Truth is in the head.
A nod and shake compatibility effect

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Abstract

Studies from the embodiment perspective on language processing have shown facilitation or interference effects depending on the compatibility between verbal contents, concrete or abstract, and the motion of various parts of the body. The aim of the present study was to test whether such compatibility effects can be found when a higher cognitive process like truth evaluation is accomplished with head movements. Since nodding is a vertical head gesture typically performed with positive and affirmative responses, and shaking is a horizontal head gesture associated with negative and dissenting contents, faster response times can be expected when true information is evaluated by making a vertical head movement and false information by making a horizontal head movement.

Three experiments were designed in order to test this motor compatibility effect. In the first experiment a series of very simple sentences were asked to be evaluated as true or false by dragging them vertically and horizontally with the head. It resulted that truth-value was assessed faster when it was compatible with the direction of the head movement, compared to when it was incompatible. In the second experiment participants were asked to evaluate the same sentences as the first experiment but by moving them with the mouse. In the third experiment, a non-evaluative classification task was given, where sentences concerning animals or objects were to be dragged by vertical and horizontal head movements. In the second and third experiment no compatibility effect was observed. Overall results support the hypothesis of an embodiment effect between the abstract processing of truth evaluation and the direction of the two head movements of nodding and shaking. Cultural aspects, cognitive implications, and the limits of these findings are discussed.

Keywords

Head nod; Head shake; Truth-value processing; Embodiment effect; Motor compatibility.

Software for exploring head compatibility effects may be obtained free of charge
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1. Introduction

The body plays a crucial role in human communication and activity. In everyday social interactions, nonverbal behavior serves as an important cue that facilitates understanding what is expressed verbally. Mental contents like beliefs, feelings, and intentions are often better revealed by body movements like gestures, facial expressions and bodily postures rather than by explicit communication and this is why their nature has always fascinated scholars in very different fields of knowledge, from linguistics to social psychology.

Head nods and shakes are among the first bodily expressions acquired by infants (Guidetti, 2005; Darwin, 1872). These gestures are of particular interest because they are mostly used to communicate agreement and disagreement: the vertical movement of nodding is typically used in Western culture to communicate agreement or acceptance, while the horizontal movement of shaking is commonly used to communicate dissent or denial (Ekman, 1979; Morris, 1979; Jakobson, 1972). This communication can occur without speaking, by simply moving the head up and down or left and right, but these movements are also often performed accompanying positive and affirmative or dissenting and negative verbal expressions. According to this kind of communicative function, such gestures interact with language, and their habitual use since early communication makes these two head movements physically embodied habits (Andonova & Taylor, 2012; Horstmann & Ansorge, 2011).

In general, the relationships between gestures and language have been much studied in the literature. Several models and different explanations of this relationship have been proposed. For example, the well-known facilitation effects of gestures on speech production (Krauss, 1998; Krauss, Chen, & Chawla, 1996; McNeill, 1992) and comprehension (McNeil, Alibali, & Evans, 2000; Kelly, Barr, Church, & Lynch, 1999; Clark, 1996), are explained because they can help speakers to express ideas that are hard to capture, by spatially simulating the meaning or by simplifying the access to words in memory.

Most of the models concerning the relationship between gestures and speech agree with the idea that language processing is closely tied to the body (Pouw et al., 2014; Hostetter & Alibali, 2008; Goldin-Meadow, 2003; Kita & Özyürek, 2003; Krauss, Chen, & Gotfexnum, 2000). Therefore, gestures have been considered to constitute valid evidence for the embodiment approach, which places the body increasingly central to the study of cognition (Dijkstra & Post, 2015; Alibali et al., 2014; Zwaan, 2014).

The line of research pursued by the embodiment approach, indeed, has shown evidence that language understanding, and even higher cognitive processes like judgment and planning, are founded on sensorimotor mechanisms, which lead to partial simulations of sensory, motor, and affective states (Glenberg, 1997; Goldstone & Barsalou, 1998; Barsalou, 1999; 2003; 2008; Wilson, 2002; Barsalou, Niedenthal, Barbey, & Ruppert, 2003; Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan & Madden 2005; Gibbs Jr, 2005; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005; Niedenthal, 2007; Mahon & Caramazza, 2008; Reimann et al., 2012; Meteyard et al., 2012; Johnson 2015; Dominey et al., 2015; Soylu 2016; Iran-Nejad & Irannejad, 2017). These simulations are based on previously acquired information and are considered to be the result of the evolution of mechanisms which originally allowed individuals to make inferences and represent information in the absence of physical stimuli. Thus, the effects of this grounding are considered to occur even when cognition is disconnected from the environment in which the sensorimotor patterns were acquired or activated (Körner et al., 2015; Niedenthal et al., 2005), and it has been shown that these effects generally show up as a facilitation or interference in cognitive processing and motor responses, based on whether bodily activity and cognitive states are compatible or not.

According to this perspective, actions that people perform (both physical and simulated) can thus affect cognitive processing and vice versa (Korner et al., 2015; Kaschak et al., 2014; Glenberg et al., 2013; Barsalou 2010). In this view, hence, gestures, as a special form of action deriving from sensorimotor simulations (Hostetter & Alibali, 2008; 2010), are deemed to interact with cognitive processing.

In line with this hypothesis, the goal of the present study was to test the presence of an interaction between the two vertical and horizontal head movements, involved in nodding and shaking gestures, and the truth-value processing of verbal expressions. Our main expectation was to find a motor compatibility effect when stimuli evaluated as true are moved with the head vertically, the movement typically performed with positive/affirmative verbal expressions, and when sentences evaluated as false are moved horizontally, the movement performed with negative/dissenting verbal expressions.

1.1. Basic distinctions about compatibility

The “compatibility” relationship between body and mind is a central concept in embodied cognition approaches. However, compatibility is a complex and multifaceted phenomenon and several aspects of it have been investigated with different experimental designs, stimuli, and instructions. Considering that the aim of the present work was to test a specific motor compatibility effect, some distinctions are needed.

First, two general kinds of stimuli have been used in the literature: objectively understandable and subjectively evaluable verbal expressions. In the first case, the focus is on the relationship between a bodily state or action and the mere understanding of the meaning of words or sentences. In the second case, the relationship is with the evaluation processing (judging affective meaning, pleasantness, value, etc...) of polarized and valenced words or sentences. In our research, we have chosen to study a peculiar kind of evaluation, the objective assessment of the truth-value of a statement, which has yet to be investigated in the perspective of embodiment.

As regards stimulus presentation and response modality, two kinds of compatibility effects have been investigated: spatial and motor. For the first type of effect, embodiment accounts postulate that language comprehension is based on spatial schemas. Thus, schematic spatial representations and spatial dimensions of meaning have been considered for both concrete or implicit location words (Barsalou, 2008; Zwaan, & Yaxley, 2003; Pecher, Van Dantzig, Boot, Zanolie, & Huber, 2010; Estes, Verges, & Šetic & Domijan, 2007) and for abstract concepts or valenced words (Glenberg et al., 2008; Barsalou et al., 2003; Lakoff and Johnson, 1999, 1980; Chasteen, Burdzy, & Pratt, 2010; Meier et al., 2007; Meier & Robinson, 2004; Proctor & Cho, 2006; Hall, Coats, & Smith LeBeau, 2005; Schubert, 2005).

Hence, even with stimuli not having any concrete spatial position in reality nor a directional dimension, like abstract or valenced concepts, spatial effects have been found for the “left-right” dimension (e.g., Casasanto & Chrysikou, 2011; Chasteen et al. 2010; Casasanto, 2009; Maass & Russo, 2003) and for the “up-down” dimension (e.g., Dudschig, de la Vega, De Filippis, & Kaup, 2014; Meteyard, Bahrami, & Vigliocco, 2007; Meier et al., 2007; Meier & Robinson, 2004). Considering the first kind of stimuli, objectively understandable, when the location of a word on the screen was congruent with the typical perceived location of its referent in space (e.g., ‘bird’ at the top of the computer screen) faster processing was observed. Similarly, faster detection times were found when words expressing positive concepts (e.g., happy, good, heaven, god) were located in the upper part of a computer screen and vice versa when negative ones (e.g., sad, bad, hell, devil) were in the lower part. Sometimes, conflicting predictions of spatial effects among implicit location words, motion verbs, and valenced words (e.g. contradicting concepts with the same spatialization) can be found in the literature, due to the task specificity (Dudschig, de la Vega, & Kaup, 2015; de la Vega, De Filippis, Lachmair, Dudschig, & Kaup, 2012; Hurtienne et al., 2010) or the body specificity (Casasanto & Chrysikou, 2011; Casasanto & Jasmin, 2010; Casasanto, 2009).

In studies concerning spatial compatibility, the stimulus location is manipulated but no motor action is requested. When motor compatibility is investigated, by contrast, the interaction between a stimulus and a bodily action is tested within motor response paradigms. In these studies the effect occurs with both concrete (Kaschak et al., 2005; Borghi, Glenberg, & Kaschak, 2004; Zwaan & Yaxley, 2003; Richardson, Spivey, Barsalou, & McRae, 2003; Glenberg & Kaschak, 2002; Glenberg, 1997) and abstract or valenced materials (Solarz, 1960; Cacioppo, Priester, & Bernston, 1993; Förster & Strack, 1998; Chen & Bargh, 1999; Wentura, Rothermund, & Bak, 2000; Neumann & Strack, 2000; Strack & Deutsch, 2004; Guan, Meng, Yao, & Glenberg, 2013; Carraro, Castelli, & Negri, 2016). For example, Glenberg and Kaschak (2002) observed what they have called the “Action-Sentence Compatibility Effect” or ACE, that is, faster response times when the arm movement to be executed was in the same direction as the concrete action expressed by a sentence. Similar effects occurred with the evaluation of valenced stimuli (e.g. Chen & Barg, 1999): the response to a positive stimulus was faster when the direction of the movement to make in order to evaluate it was an approach movement (arm flexion toward the body), and vice versa an avoidance movement (arm extension away from the body) when stimuli were negatively valenced.

Finally, a fundamental distinction regards the notion of motor compatibility. Since embodiment can function both as a response and as a stimulus (Barsalou, 2003), two kinds of motor compatibility can be found in literature: (a) when the processing of a content automatically activates the simulation of a compatible action (the action is a response) and (b) when an induced action subsequently influences the processing of a content (the action is a stimulus).

