native-like ability, they increasingly rely upon simulation in processing linguistic input.

One possible objection to this idea of a correlation between vocabulary performance and simulation says that if a subject knows more of the verbs, the simulation interference effect size would be greater. This was nullified by the exclusion of all incorrect responses prior to analysis so they could not influence the effect. Conversely, one might object that due to a large number of unknown verbs, the effect size was actually diluted. This could, in fact, be a valid claim. However, if we assume subjects were guessing on the unknown verbs (a fifty percent chance of accuracy), this only accounts for half of the verbs they didn't know while the other half they guessed correctly, even though they didn't know their meaning or perform any imagery. This interpretation would lead us to a different but interesting line of reasoning that suggests second language learners are able to perform in native-like ways on some tasks without engaging in the same process of understanding that native speakers would rely upon, in this case mental simulation.

General Discussion

As predicted, non-native English-speaking subjects took longer to respond when an image action and verb action were different but the effector (mouth, hand, foot) necessary to perform the action was the same, as compared to different actions with different effectors. These results agree with neurophysiological evidence that a subset of the neural regions critical to action execution becomes active in response to non-overt representations (pictures, language, imagery) of an action. The visuo-motor system has been repeatedly linked to action-related information including action observation and action images (Kourtzi et al., 2000; Kable et al., 2002; Culham & Valyear, 2006) by way of mirror neurons (overlapping neural structures that become selectively active when both performing and perceiving an action). The mirror system is involved in mimicking, understanding, and learning (Buccino et al., 2004; Stefan et al., 2005) making it an integral part of memory storage and recall. In addition to action execution, action language also activates the mirror system (Hurford, 2002; Hamzai et al., 2003) which indicates that understanding how to do something and how to talk about doing something are neurally related.

This kind of event-semantic correlation suggests a theory of processing that takes action-related input and, in addition to modality-specific perceptual structures, activates a subset of systems that facilitate action execution (premotor cortex, supramarginal gyrus, anterior intraparietal gyrus; Noppeney et al., 2005), in effect performing a simulation of what it would be like to perform the action.

If native language speakers are relying on a simulation-based system when understanding language, non-native speakers, it would seem, could employ the same tactics when learning and understanding new linguistic concepts. In this experiment the response times were longer overall than among native English speakers (Bergen et al., 2003), which suggests some additional processing. We argue that non-native speakers have not quite achieved automatic (language) processing (McLaughlin, 1987) yet, which slows access through the comprehension process for linguistic input. Thus a word like *kick* might be analyzed as an action and then a foot action and finally integrate the perceptuo-motor details involved in kicking, while a native speaker would have a direct route to the final step.

Conclusion

The research reported here supports previous evidence that processing language about actions requires activation of neural structures devoted to action execution. It goes beyond other studies to show that non-native English speakers rely on mental imagery in understanding in the same way native English speakers do. Further, increased proficiency (as measured by vocabulary accuracy) is shown to correlate with a stronger interaction effect indicating increasing simulation as a function of proficiency. In other words, the more you simulate, the more you understand; or conversely, the more you understand, the more you simulate.

Acknowledgments

Many thanks to our advisor Dr. Ben Bergen for invaluable input and support along the way. Also, to members of the University of Hawai'i Language and Cognition Laboratory for ongoing advice and encouragement.

References

Bergen, Benjamin and Nancy Chang. (2005). Embodied Construction Grammar in Simulation-Based Language Understanding. In Jan-Ola Östman and Miriam Fried (Eds.), *Construction Grammar(s): Cognitive Grounding and Theoretical Extensions*. Amsterdam: Benjamin: 147-190.

Bergen, B., S. Narayan, and J. Feldman. (2003). Embodied verbal semantics: evidence from an image-verb matching task. In Proceedings of the Twenty-Fifth Annual Conference of the Cognitive Science Society.

Buccino, G., F. Binkofski, G. R. Fink, L. Fadiga, L. Fogassi, V. Gallese, R. J. Seitz, K. Zilles, G. Rozzolatti, and H. J. Freund. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Journal of Neuroscience*, 13 (2), 400-404.

Buccino, G., Vogt, S., Ritzi, A., Fink, G. R., Zilles, K., Freund, H.-J., & Rizzolatti, G. (2004). Neural circuits underlying imitation learning of hand actions: An event-related fMRI study. *Neuron*, 42, 323–334.

Culham, J.C. and K. F. Valyear. (2006). Human parietal cortex in action. *Current Opinion in Neurobiology*, 16, 1-8.

Ehrsson, H. H., S. Geyer, and E. Naito. (2003). Imagery of voluntary movement of fingers, toes, and tongue activates corresponding body-part specific motor representations. *Journal of Neurophysiology*, 90, 3304-3316.

Epstein, S.D., Flynn, S., & Martohardjono, G. (1996). Second language acquisition: Theoretical and experimental issues in contemporary research. *Behavioral and Brain Sciences* 19 (4), 677-758.

Feldman, J. and S. Narayanan. (2004). Embodiment in a Neural Theory of Language. *Brain and Language*, 89, 385-392.

Gallese, V., L. Fadiga, L. Fogassi, & G. Rizzolatti. (1996). Action recognition in the premotor cortex. *Brain* 119, 593-609.

