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

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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

“They 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 (Rub, 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,
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., Boulangier, Hauk, & Pulvermüller, 2009; Marino, Gough, Gallesie, 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, & An, 2012; Pavlenko, 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 controversially 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” was 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...
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