The first type of motor compatibility has been investigated in tasks requiring to process stimuli while executing actions (mostly with arm movements) (e.g. Glenberg and Kaschak, 2002; Kaschak et al., 2014; Borghi & Cimatti, 2009; Fischer and Zwaan, 2008; Gibbs, 2006; Gallese & Lakoff, 2005; Zwaan, 2004). In this case, actions are facilitated when they match the simulated actions and hindered when there is a mismatch between the two (Dijkstra & Post, 2015). Compatibility occurs because the affected cognitive processing entails a mental simulation that reactivates the same neuronal paths that were active while experiencing the situation expressed verbally (Zwaan & Taylor, 2006; Zwaan & Madden, 2005).

The second kind of motor compatibility, instead, can be found in paradigms where it is asked to perform actions (with different body parts and body movements) and subsequently to process a stimulus. In such cases, a bodily state directly affects a person's state of mind or feelings (Niedenthal, 2007; Neumann et al., 2003; Barsalou et al., 2003).

Effects concerning head movements have been investigated exclusively within the second motor compatibility paradigm. Wells and Petty (1980), for example, in one of the earliest studies on head gestures, demonstrated that nodding and shaking can be involved in the formation and use of attitudes. These authors found that participants who were asked to nod their heads (up and down) while listening to an editorial radio broadcast, subsequently expressed a greater agreement with the content of the message, compared to those who were asked to shake their heads (from side to side). Similarly, Briñol and Petty (2003) found that the degree of persuasion of a message may increase if it is given while nodding instead of shaking. In line with this account, other studies showed that induced nodding and shaking can affect the evaluations of respectively positive and negative valenced stimuli (Förster, 2004), or create an attitude for a neutral object as well (Tom, Pettersen, Lau, Burton & Cook, 1991). Förster and Strack (1996) found a similar effect using the same paradigm as Wells and Petty but in a memory task, and found that positive words learned while nodding were remembered more than negative ones, whereas opposite results occurred with shaking. The authors hypothesized that vertical head movements were compatible with positive contents and facilitated the generation of favorable thoughts, while the reverse situation happened with horizontal movements.

Since no study involving head movements has yet been carried out on the first kind of motor compatibility, the present study arose from this lack of findings and aimed to test whether the processing of true and false sentences activates the simulation of vertical and horizontal head movements.

1.2. Overview of the present study

Nodding and shaking are head gestures typically performed with positive/affirmative and negative/dissenting contents, respectively. A relevant idea within the embodiment perspective is that gestures are simulated actions (Alibali et al., 2014) and that sensorimotor simulation is one of the main mechanisms underlying compatibility effects (Dijkstra & Post, 2015), which is based on previous experience (Zwaan & Madden, 2005; Zwaan & Taylor, 2006; Pecher and Winkielman, 2013) and occurs automatic, unintentionally and fast (Shtyrov et al., 2014; Moors & De Houwer, 2006).

In accordance with this view, our hypothesis was that processing an information with the purpose of evaluating its truth or falsity may elicit an internal simulation of the head movement usually experienced with affirmative or negative verbal expression, in a way that processing true contents reactivates head nod experiential traces (e.g. the movement usually performed with a "Yes, it is true" response), and processing false information reactivates head shake experiential traces ("No, it is false"). Thus, the main goal of the present study was to test whether a motor compatibility effect occurs when head movements and true and false verbal expression match, that is whether a facilitation or interference effect shows up when an abstract evaluation, like the assessment of truth-value, is performed with vertical and horizontal head movements.

In order to test this hypothesis, we designed an experimental study in which the assessment of the truth-value of a sentence was made possible through head movements.
We expected to find a motor compatibility effect when the head movement requested to evaluate a sentence as true was vertically-oriented, like the movement involved in the nodding gesture, and when the movement requested to evaluate a sentence as false was horizontally-oriented, like in the shaking head gesture. Conversely, when the orientation of the head movements did not match the truth-value, an interference effect was expected. Thus, our expectation was that response times would be faster when truth-value was compatible with the head movement compared to when it was incompatible.

We designed three experiments with the aim of examining whether there is a relationship between a high semantic process, like truth evaluation, and the activation of a sensorimotor simulation, and whether this relationship is a necessary condition in order to produce a compatibility effect. Therefore, we controlled whether the effect occurred independently of the head movements (in experiment 2) and independently of the truth-value processing (in experiment 3). Our general expectation was to find a motor compatibility effect in the first experiment only.

The first experiment was designed in order to test whether the motor compatibility, found in studies with the evaluation of positive and negative stimuli, could be extended to a more abstract kind of evaluation, like truth-value judgment. Thus, participants were asked to assess as true or false a series of simple one-sentence statements, by moving them on a computer screen vertically (to the top or bottom of the screen) or horizontally (to the left or right side).

The second experiment differed in response modality: in the first experiment, participants were enabled to control the mouse pointer on the computer screen with their head movements, while in the second experiment participants controlled the mouse with their arm movement. Thus, the second experiment was expected to reveal whether truth-value processing specifically interacts with vertical and horizontal head movements or, more generally, with verticality and horizontality, independently of head motion.

The third experiment explored whether a motor compatibility effect occurs with head movements in a task different from truth evaluation. For this reason, a non-evaluative categorization task was designed. A list of one-sentence statements concerning animals or objects was presented and participants were asked to classify them by moving the sentences vertically or horizontally through head motion.

2. Experiment 1

2.1. Method

2.1.1. Participants

A total of 96 undergraduates (82 female, mean age 21.5, sd 4.91) participated in the experiment for course credit. They had normal color vision and normal or corrected-to-normal visual acuity. Informed consent was obtained at the beginning of the experiment.

2.1.2. Materials and apparatus

The monitor (HP1955 LCD 19-inch flat panel color monitor) was placed approximately 57 cm from participants' faces. The procedure was controlled using a custom program written in Visual Basic 6. In order to control the mouse pointer on the screen with the head, the Enable Viacam v.1.7.2 free software was used (CREA Software, released under the GNU General Public License, www.crea-si.com, with the following settings: X-axis speed 12, Y-axis speed 9, acceleration 2, motion threshold 0, smoothness 3; dwell click enabled, dwell time ds 10, dwell area 3). This software makes use of a common webcam mounted on the top center of the monitor to capture head movements and to convert them into pointer motion. A Logitech C210 webcam was used, allowing the required 30 fps rate.

Sentences consisted of 120 simple utterances which could be either True or False. We choose also to control grammatical forms, as sentences were constructed either as Copulative Sentences (CS) or Non-copulative Sentences (NS). Half of them were in the first block and the other half in the second block. In each block: 10 CSs were true (like “Football is a sport”), and 10 were false (like “Perfume is smelly”); 20 NSs were true (like “A cat meows”) and 20 were false (like “A snail runs”). A total of 60 different sentences were displayed in each block, in a different random order for each participant.

2.1.3. Procedure

The experiment took place in a quiet separate room and participants were asked to hold their torso as still as possible. The following instructions were presented on the screen: “In this experiment you will control the mouse pointer by moving your head. The webcam that you see on the monitor is used to capture these movements. It works like this: moving the head moves the mouse pointer, holding the pointer still is like making a click”. All instructions and stimuli were in Italian.

A practice session was first performed. Participants were asked to keep their gaze fixed on a cross at the center of the screen and not to move their head, while the calibration procedure was run. This procedure set the Eviacam software to generate a left-click when the pointer stopped for a while (dwell time) on the target object in the screen. When calibration ended, a message requested participants to leave the mouse (hitherto used for proceeding with instructions) and to use their head to control the pointer. A screen showing a central black bar on a grey background appeared, and participants were instructed to move their head to locate the pointer inside this rectangle and to stop over it until they heard a click sound. To enable practice of the task, with every click the black bar location was changed to a different position six times. The next screen then informed the participant that the same procedure (stopping the pointer to click) would be used to drag the rectangle using head movements. A black box (approx. size 11 x 3 cm) was then shown in the center on a grey background screen, and a side instruction asked participants to move the pointer over the box and stop until they heard a click sound. At the click, the words “This is a sentence” (in white Lucida SansUnicode 12 pt font) appeared inside the box and four yellow bars (sized 15 mm) appeared at each screen border. Participants were requested to drag (using head movements) the box to one of these bars and stop to hear a new click sound. ‘Clicked’ bars, one at a time, disappeared so that participants could practice with all borders (top, down, left, right) in the order they preferred. Each time, a new black box appeared at the center and the sentence appeared at the click. This warm up procedure was repeated until participants had fully understood the instructions or had practiced the task sufficiently.

The main task then began. Instructions explained that simple sentences displayed inside the black box were true or false, and asked participants to evaluate their truth-value by moving (with their head) the box to the appropriate border bar. Each sentence appeared when the box was clicked and this was taken as the starting time for that trial. Border bars were positioned like the yellow bars used during the practice session; two of them were green with the caption “True” and two were red with the caption “False”. In one condition, the green bars were located in the top and bottom positions, thus requiring a vertical movement for the “true” judgment, and the red bars were in the left and right locations, requiring a horizontal movement for the “false” judgment. This was the “compatible” condition because it is in agreement with the direction of head movements usually made for agreeing or disagreeing. In the “incompatible” condition the position of green and red bars was reversed, thus requiring opposite head movements. Participants could freely choose the direction of their response (top or bottom, left or right) each time. Participants were randomly assigned to two groups (48 participants in each group): Group A had the compatible condition in block 1 and the incompatible condition in block 2; vice versa for Group B.

2.1.4. Data analysis

Response times (RT) were recorded from when the box was clicked and the sentence appeared to when the box movement started. The start of the movement was defined as when the cursor moved 20 pixels from its starting point. This measure was set as to maximize sensitivity to actual responses and minimize it to small random movements. Response times thus measured can be considered the time required for the evaluation processing (understanding the sentence meaning, judging its truth, and deciding the response).

To clean the data, trials 1-8 for each block were considered additional practice and were removed; wrong answers (only 1%, given the ease of the task) were also removed. Considering the peculiarity of the task of controlling sentence motion with head movements, possible inaccuracies due to unintentional quick head movements occurred; sometimes, control got lost or slowed down, and this entailed long response time outliers, yielding a right-skewed distribution. For these reasons, response times shorter than 300 ms (.7 %) and longer than 3000 ms (6.7 %) were considered invalid and removed. Since the resulting distribution was still right-skewed, a log transformation was performed on data (reducing skewness from .82 to -.12).