Glenberg, A. and M. Kaschak. (2002). Grounding Language in Action. *Psychonomic Bulletin & Review*, 9(3), 558-565.

Hamzei, F., M. Rijntjes, C. Dettmers, V. Glauche, C. Weiller, & C. Buchel, (2003). The human action recognition system and its relationship to Broca's area: an fMRI study. *Neuroimage*, 19, 637, 644.

Kable, J.W., J. Lease-Spellmeyer, & A. Chatterjee, (2002). Neural substrates of action event knowledge, *Journal of Cognitive Neuroscience*, 14, 795–805.

Kourtzi, Z. and N. Kanwisher, (2000). Activation in human MT/MST by static images with implied motion, *Journal of Cognitive Neuroscience*, 12, 48–55.

Hurford, J.R. (2002). Language beyond our grasp: What mirror neurons can, and cannot, do for language evolution. Kimbrough Oller, D., U. Griebel and K. Plunkett (eds.) *The Evolution of Communication Systems: A Comparative Approach*. The Vienna Series in Theoretical Biology, MITPress, Cambridge MA.

Kosslyn, S. M., G. Ganis, and W. L. Thompson. (2001). Neural foundations of imagery. *Nature Reviews Neuroscience*, 2:635 -642.

Lotze, M., P. Montoya, M. Erb, E. Hülsmann, H. Flor, U. Klose, N. Birbaumer, and W. Grodd. (1999). Activation of cortical and cerebellar motor areas during executed and imagined hand movements: An fMRI study, *Journal of Cognitive Neuroscience*, 11(5), 491-501

Matsunaga, S. (2001). "Subvocalization in Reading Kanji: Can Japanese Text Be Comprehended Without It?" In *Advances in Japanese Language Pedagogy*, edited by H. Nara, 30-46. Columbus: National East Asian Languages Resource Center.

McLaughlin, B. (1987). Theories of second language learning. London: Edward Arnold.

Narayan, S, Bergen, B., Weinberg, Z. (2004). Embodied Verbal Semantics: Evidence from a lexical matching task. *Proceedings of Berkeley Linguistics Society 30.*

Noppeney, U., O. Josephs, S. Kiebel, K.J. Friston, & C.J. Price. (2005). Action selectivity in parietal and temporal cortex. *Cognitive Brain Research*, 25, 641-649.

Nyberg, L., K. M. Petersson, L. G. Nilsson, J. Sandblom, C. Åberg, and M. Ingvar. (2001). Reactivation of motor brain areas during explicit memory for actions. *NeuroImage*, 14, 521-528.

Pich, J. (2000). The Role of Subvocalization in Rehearsal and Maintenance of Rhythmic Patterns. *The Spanish Journal of Psychology* 3 (1): 63-67.

Porro, C. A., M. P. Francescato, V. Cettolo, M. E. Diamond, P. Baraldi, C. Zuian, M. Bazzocchi, and P. E. di Prampero. (1996). Primary motor and sensory cortex activation during motor performance and motor imagery: a functional magnetic resonance imaging study. *Journal of Neuroscience* 16, 7688–7698.

Pulvermueller, F., Haerle, M., and Hummel, F. (2001). Walking or Talking?: Behavioral and Neurophysiological Correlates of Action Verb Processing Brain and Language 78, 143–168.

Rizzolatti, G., F. Luciano, G. Vittorio, L. Fogassi. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, 3, 131-141.

Slowiaczek, M. L. and C. Clifton, Jr. (1980). Subvocalization and reading for meaning. *Journal of Verbal Learning and Verbal Behavior* 19, 573-582.

Smith, J.D., Wilson, M., and Riesberg, D. (1995). Subvocalization in Auditory Imagery. *Neuropsychologia*, 33, 11, 1433-1454.

Stefan, K., L.G. Cohen, J. Duque, R. Mazzocchio, P.. Celnik, L. Sawaki, L. Ungerleider, & J. Classen. (2005). Formation of a Motor Memory by Action Observation. *The Journal of Neuroscience*, October 12, 2005, 25(41):9339-9346

Tettamanti, M., Buccino, G., Saccuman, M.C., Gallese, V., Danna, M., Perani, D., Cappa, S.F., Fazio, F., & Rizzolatti, G. (2005). Sentences describing actions activate visuomotor execution and observation systems. *Journal of Cognitive Neuroscience*. 17(2), 273-281.

Watkins KE, A.P. Strafella, & T. Paus: (2003). Seeing and hearing speech excites the motor system involved in speech production. *Neuropsychologia*, 41:989-994.

Watkins K & T. Paus. (2004). Modulation of motor excitability during speech perception: the role of Broca's area. *Journal of Cognitive Neuroscience*, 16:978-987.

Wheeler, M. E., S. E. Petersen, and R. L. Buckner. (2000). Memory's echo: Vivid remembering reactivates sensory specific cortex. Proceedings of the National Academy of Science, USA, 97, 11125–11129.

Zwaan, R. A., R. A. Stanfield and R. H. Yaxley. (2002). Do language comprehenders routinely represent the shapes of objects? *Psychological Science*, 13, 168-171.

Zwaan, R.A. (1999). Embodied cognition, perceptual symbols, and situation models. Discourse Processes, 28, 81-88.