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Embodiment and second-language: Automatic activation of motor responses during processing spatially associated L2 words and emotion L2 words in a vertical Stroop paradigm

Carolin Dudschig *, Irmgard de la Vega, Barbara Kaup

University of Tübingen, Germany

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ABSTRACT

Converging evidence suggests that understanding our first-language (L1) results in reactivation of experiential sensorimotor traces in the brain. Surprisingly, little is known regarding the involvement of these processes during second-language (L2) processing. Participants saw L1 or L2 words referring to entities with a typical location (e.g., *star*, *mole*) (Experiment 1 & 2) or to an emotion (e.g., *happy*, *sad*) (Experiment 3). Participants responded to the words' ink color with an upward or downward arm movement. Despite word meaning being fully task-irrelevant, L2 automatically activated motor responses similar to L1 even when L2 was acquired rather late in life (age >11). Specifically, words such as *star* facilitated upward, and words such as *root* facilitated downward responses. Additionally, words referring to positive emotions facilitated upward, and words referring to negative emotions facilitated downward responses. In summary our study suggests that reactivation of experiential traces is not limited to L1 processing.

1. Introduction

"*The limits of my language mean the limits of my thoughts*" (Wittgenstein, 1922). Learning a second-language (L2) in school demands time and dedication but also opens the doors to new cultures and experiences. To what extent, however, do we become familiar with our second language? Recently, increasing evidence suggested that first-language (L1) processing is closely linked to spatial cognition, motor- and perceptual processing. For example, L1 can automatically activate motor responses compatible to the linguistically described event (e.g., Glenberg & Kaschak, 2002). Also, when reading words such as *kick*, specific motor cortex areas become activated that are also involved in performing the according action (e.g., Hauk, Johnsrude, & Pulvermüller, 2004). Additionally, even single words can trigger action-affordances (Bub, Masson, & Cree, 2008). These findings regarding a relationship between language, action and perception are typically explained within the grounded models of language understanding, suggesting that language comprehension relies on reactivation of sensorimotor experiences (Barsalou, 1999; Glenberg & Gallese, 2012; Glenberg & Kaschak, 2002; Zwaan & Madden, 2005). However, what role does sensorimotor information play during L2 comprehension?

When learning L1 we often hear a word in situations where we also experience its referent in the real world (Zwaan & Madden, 2005). For example, when encountering the word *airplane* as a child, this typically occurs in situations where someone points upward to the sky, with the child looking upward to see an airplane. According to the grounded language processing models, these manifold sensory experiences become reactivated when processing the word *airplane* and build the basis of understanding (Barsalou, 1999; Glenberg & Kaschak, 2002; Richter, Zwaan, & Hoever, 2009; Zwaan & Madden, 2005). Specifically, it is suggested that the neural sensorimotor activation during language understanding is similar to the neural activation when actually seeing the described entity or performing the described action (e.g., Lyons, Mattarella-Micke, Cieslak, Nusbaum, Small, & Beilock, 2010; Scorolli & Borghi, 2007, Pulvermüller, Shtyrov, & Ilmoniemi, 2005). Evidence for the involvement of sensorimotor processes during language comprehension is typically drawn from studies investigating the effect of language on subsequent perceptual or motor processes. For example, Estes, Verges, & Barsalou (2008) showed that centrally presented words referring to entities with a typical location in the world (e.g., *sun*, *shoe*) influence subsequent visual target processing in upper or lower screen locations. Similar results have been reported for studies implementing verbs (Verges & Duffy, 2009) and sentences (Bergen, Lindsay, Matlock, & Narayanan,

* Corresponding author. Address: University of Tübingen, Fachbereich Psychologie, Schleichstr. 4, 72076 Tübingen, Germany. Fax: +49 (0)7071 29 3363.
E-mail address: carolin.dudschig@uni-tuebingen.de (C. Dudschig).

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2007). In addition to the influence of direction-associated language on visual processing (Bergen et al., 2007; Dudschig, Lachmair, de la Vega, De Filippis, & Kaup, 2012b; Gozli, Chasteen, & Pratt, 2013), language also interacts with motor responses (Dudschig, de la Vega, De Filippis, & Kaup, submitted for publication; Lachmair, Dudschig, De Filippis, de la Vega, & Kaup, 2011; Thornton, Loetscher, Yates, & Nicholls, 2012). For example, motor responses are faster if the response direction matches the typical location of the word's referent in the real world (e.g., upward arm movements are faster following words such as *sun*). Similar language-action compatibility effects have been reported for verbs (e.g., *fall*, *rise*) (Dudschig, Lachmair, de la Vega, De Filippis, & Kaup, 2012a) and when measuring eye-movements (e.g., Dudschig, Souman, Lachmair, de la Vega, & Kaup, 2013). Beyond the influence of direction-associated words on motor or perceptual processing, other word categories, such as action words, are also directly linked to motor processes (e.g., Boulenger, Hauk, & Pulvermüller, 2009; Marino, Gough, Gallese, Riggio, & Buccino, 2013; Zwaan & Taylor, 2006). According to the embodied cognition framework of language comprehension, abstract language referring to things or situations we cannot directly experience also becomes related to sensory experiences (Glenberg, Sato, Cattaneo, Riggio, Palumbo, & Buccino, 2008; Lakoff & Johnson, 1980; Meier & Robinson, 2004; Santiago, Ouellet, Román, & Valenzuela, 2012). For example, language referring to something positive (negative) has been suggested to activate upper (lower) visual space. Taken together, according to the grounded models of language comprehension, language understanding is based upon modal experiences, and is not separate from our sensory system (e.g., Barsalou, 1999).