A common problem in linguistic tasks concerns concurrently accounting for both participant and item variability (Baayen, Davidson, & Bates, 2008; Brysbaert, 2007). In order to overcome this problem, we used the Linear Mixed Modeling (LMM, Baayen et al., 2008; Baayen & Milin, 2010).

We then analyzed our results using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) in the R 3.3.2 environment (http://www.r-project.org/). F statistics were obtained using the Anova function with lmerTest package (https://cran.r-project.org/package=lmerTest). Degrees of freedom for reported F-values were estimated with a Satterthwaite approximation. Eta squared values were computed using the function eta_sq of the sj_stats package.

We started building the simplest model including all factors and ended up with a full complex model including all relevant factors and interactions. All models had response times as the criterion variable, and subjects and items as random factors. The final model included random intercepts and by-subject and by-item random slopes. Given the design of our experiment, a considerable practice effect was likely to be expected. Indeed, for participants in Group A, who started with the compatible condition, the expected interference effect in Block 2 (incompatible condition) was likely to be overridden by the facilitation effect deriving from practice; on the contrary, for participants in Group B, starting with the incompatible condition, the facilitation effects of compatibility and practice were likely to be added up in Block 2 (compatible condition). Thus, if a compatibility effect was present, it should be reliable despite the practice effect. For this reason we decided to test the effect of Block and the joint effect of Block and Group in the initial model. If the effect of this interaction resulted significant, we then tested the Compatibility effect, by analyzing the difference between Compatible (Block 1 in Group A + Block2 in Group B) and Incompatible condition (Block2 in Group A and Block1 in Group B).

2.2. Results

The first model included Block, Block X Group interaction, Grammatical-Construction (CS, NS) and sentence Truth-value (True, False) as fixed factors. In line with expectations, an overall practice effect resulted since RTs were shorter in Block 2 compared to Block 1, in both groups [F(1,116) = 9.15, SE=.014, p = .003]. More importantly, a Block X Group interaction [F(1,8032) = 39.41, SE=.01, p < .001] resulted, which was in the hypothesized direction for compatibility and practice joint effects (see Figure 1). No main effects were found for Group [F(1,94) = .13, SE=.03, p = .72] and Grammatical-Construction [F(1,116) = 1.25, SE=.015, p = .27]. Truth, by contrast, was a relevant factor, as false sentences yielded significantly longer RTs than true sentences [F(1,116) = 47.57, SE=.011, p < .001]. Mean RTs, Summary, and ANOVA data of this first model are reported in Appendix [Table 1 (a, a1, a2)].

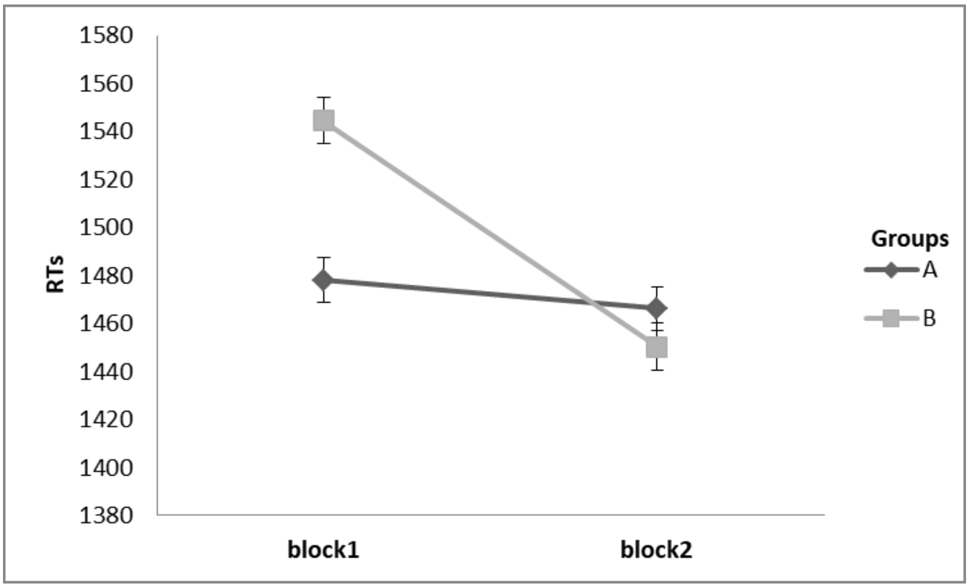

Figure 1 - Mean RTs in block 1 and block 2 for group A and group B in Experiment 1. Original values are reported for ease of interpretation. Error bars indicate SE.

Given the resulting Block X Group interaction, in the following analysis we controlled the condition effect collapsed by Compatibility (Compatible condition: Block1GroupA & Block2GroupB; Incompatible condition: Block2GroupA & Block1GroupB). The subsequent model included random intercepts and by-subject and by-item random slopes for the effect of Compatibility. Fixed factors were Compatibility X Group interaction[1], Truth and Grammatical Construction [Table 1 (b1)].

Compatibility, Truth, and Compatibility x Group interaction resulted significant: in line with hypotheses, RTs were faster in Compatible condition compared to Incompatible condition [F(1,92) = 6.06, SE = .012 , p =.02, eta squared = .11] (Figure 2), and, faster for True sentences compared to False sentences [F(1,115) = 39.95, SE = .013, p < .001]. Compatibility X Group interaction was also significant [F(1,177) = 5.97, SE = .035, p = .02 [Table 1 (b2)].

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[1] The interaction of Compatibility with Group (that is the effect of Block) was added in the model in order to control the practice effects due to the block design.

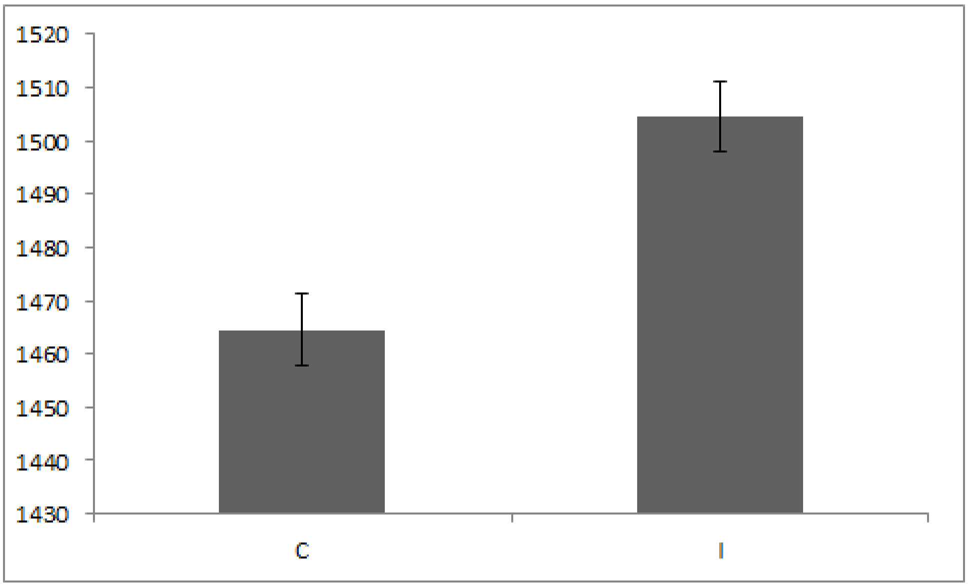

Figure 2 - Mean RTs in Compatible and Incompatible conditions in Experiment 1. Error bars indicate SE.

In order to see if truth-value interacted with conditions a third model was built with Compatibility X Group X Truth interaction, plus Grammatical Construction as fixed factors, and random intercepts and by-subject and by-item random slopes for the effect of Compatibility [Table 1 (c1)]. Compatibility and Truth were still significant and their interaction resulted significant too: RTs faster in Compatible condition compared to Incompatible condition [F(1,93) =5.98, SE = .012, p =.02, eta squared = .10, and True sentences processed faster than False sentences [F(1,115) = 46.43, SE = .016, p < .001]. Compatibility X Truth significant interaction [F(1,1125) = 10.60, SE = .010, p = .001, eta squared = .17] shows that a compatibility effect occurred for both true and false sentences, even if false sentences required more time to be processed (Figure 3) [Table1 (c2)].

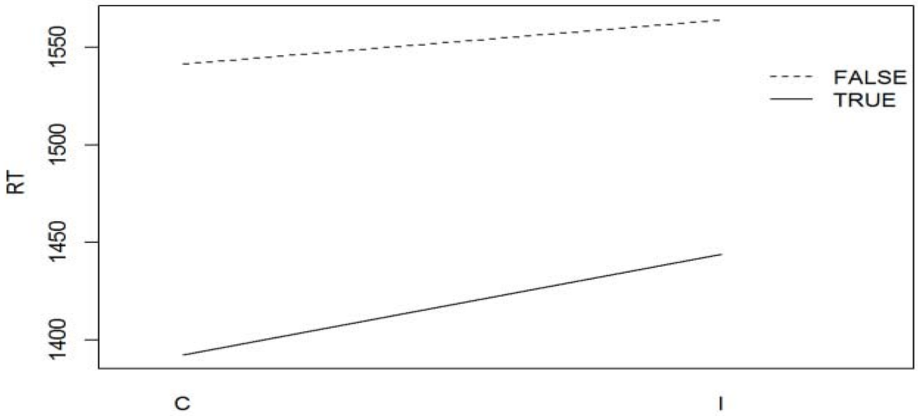

Figure 3 - Interaction plot of Compatibility (Compatible/Incompatible conditions) and Truth (True/False sentences) in Experiment 1.

The final model included Compatibility X Group interaction, Truth and Grammatical Construction as fixed factors, and random intercepts and by-subject random slopes for the effect of Compatibility, the effect of Truth and their interaction, and by-item random slopes for the effect of Compatibility only [Table1 (d1)]. In line with expectations, the difference between Compatible and Incompatible conditions was still significant [F(1,93) = 3.91, SE = .011, p = .05, eta squared = .07], as well as between True and False sentences [F(1,129) = 41.35, SE = .014, p < .001]. Interaction between Compatibility and Group was still significant, too [F(1,176) = 6.05, SE = .035, p = .01] [Table1 (d2)].

2.3. Discussion

Results of first experiment show that response times were faster when the movement required to evaluate sentences as true was in the same direction as the movement typically performed with positive/affirmative responses (nodding), and when the movement required to evaluate sentences as false was in the same direction as that movement usually performed with negative/dissenting responses (shaking). On the contrary, it took longer when the required movements were in the opposite direction (horizontal for sentences evaluated as true and vertical for sentences evaluated as false). This result can be interpreted as evidence for a motor compatibility effect between truth-value processing and head movements.

An interesting result was that of Truth effect: false sentences were significantly more difficult to process and indeed required more time to be evaluated. This is an interesting side effect, which confirms previous findings about veracity judgments (Carpenter & Just, 1975; Wason, 1980; Fischler et al., 1983; see also Hald, Hocking, Vernon, Marshall, & Garnham, 2013). Anyway, despite this difference, both true and false sentence where processed faster in the compatible condition compared to the incompatible one.

In order to control the possibility of a general interaction with the vertical and horizontal dimensions, we performed a second experiment, using exactly the same stimuli and procedure as the first experiment, but asking participants to perform the task by moving the mouse.

3. Experiment 2

3.1. Method

3.1.1. Participants

A total of 75 undergraduates[2] (49 female, mean age 22.43, sd 7.19) participated in the experiment for course credit. They were all right-handed, or accustomed to using the mouse

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[2] The total sample was composed of an initial sample (48 undergraduates, 31 female, mean age 22.02, sd 7.19), and a subsequent sample collected in order to increase the power of results, given that null effects are reported.

with their right hand, had normal color vision, and normal or corrected-to-normal visual acuity. Informed consent was obtained at the beginning of the experiment. No participant had been involved in the previous experiment.

3.1.2. Materials and apparatus

The apparatus was the same as in the first experiment. In order to avoid the possibility of responses being biased by an excessive mouse sensitivity, the mouse speed was slowed down calling the function SystemParametersInfo, included in the API Windows library user32.dll, parameter SPI_SETMOUSESPEED, with the pvParam value = 4. Sentences were also the same as in the previous experiment.

3.1.3. Procedure

The experiment took place in a quiet separate room. Instructions, practice sessions and the main task were identical to the ones used in the first experiment, except for the references to head movements that were replaced with ones to mouse movements.

Participants were randomly assigned to two groups: one group (hereafter, Group C) started, in block 1, with the True bars on the top and the bottom, and the False bars on the left and right side of the screen (we call it “compatible” condition, due to the possibility of a metaphoric compatibility effect), and ended with the reversed bars positions, in block 2 (“incompatible” condition); in the other group (Group D) the order of the blocks was inverted.

3.1.4. Data analysis

Times elapsed between when the box was clicked and when the box movement started were recorded like in the first experiment. The same criteria used in Experiment 1 for data cleaning were adopted; thus, trials 1-8 for each block, wrong answers (2%), response times shorter than 300 ms (.4 %) and longer than 3000 ms (4%) were removed, and data was log transformed (skewness was reduced from .99 to .15).

The same Linear Mixed Models procedure was performed for the analysis. The model included response times as the criterion variable, and participants and items as random factors. In order to control the practice effect, like in Experiment 1, Groups (C, D) and Blocks (1, 2) were entered separately in the model, with the interaction term. Fixed factors were Block, Block X Group interaction, Grammatical Construction (CS, NS) and sentence Truth-value (True, False).

3.2. Results

As expected, a practice effect resulted, as shown by faster RTs in Block2 compared to Block1 [F(1,7103) = 28.22, SE = .006, p < .001]. More importantly, no Block X Group interaction resulted in this experiment [F(1,7103) = 0.93, SE = .013, p = .33] (Figure 4). An effect of Grammatical Construction resulted, too: Copulative Sentences were assessed slower than Non-copulative Sentences [F(1,7139) = .65, SE = .007, p < .01]. Like in the previous experiment, True sentences were evaluated faster than False sentences [F(1,7127 = 125.06, SE = .006, p < .001] [Table 2 (a, a1, a2)].

Since the absence of Block X Group interaction, data were not collapsed by Compatibility and no subsequent model was needed.

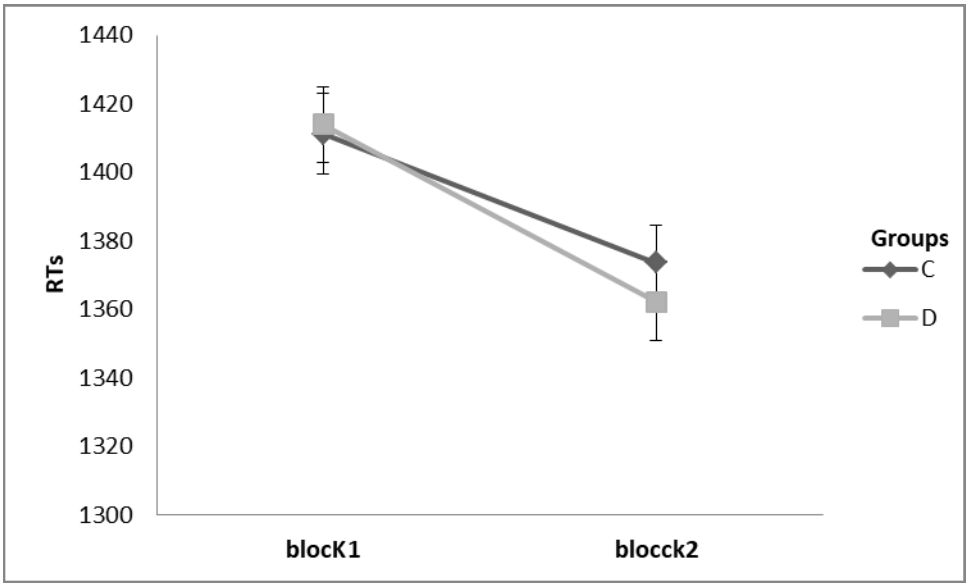

Figure 4 - Mean RTs in block 1 and block 2 for group C and group D in Experiment 2. Error bars indicate SE.

3.3. Discussion

In this second experiment participants evaluated the truth-value of the same set of sentences as in Experiment 1, under the very same conditions except for giving their responses by using the mouse motion instead of using their head movements. In line with the hypothesis, no interaction was found between the two blocks and the two groups. The significant effect of Block showed that practice effect, in this case, did not interact with any compatibility effect. This finding supports the hypothesis that the facilitation and interference found in the first experiment were ascribable to an embodiment effect due to the activation of the gesture’s simulation, since the effect did not occur without moving the head in order to do the evaluation.

It has to be noted that, like in the first experiment, even in this second experiment false sentences required significantly more time to be processed, confirming an important finding in the literature (see Section 2.3). On the contrary, we do not have a satisfactory explanation of the effect of Grammatical Construction.

To test the hypothesis that truth-value processing is a necessary condition for activating head movements simulation, a third experiment was devised, in which the paradigm of Experiment 1 was maintained but sentences were changed, replacing the truth evaluation task with a classification task.

4. Experiment 3

4.1. Method

4.1.1. Participants

A total of 80 undergraduates[3] (53 female, mean age 22.3, sd 3.69) participated in the experiment for course credit. They had normal color vision and normal or corrected-to-normal visual acuity. Informed consent was obtained at the beginning of the experiment. No participant had been involved in previous experiments.

4.1.2. Apparatus, materials, and procedure

Apparatus and procedure were identical to Experiment 1. The only difference concerned sentences, which were 120 simple statements about animals or objects, always true, and constructed as Copulative Sentences (CS) or Non-copulative Sentences (NS), in order to control for possible effects of different grammatical forms. In each block 10 CS sentences concerned an animal (like “An eagle is a bird”), and 10 an object (like “A pillow is soft”); 20 NS sentences concerned an animal (like “A cat meows”) and 20 an object (like “A telephone rings”). A total of 60 different sentences were thus displayed in each block, in a different random order for each participant.

Instructions explained that simple sentences would be displayed inside the black box and could refer to animals or objects. Participants were asked to detect and choose the respective category by moving (using their head) the box to the appropriate border bar. Border bars were positioned like the yellow bars used during the practice session; two of them were green with the caption “Object” and two were red with the caption “Animal”. The task was divided into two blocks where the order of conditions was reversed. Participants were randomly assigned to two groups: Group E had the “object-vertical, animal-horizontal” condition in block 1 and the “animal-vertical, object-horizontal” one in block 2; Group F had the inverted order of conditions. Participants could freely choose the direction of their response each time (top or bottom, left or right).

4.1.3. Data analysis

Like in Experiment 1 and 2, response times were recorded from when the box was clicked and the sentence appeared to when the box movement started. The procedure of data cleaning was identical to the one adopted in the other experiments. Similarly to Experiment 1, the uncommon task of controlling an object on the screen by moving the head required considerable practice and yielded invalid response times. Trials 1-8 for each block, wrong answers (.02 %), and response times shorter than 300 ms (.7%) and longer than 3000 ms (2.3%) were removed. As the distribution was still very right-skewed, also in this case data was log transformed (right-skewness was reduced from 1.28 to .26).

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[3] The total sample was composed of an initial sample (46 undergraduates, 35 female, mean age 22.4, sd 3.07), and a subsequent sample collected in order to increase the power of results.

Like in previous experiments, a Linear Mixed Models procedure was performed for the analysis. A full model was built with response times as the criterion variable; Block, Block X Group interaction, Grammatical Construction, and Type (Animal, Object) were entered as fixed factors, and subjects and items as random intercepts.

4.2. Results

Like in Experiment 1 and 2, in the second block RTs were faster than in the first block [F(1,115) = 28.14, SE = .014, p < .001], due to the practice effect. However, no Block X Group interaction resulted [F(1,8650) = .75, SE = .01, p = .38] (Figure 5) [Table 3 (a, a1, a2)], so that no further analysis about Compatibility effects was required. No significant effect resulted for Grammatical Construction [F(1,115) = 2.11, SE = .012, p = .15], while a Type effect was present: sentences about animals were evaluated faster than sentences about objects [F(1,115) = 24.62, SE = .011, p < .001].