Previous research investigating L2 understanding has primarily focused on the degree of automaticity to which L2 is accessed. These studies have focused on two aspects of language processing. First, it was investigated how emotional content becomes activated during L2 processing. Some findings suggest that emotional content (negative and taboo words) similarly recruits selective attention for L1 and L2 and as a result, slows subsequent behavioral responses (e.g., Eilola, Havelka, & Sharma, 2007; Sutton, Altarriba, Gianico, & Basnight-Brown, 2007). However, other studies show that negative words elicit greater autonomic arousal, as measured by skin conductance, in L1 compared to L2 (Harris, Aycicegi, & Gleason, 2003), especially when L2 was acquired rather late in life (after the age of 12) (see Pavlenko, 2012).

Another paradigm used to investigate the automaticity of meaning access during L2 processing is the Stroop paradigm (Stroop, 1935). In the Stroop color-naming paradigm, task-irrelevant words are presented in a color whereby the color determines the response (for reviews see, Lu & Proctor, 1995; MacLeod, 1991). For example, participants see the word *red* that is printed in blue, and have to respond by saying "blue" and ignore the word meaning. Responses are faster if word meaning and response color match (e.g., the word *red* printed in red color). This finding is typically attributed to the automatic access of word meaning that interferes with the less dominant color naming process, whereby opposing color information results in conflicts and selective attention is required in order to overcome these conflicts (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; MacLeod, 1991). In L2 studies, a within-language or between-language version of the Stroop paradigm is typically implemented (e.g., Naylor, Stanley, & Wicha, 2012). In the between-language version, participants are presented with words in one language, but have to respond in their other language (e.g., by speaking out loud the words' ink color). In the within-language version, the language of the task-irrelevant word matches the response language. Both the within and the between-language paradigms show Stroop interference effects with the within-language paradigm showing significantly larger Stroop interferences than the between-language paradigm (Dyer, 1971; Francis, 1999), whereby the size of the interference effects depends on language proficiency (e.g., Mägiste, 1984). The dominance of within-language Stroop interference is attributed to response-set competition on the conceptual and lexical level being present in the within-language Stroop paradigm, whereas in the between-language Stroop paradigm, only conceptual overlap can cause response conflict (Goldfarb & Tzelgov, 2007; Roelofs, 2003).

Taken together, these Stroop interference effects suggest that we automatically access word meaning when seeing L2 words to a level that subsequent color-naming responses can be influenced. However, this leaves open whether L2 processing is related to sensorimotor processes or not. Specifically, does automatic access to L2 word meaning result in action-compatibility effects to a similar degree than words from L1 (e.g., Glenberg & Kaschak, 2002; Lachmair et al., 2011; Thornton et al., 2012)? Typically we learn L2 in school and school-based language learning is rather different from L1 learning (e.g., Lave, 1996). L1 learning evolves over many years, on an everyday basis and in a very interactive manner with many people, and in various settings. Especially during childhood we often encounter language in situations where we also perceive the events, entities or feeling described. Moreover, these language percepts are typically combined with specific gestures, eye-movements and physical orientations towards the described entity (Engelen, Bouwmeester, de Bruin, & Zwaan, 2011; Glenberg & Gallese, 2012). In contrast, L2 learning in school typically takes place in a very specific and limited setting, whereby interactions with other people and physical experiences are less dominant during the learning phase. Indeed, many L2-acquisition researchers "view the object of inquiry as in large part an internal, mental process: *the acquisition of new (linguistic) knowledge*" (Long, 1997, p. 319). In such a view of L2 learning there is a "basic division between mind and world" (Atkinson, Nishino, Churchill & Okada, 2007, p. 170). Thus, if not only L2 acquisition but also L2 understanding is functionally different from L1, sensorimotor information might not be activated during L2 comprehension. Comparing L1 and L2 according to their association with sensorimotor processes is particularly interesting, as currently, it is controversally discussed whether L2 processing only semantically compares to L1 processing or also regarding its grounding in emotion and experience (Keysar, Hayakawa, & An, 2012; Pavlenko, 2012).

The current study investigates basic associations between L2 and the sensorimotor system. We implement a paradigm that has previously been used to investigate whether L1 automatically activates motor responses (Lachmair et al., 2011; Thornton et al., 2012). In this paradigm, participants are presented with colored words and are required to respond to the color with an upward or downward arm movement while ignoring the meaning of the word. In Experiment 1 and 2 of the current study the L2 words referred to entities in the world with a typical location (e.g., *bird* vs. *shoe*). In Experiment 3 of the current study the association between "positive is up" and "negative is down" is investigated for L2 processing (Brookshire, Casasanto, & Ivry, 2010; Dudschig, de la Vega, & Kaup, submitted for publication; Meier & Robinson, 2004; Santiago et al., 2012). If the grounded models of language understanding are a general approach towards all types of language understanding, we predict that during L2 processing, sensorimotor information becomes similarly activated as during L1 processing. Evidence towards the involvement of sensorimotor processes during L2 understanding would largely increase the impact of the embodied models of language understanding by suggesting that interconnections to sensorimotor processing are not limited to L1 comprehension. In contrast, if L2 processing is based on non-modal representations of meaning, then L2 should not automatically activate sensorimotor processes in the same way as L1, and no sensorimotor associations should be observed during L2 comprehension. Indeed, it is possible that the interconnections between language