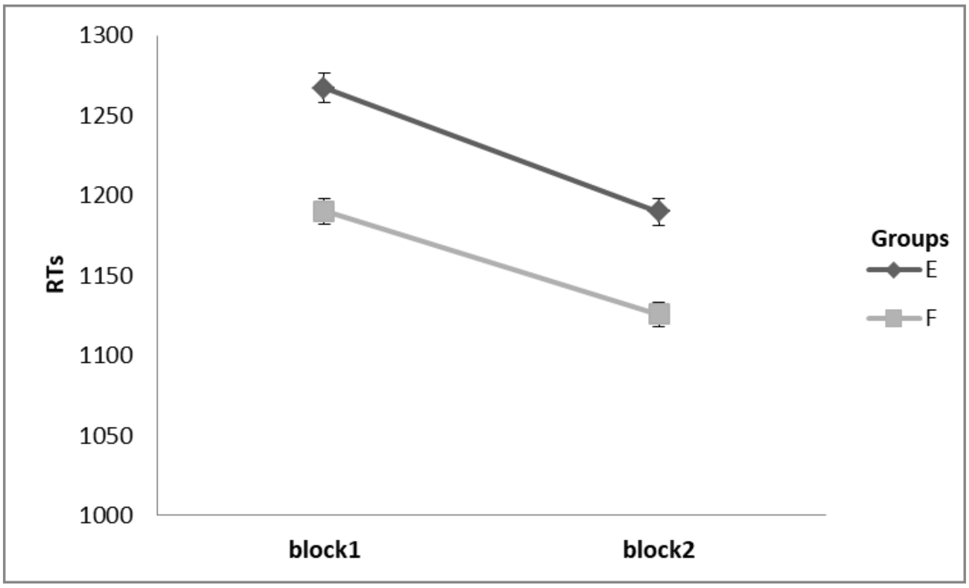

Figure 5 - Mean RTs in block 1 and block 2 for group E and group F in Experiment 3. Error bars indicate SE.

4.3. Discussion

The results of the third experiment show that with a classification task different from a truth evaluation task, the direction (vertical or horizontal) of the required head movements had no effect on response times. In Experiment 1 shorter RTs had been found in conditions where head movements to be performed were compatible with the truth-value of sentences (vertical-true, horizontal-false). In line with expectation, this pattern was not found in Experiment 3.

As an additional note, we do not have any satisfactory hypothesis about Type and Grammatical Construction effects, but we believe that an explanation of this data is beyond the scope of our work.

5. General discussion and conclusions

The present study examined the relationship between the directional movements of the two head gestures of nodding and shaking, that is vertical and horizontal head movements, and the high-level cognitive processing of judging the truth-value of a verbal expression. Overall results provide support for the hypothesis of a motor compatibility between the abstract evaluation of truth and falsity and the two head movements commonly performed to give positive/affirmative and negative/dissenting responses.

To the best of our knowledge, studies on head movements within the embodiment perspective have limited themselves in examining a compatibility effect caused by the induction of the two head gestures on the subsequent evaluation of a stimulus (Brinol & Petty, 2003; Forster, 2004; Forster & Strack, 1996; 1997; Tom et al., 1991; Wells & Petty, 1980; Andonova & Taylor, 2012), without investigating the reverse compatibility. For this reason, we considered contributing with a new experimental paradigm that made possible the evaluation of a series of stimuli directly with head motion. Our main goal was to test whether the processing of the truth-value of a sentence may interact with the typical vertical and horizontal head movements involved in nodding and shaking.

According to one of the main claims of embodiment perspective, actions are eased when they are congruent with the simulated actions and hampered when they are incongruent (Dijkstra & Post, 2015; Körner et al., 2015). In order to test this interaction, three experiments were designed. All of them were binary evaluation tasks: Experiment 1 required to assess the truth-value of a series of sentences by dragging them with vertical and horizontal head movements; in Experiment 2, the same sentences were evaluated by moving the mouse pointer, vertically and horizontally on the computer screen; in Experiment 3, a series of sentences were required to be classified as belonging to animal or object categories, by dragging them with the head, vertically and horizontally.

Response times in the first experiment were faster when the movement requested for evaluating a sentence as true or false matched the simulated movements involved in the typical gestures of nodding or shaking respectively, compared to the condition in which the direction of the response action was reversed (horizontal for true sentences and vertical for false sentences). In the second experiment, in which the same evaluation task was performed but without moving the head, no significant difference between compatible and incompatible conditions resulted. Similarly, in the last experiment, classifying animals and objects did not activate horizontal or vertical head movement simulation.

Our results support the hypothesis of a motor compatibility between high cognitive processes and the motion of bodily parts (Dominey et al., 2015; Körner et al., 2015; Glenberg et al., 2013; Meteyard et al., 2012; Barsalou 2010; Mahon & Caramazza, 2008; Zwaan & Madden, 2005), and provides new evidence about gestures as bodily actions strongly connected not only with speaking but even with thinking (Hostetter & Alibali, 2008; 2010; Alibali et al., 2014). The compatibility effect found in our first experiment, indeed, can be explained by the reactivation of the experiential traces associated with true and false contents, so that processing true information automatically activates the simulation of the vertical head movement usually executed while giving positive and affirmative responses, and processing false information triggers the simulation of the horizontal head movement typically performed while giving negative and dissenting responses.

However, the extent to which a high-level cognitive processing is actually embodied, that is, to what extent and at what level the activation of the sensorimotor simulation is automatic, is still a main issue within embodiment approaches (e.g. see Körner et al., 2015). Some authors argued that simulation is a default mechanism which occurs unintentionally and precisely at the time in which the stimulus is processed, suggesting that cognition is a sensorimotor simulation in itself (e.g. Zwaan & Taylor, 2006; Moors & De Houwer, 2006; Shytrov et al., 2014). Nevertheless, some recommendations have been made regarding the need to take into account that there is a gradual difference between embodied and disembodied cognition (Chatterjee, 2010; Mahon & Caramazza, 2005; 2008; Sakreida et al., 2013) and that, as regards language comprehension, the degree to which it is grounded on sensorimotor simulations depends on how much a particular act of language is embedded in the environment (Zwaan, 2014).

In the current study, the nature of the task did not allow distinguishing at which level the compatibility effect takes place, namely understanding the sentence meaning, judging its truth, or deciding the response direction. Since facilitation and inhibition of processing are generally revealed by measuring response times, the most straightforward interpretation places the effect at early levels, that is at the preparation times. Automaticity is further assumed by the fact that interaction is triggered without intention and proceeds without participant awareness. In our experiments, indeed, participants were not made conscious of the communicative intent of the required head movements, that is they were not asked to nod or shake explicitly, but to drag sentences by making a head movement along the same axis (vertical or horizontal) of the movements involved in nod or shake gestures. Moreover, since these movements were to be oriented only to one of the four side of the screen at a time, that is up or down or left or right (not both up and down, or left and right, as it can occur in nodding and shaking), then the association with the two gestures was not explicit at all. In fact, according to what each participant reported in the debriefing phase at the end of the experiment, only one of them noticed the association. Hence, like in most studies conducted within the embodiment perspective in which the body action is a response and not a stimulus, the motor compatibility effect here found is not with the overt movements of nodding and shaking, but with their internal (i.e., partial) simulation.

Nevertheless, we believe that further research is needed in order to better identify the locus of facilitation effects implied in motor compatibility and to clarify the degree of automaticity of this kind of interactions. For instance, it could be tested whether the activation of compatible head movements is triggered, with true and false statements, when there is no explicit request to evaluate their truth-value so that simple purposeless vertical or horizontal drag and drop movements are required. In this case, faster response times in the compatible condition would make more plausible placing the effect at an early stage of understanding, when the truth-value is implicitly processed.

Another important question concerns different kinds of truth-value assessment. In our first two experiments, we chose to use very simple sentences, whose truth-value is objectively established and very easy to judge. However, there are statements whose truth-value can be assessed differently from person to person, on the basis of personal preferences, beliefs or experiences. In these cases, evaluating information as true may mean accepting that information, that is having a positive attitude towards it, or to avoid it when evaluated as false, which means that more subjective and emotional aspects may come into play in the judgment process. In line with this view, an experiment conducted with vertical and horizontal head movements and subjectively true and false evaluable stimuli (Greco & Moretti, 2017) showed the same kind of compatibility effect found within our first experiment. This result shed light on the possibility that the movement of nodding - which is a vertical movement that goes toward the body - be interpreted as an approach-like movement, and shaking - going from side to side, away from the body - avoidance-like. This interpretation is not new: an early physiological explanation of the two head gestures of nodding and shaking was known since Darwin's book on the expression of emotion in man and animals (Darwin, 1872). According to his view, the origin of the nod-shake system could be traced back to the childish actions of rejecting the breast, or a feeding bottle, or a spoonful of food, and conversely of accepting food and keeping it in the mouth. Hence, it is possible to conclude that what we evaluate as true and false can be related to something that we accept and reject at a more physical level.

However, an important remark is necessary: nodding and shaking are a widespread cultural practice used in the United States and most of Europe to mean respectively "yes" and "no", but they are not universal. Different cultures express agreement and disagreement with different head movement directions. For example, the same gestures in Bulgaria can have exactly the opposite meaning. Similarly, in Greece, Turkey, and the south of Italy, instead of the "nod-shake" system a "dip-toss" system can be used, i.e. dipping head forward or downward means "yes", while pushing it backward or upward means "no". Differently, a head wobble is used in some parts of Iran and Bengal to say "yes" (Morris, 1979). Thus, if cultures embody consent and dissent differently, then a different direction of the compatibility effects should be expected. Andonova and Taylor (2012) conducted a study with US and Bulgarian participants, in which vertical and horizontal head movements were induced to test their influence on attitudes and feelings. The authors found a compatibility effect with the US sample but did not replicate the effect with Bulgarians. Thus, they concluded that embodiment effects are not universal but culture-specific. However, this study only investigated embodiment as a stimulus, that is (as discussed in Section 1.1) the subsequent effect of bodily actions on attitudes or mental states. Hence, we believe that further cross-cultural studies concerning embodiment as a response (i.e. effect taking place when the processing of a stimulus automatically activates a bodily state) are needed in order to clarify how much embodiment - or at least the embodiment of gestures - is universal or arbitrary.

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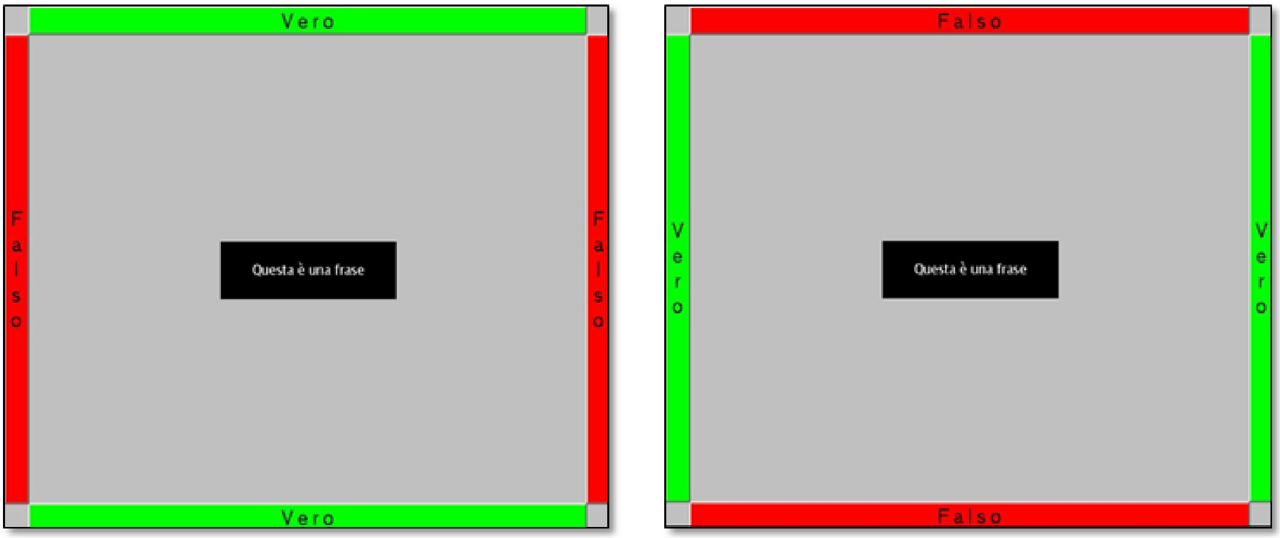
Appendix



Questa è una frase

Questa è una frase

Figure A

Figure B

Screenshot examples of the main task: Compatible (Figure A) and Incompatible (Figure B) conditions. Captions text (in Italian): “This is a sentence” on the black box; “True” on the green border bars and “False” on the red border bars (In Experiment 3, captions were “Animal” and “Object”).

Table 1

(a) Mean RTs in Experiment 1 (in ms, original values)

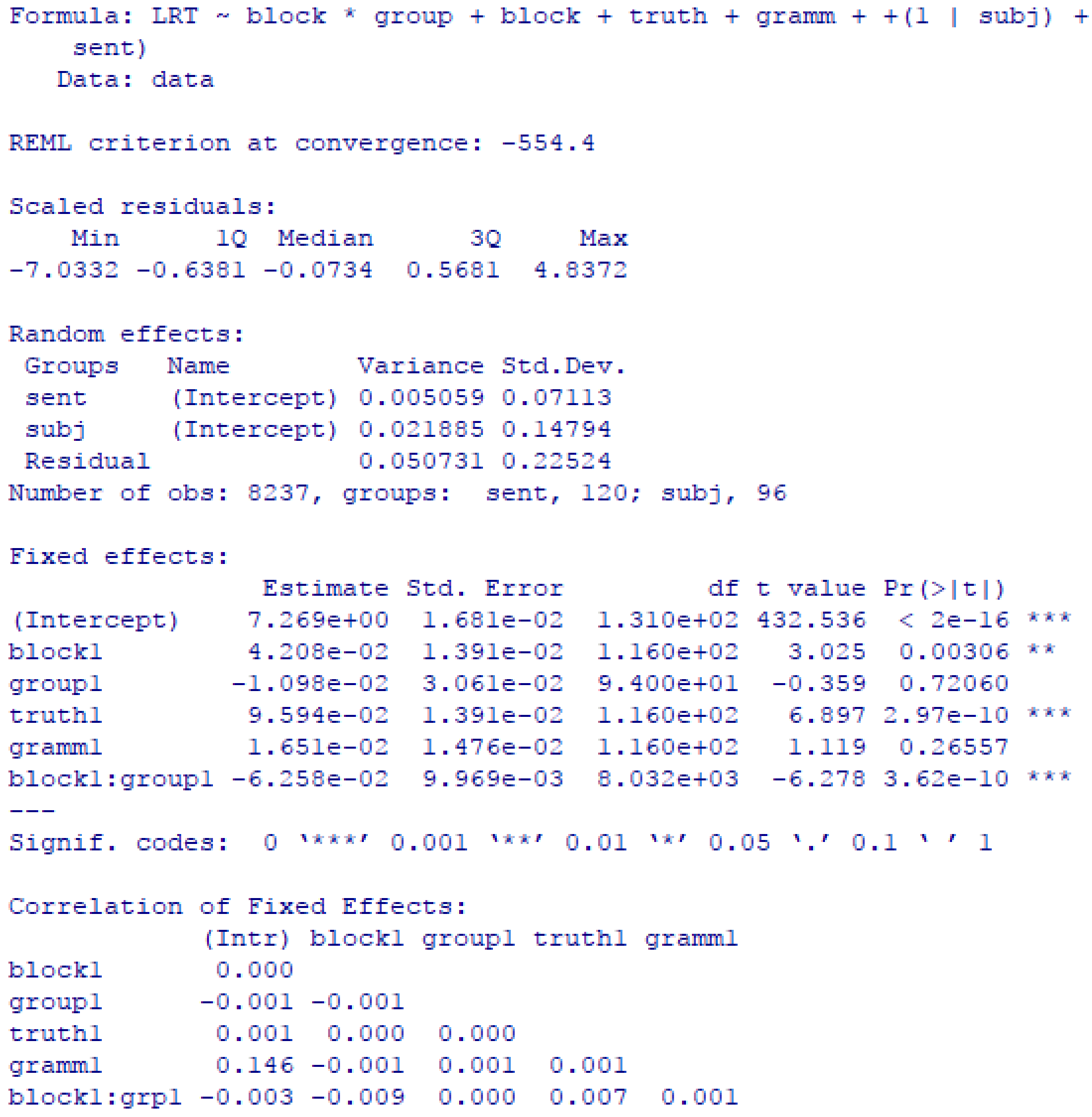
	A	B	
Block 1	1478	1545	1510
Block 2	1466	1450	1458
	1472	1496	

True	1417
False	1553

NS	1501
CS	1476

Compatible	1464
Incompatible	1504

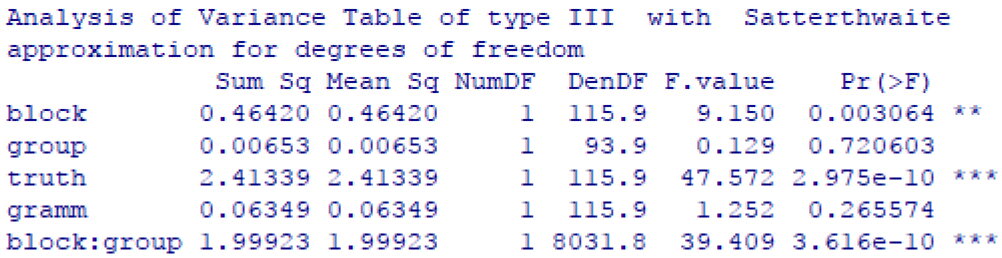
(a1) Summary of the first model of Experiment 1



```
Formula: LRT ~ block * group + block + truth + gramm + +(1 | subj) + (1 |
    sent)
   Data: data

REML criterion at convergence: -554.4

Scaled residuals:
    Min      1Q  Median      3Q     Max
-7.0332 -0.6381 -0.0734  0.5681  4.8372

Random effects:
 Groups   Name        Variance Std.Dev.
 sent     (Intercept) 0.005059 0.07113
 subj     (Intercept) 0.021885 0.14794
 Residual             0.050731 0.22524
Number of obs: 8237, groups:  sent, 120; subj, 96

Fixed effects:
                Estimate Std. Error         df t value Pr(>|t|)
(Intercept)    7.269e+00  1.681e-02  1.310e+02 432.536  < 2e-16 ***
blockl         4.208e-02  1.391e-02  1.160e+02   3.025  0.00306 **
groupl        -1.098e-02  3.061e-02  9.400e+01  -0.359  0.72060
truthl         9.594e-02  1.391e-02  1.160e+02   6.897 2.97e-10 ***
gramml         1.651e-02  1.476e-02  1.160e+02   1.119  0.26557
blockl:groupl -6.258e-02  9.969e-03  8.032e+03  -6.278 3.62e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) blockl groupl truthl gramml
blockl       0.000
groupl      -0.001 -0.001
truthl       0.001  0.000  0.000
gramml       0.146 -0.001  0.001  0.001
blockl:grpl -0.003 -0.009  0.000  0.007  0.001
```

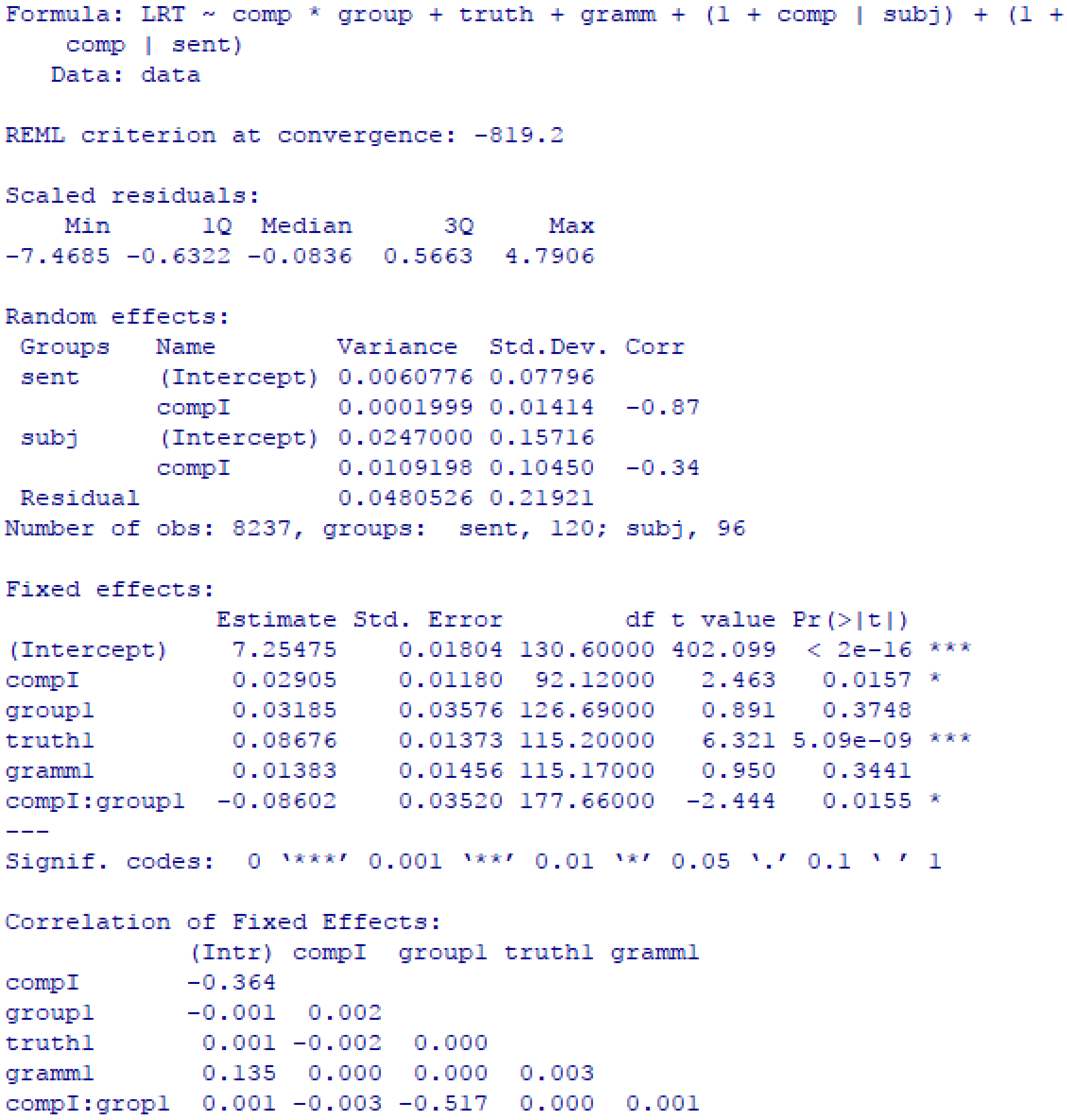
Table 1 (continued)

(a2) Anova of the first model of Experiment 1



```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
             Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)    
block       0.46420 0.46420     1  115.9   9.150  0.003064 ** 
group       0.00653 0.00653     1   93.9   0.129  0.720603    
truth       2.41339 2.41339     1  115.9  47.572 2.975e-10 ***
gramm       0.06349 0.06349     1  115.9   1.252  0.265574    
block:group 1.99923 1.99923     1 8031.8  39.409 3.616e-10 ***
```

(b1) Summary of the second model of Experiment 1



```
Formula: LRT ~ comp * group + truth + gramm + (1 + comp | subj) + (1 +
    comp | sent)
   Data: data

REML criterion at convergence: -819.2

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-7.4685 -0.6322 -0.0836  0.5663  4.7906 

Random effects:
 Groups   Name        Variance  Std.Dev. Corr 
 sent     (Intercept) 0.0060776 0.07796       
          compI       0.0001999 0.01414  -0.87
 subj     (Intercept) 0.0247000 0.15716       
          compI       0.0109198 0.10450  -0.34
 Residual             0.0480526 0.21921       
Number of obs: 8237, groups:  sent, 120; subj, 96

Fixed effects:
              Estimate Std. Error        df t value Pr(>|t|)    
(Intercept)    7.25475    0.01804 130.60000 402.099  < 2e-16 ***
compI          0.02905    0.01180  92.12000   2.463   0.0157 *  
groupl         0.03185    0.03576 126.69000   0.891   0.3748    
truthl         0.08676    0.01373 115.20000   6.321 5.09e-09 ***
gramml         0.01383    0.01456 115.17000   0.950   0.3441    
compI:groupl  -0.08602    0.03520 177.66000  -2.444   0.0155 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) compI  groupl truthl gramml
compI       -0.364                            
groupl      -0.001  0.002                     
truthl       0.001 -0.002  0.000              
gramml       0.135  0.000  0.000  0.003       
compI:gropl  0.001 -0.003 -0.517  0.000  0.001
```

Table 1 (continued)

(b2) Anova of the second model of Experiment 1

```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
             Sum Sq Mean Sq NumDF   DenDF F.value    Pr(>F)
comp        0.29141 0.29141     1  92.118   6.064   0.01565 *
group       0.00639 0.00639     1  94.150   0.133   0.71619
truth       1.91985 1.91985     1 115.200  39.953 5.089e-09 ***
gramm       0.04337 0.04337     1 115.166   0.903   0.34407
comp:group  0.28693 0.28693     1 177.659   5.971   0.01552 *
```

(c1) Summary of the third model of Experiment 1

```
Formula: LRT ~ comp * group * truth + gramm + (1 + comp | subj) + (1 +
    comp | sent)
   Data: data

REML criterion at convergence: -811.5

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-7.5134 -0.6356 -0.0873  0.5645  4.8295 

Random effects:
 Groups   Name        Variance Std.Dev. Corr 
 sent     (Intercept) 0.006021 0.07760       
          compI       0.000119 0.01091  -1.00
 subj     (Intercept) 0.024696 0.15715       
          compI       0.010983 0.10480  -0.34
 Residual             0.048013 0.21912       
Number of obs: 8237, groups:  sent, 120; subj, 96

Fixed effects:
                      Estimate Std. Error         df t value Pr(>|t|)    
(Intercept)          7.255e+00  1.803e-02  1.305e+02 402.388  < 2e-16 ***
compI                2.886e-02  1.180e-02  9.340e+01   2.446  0.01630 *  
groupl               3.165e-02  3.573e-02  1.266e+02   0.886  0.37742    
truthl               1.118e-01  1.572e-02  1.162e+02   7.114 9.93e-11 ***
gramml               1.367e-02  1.464e-02  1.147e+02   0.934  0.35228    
compI:groupl        -8.576e-02  3.531e-02  1.776e+02  -2.429  0.01614 *  
compI:truthl        -3.230e-02  9.923e-03  1.125e+03  -3.255  0.00117 ** 
groupl:truthl       -1.119e-03  3.143e-02  1.162e+02  -0.036  0.97166    
compI:groupl:truthl -9.476e-03  5.616e-02  1.149e+02  -0.169  0.86630    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) compI  groupl truthl gramml cmpI:gl cmpI:tl grpl:l
compI       -0.361                                                   
groupl      -0.001  0.002                                            
truthl       0.003 -0.004 -0.001                                     
gramml       0.135  0.000  0.000  0.000                              
compI:gropl  0.001 -0.003 -0.517  0.001  0.001                       
compI:trthl -0.004  0.006  0.001 -0.478  0.006 -0.002                
gropl:trthl -0.001  0.001  0.003 -0.005  0.000 -0.003   0.007        
cmpI:grpl:l  0.000 -0.001 -0.002  0.003  0.001  0.001  -0.009  -0.951
```

Table 1 (continued)

(c2) Anova of the third model of Experiment 1

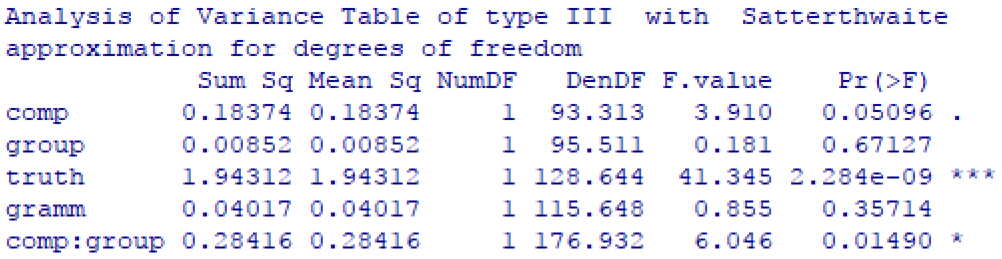
```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
                  Sum Sq Mean Sq NumDF   DenDF F.value    Pr(>F)    
comp             0.28733 0.28733     1   93.38   5.984  0.016305 *  
group            0.00647 0.00647     1   94.06   0.135  0.714283    
truth            2.22905 2.22905     1  114.90  46.426 4.627e-10 ***
gramm            0.04188 0.04188     1  114.73   0.872  0.352285    
comp:group       0.28327 0.28327     1  177.57   5.900  0.016139 *  
comp:truth       0.50875 0.50875     1 1124.88  10.596  0.001167 ** 
group:truth      0.01673 0.01673     1 1125.15   0.348  0.555132    
comp:group:truth 0.00137 0.00137     1  114.91   0.028  0.866298    
```

(d1) Summary of the final model of Experiment 1

```
Formula: LRT ~ comp * group + truth + gramm + (1 + comp + truth + comp:truth |  
    subj) + (1 + comp | sent)
   Data: data

REML criterion at convergence: -893

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-7.3811 -0.6289 -0.0943  0.5606  4.9940 

Random effects:
 Groups   Name         Variance  Std.Dev. Corr             
 sent     (Intercept)  0.0060216 0.07760                   
          compI        0.0001322 0.01150  -1.00            
 subj     (Intercept)  0.0245851 0.15680                   
          compI        0.0108604 0.10421  -0.33            
          truthl       0.0032690 0.05718  -0.54  0.52      
          compI:truthl 0.0119344 0.10924   0.39 -0.43 -0.80
 Residual              0.0469981 0.21679                   
Number of obs: 8237, groups:  sent, 120; subj, 96

Fixed effects:
              Estimate Std. Error        df t value Pr(>|t|)    
(Intercept)    7.26474    0.01739 133.62000 417.816  < 2e-16 ***
compI          0.02220    0.01123  93.31000   1.977   0.0510 .  
groupl         0.03007    0.03504 130.61000   0.858   0.3923    
truthl         0.09264    0.01441 128.64000   6.430 2.28e-09 ***
ramml         0.01344    0.01454 115.65000   0.925   0.3571    
compI:groupl  -0.08588    0.03493 176.93000  -2.459   0.0149 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) compI  groupl truthl gramml
compI       -0.305                            
groupl      -0.002  0.002                     
truthl      -0.043  0.016 -0.001              
gramml       0.139  0.001  0.000  0.002       
compI:gropl  0.002 -0.004 -0.506  0.000  0.001
```

Table 1 (continued)

(d2) Anova of the final model of Experiment 1



```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
            Sum Sq Mean Sq NumDF   DenDF F.value    Pr(>F)
comp       0.18374 0.18374     1  93.313   3.910   0.05096 .
group      0.00852 0.00852     1  95.511   0.181   0.67127
truth      1.94312 1.94312     1 128.644  41.345 2.284e-09 ***
gramm      0.04017 0.04017     1 115.648   0.855   0.35714
comp:group 0.28416 0.28416     1 176.932   6.046   0.01490 *
```

Table 2

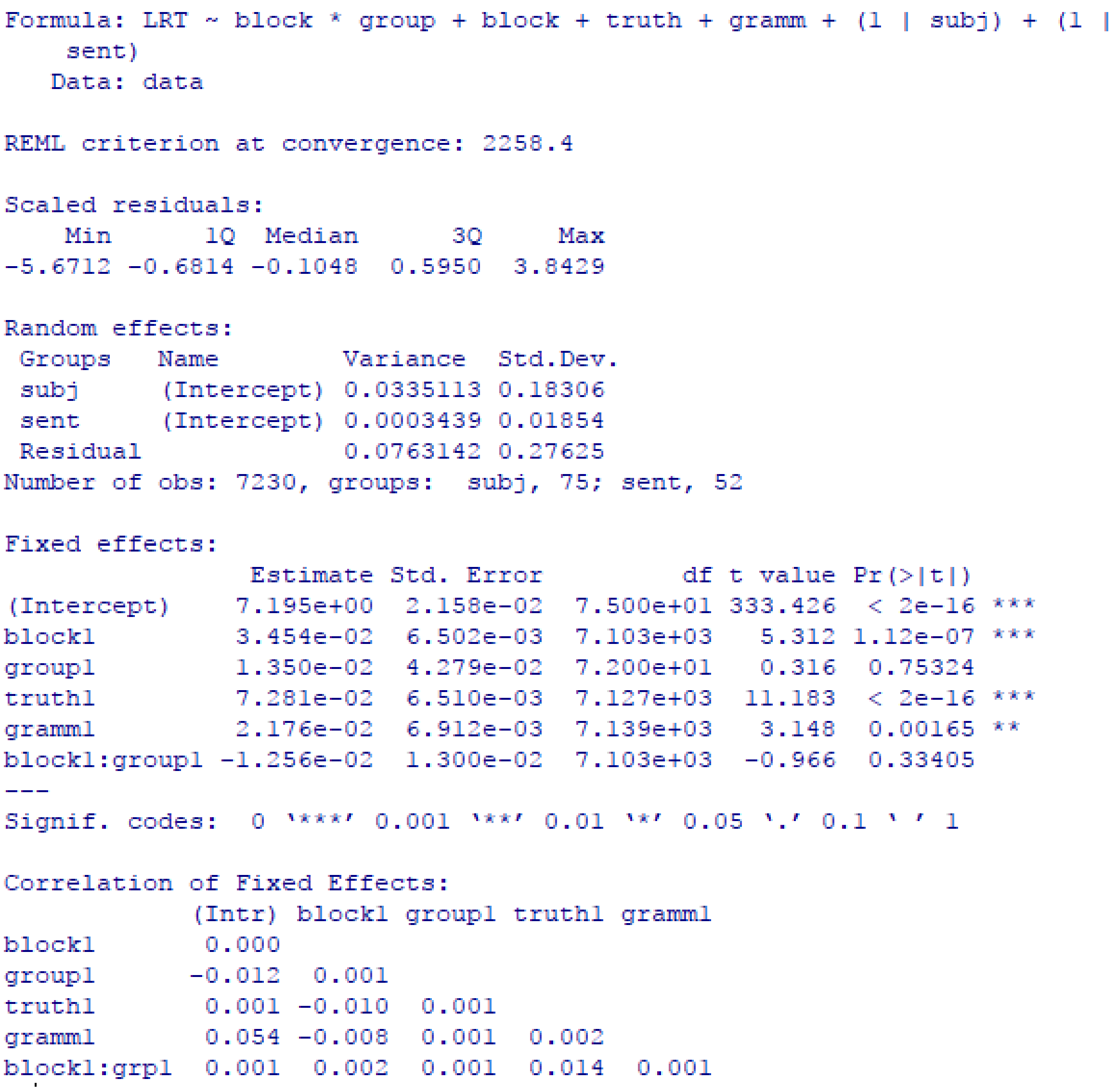
(a) Mean RTs in Experiment 2 (in ms, original values)

	C	D	
Block 1	1411	1414	1413
Block 2	1374	1362	1368
	1392	1388	

True	1342
False	1439

NS	1381
CS	1408

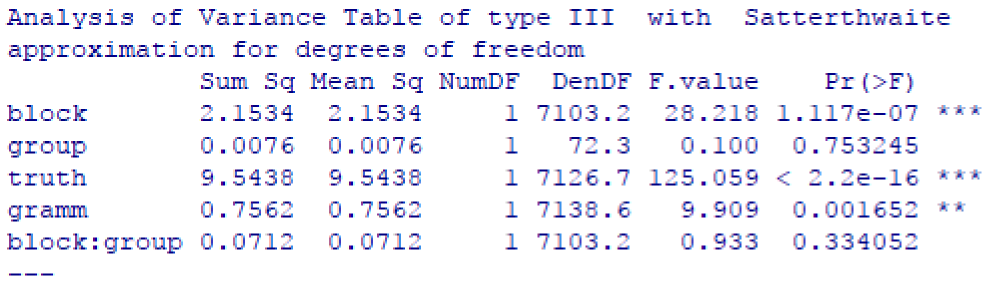
(a1) Summary of the model of Experiment 2



```
Formula: LRT ~ block * group + block + truth + gramm + (1 | subj) + (1 |
    sent)
   Data: data

REML criterion at convergence: 2258.4

Scaled residuals:
    Min      1Q  Median      3Q     Max
-5.6712 -0.6814 -0.1048  0.5950  3.8429

Random effects:
 Groups   Name        Variance  Std.Dev.
 subj     (Intercept) 0.0335113 0.18306
 sent     (Intercept) 0.0003439 0.01854
 Residual             0.0763142 0.27625
Number of obs: 7230, groups:  subj, 75; sent, 52

Fixed effects:
                Estimate Std. Error         df t value Pr(>|t|)
(Intercept)    7.195e+00  2.158e-02  7.500e+01 333.426  < 2e-16 ***
block1         3.454e-02  6.502e-03  7.103e+03   5.312 1.12e-07 ***
group1         1.350e-02  4.279e-02  7.200e+01   0.316  0.75324
truth1         7.281e-02  6.510e-03  7.127e+03  11.183  < 2e-16 ***
gramm1         2.176e-02  6.912e-03  7.139e+03   3.148  0.00165 **
block1:group1 -1.256e-02  1.300e-02  7.103e+03  -0.966  0.33405
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) block1 group1 truth1 gramm1
block1       0.000
group1      -0.012  0.001
truth1       0.001 -0.010  0.001
gramm1       0.054 -0.008  0.001  0.002
block1:grp1  0.001  0.002  0.001  0.014  0.001
```

Table 2 (continued)

(a2) Anova of the model of Experiment 2



```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
            Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
block       2.1534  2.1534     1 7103.2  28.218 1.117e-07 ***
group       0.0076  0.0076     1   72.3   0.100  0.753245
truth       9.5438  9.5438     1 7126.7 125.059 < 2.2e-16 ***
gramm       0.7562  0.7562     1 7138.6   9.909  0.001652 **
block:group 0.0712  0.0712     1 7103.2   0.933  0.334052
---
```

Table 3

(a) Mean RTs in Experiment 3 (in ms, original values)

	E	F	
Block 1	1267	1190	1229
Block 2	1190	1126	1159
	1228	1158	

Animals	1162
Objects	1226

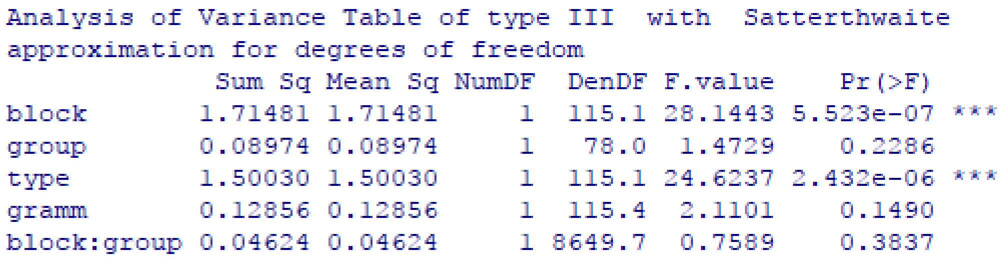
NS	1186
CS	1211

(a1) Summary of the model of Experiment 3

```
Formula: LRT ~ block * group + block + type + gramm + (1 | subj) + (1 |
    sent)
   Data: data

REML criterion at convergence: 896.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-5.4204 -0.6391 -0.1022  0.5483  4.5580

Random effects:
 Groups   Name        Variance Std.Dev.
 sent     (Intercept) 0.003056 0.05528
 subj     (Intercept) 0.032603 0.18056
 Residual             0.060929 0.24684
Number of obs: 8847, groups:  sent, 120; subj, 80

Fixed effects:
                Estimate Std. Error        df t value Pr(>|t|)
(Intercept)    7.042e+00  2.107e-02  8.900e+01 334.206  < 2e-16 ***
block1         6.037e-02  1.138e-02  1.150e+02   5.305 5.52e-07 ***
group1         4.942e-02  4.072e-02  7.800e+01   1.214    0.229
type1         -5.647e-02  1.138e-02  1.150e+02  -4.962 2.43e-06 ***
gramm1         1.754e-02  1.208e-02  1.150e+02   1.453    0.149
block1:group1  9.153e-03  1.051e-02  8.650e+03   0.871    0.384
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) block1 group1 type1  gramm1
block1       0.000
group1       0.000  0.000
type1       -0.001 -0.001  0.000
gramm1       0.096  0.001  0.000 -0.001
block1:grp1  0.000 -0.011  0.000  0.000 -0.003
```

Table 3 (continued)

(a2) Anova of the model of Experiment 3



```
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
             Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)    
block       1.71481 1.71481     1  115.1 28.1443 5.523e-07 ***
group       0.08974 0.08974     1   78.0  1.4729    0.2286    
type        1.50030 1.50030     1  115.1 24.6237 2.432e-06 ***
gramm       0.12856 0.12856     1  115.4  2.1101    0.1490    
block:group 0.04624 0.04624     1 8649.7  0.7589    0.3837    
```