# Nodding and shaking of the head
## as simulated approach and avoidance responses

## Highlights

- Simulation of vertical and horizontal head movements during semantic and affective evaluation of linguistic stimuli is investigated in explicit and implicit tasks.
- Motion detection software is implemented to allow participants to assess the stimuli with head movements.
- Accepted stimuli were evaluated faster with vertical head movements and refused stimuli with horizontal head movements.
- Semantic evaluation activated the simulation of the vertical and horizontal head movements as gestures having a communicative function “for the other”, whilst affective evaluation activated their simulation as approach and avoidance responses “for the self”.
- The greater the affective valence of the stimulus, the more implicit and automatic the simulation.

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Our recent study within the embodiment perspective showed that the evaluation of true and false information activates the simulation of vertical and horizontal head movements involved in nodding and shaking of the head (Moretti & Greco, 2018). This result was found in an explicit evaluation task where motion detection software was deployed to enable participants to assess a series of objectively true or false statements by moving them with the head vertically and horizontally on a computer screen, under conditions of compatibility and incompatibility between simulated and performed action. This study replicated that experiment, but with subjective statements about liked and disliked food, in both explicit and implicit evaluation tasks. Two experiments, plus one control experiment, were devised to test the presence of a motor-affective compatibility effect (vertical-liked; horizontal-disliked) and whether the motor-semantic compatibility found with objective statements (vertical-true; horizontal-false) could be a sub-effect of a more general and automatic association (vertical-accepted; horizontal-refused). As expected, response times were shorter when statements about liked foods and disliked foods were moved vertically and horizontally respectively by making head movements, even when participants were not explicitly required to evaluate them. In contrast, the truth compatibility effect only occurred in the explicit evaluation task. Overall results support the idea that head-nodding and shaking are simulated approach-avoidance responses. Different aspects of the meaning of these gestures and the practical implications of the study for cognitive and social research are discussed.

**Keywords**
Head nod; Head shake; Approach and Avoidance; Simulation; Motor compatibility; Embodiment

# 1. Introduction

Nonverbal behavior is a very fertile area for research into the relationships between cognition, emotion and sensorimotor mechanisms posited by the embodiment perspective (Krauss, Chen & Gotfexnum, 2000; Goldin-Meadow, 2003; Pouw, De Nooijer, Van Gog, Zwaan & Paas, 2014; Hostetter & Alibali, 2019). Many scholars have shown that both the processing and production of gestures are based on the instantaneous, automatic and unconscious mechanism of sensorimotor simulation (Gallese & Goldman, 1998; Gallese, 2001; Moors & De Houwer, 2006; Hostetter & Alibali, 2008; Shtyrov, Butorina, Nikolaeva & Stroganova, 2014). This mechanism has its roots in the kinesthetic imitation (Meltzoff & Gopnik, 1993; Chartland & Bargh, 1999; Dijksterhuis & Bargh, 2001), is influenced by experience (Zwaan & Madden, 2005; Zwaan & Taylor, 2006; Pecher & Winkielman, 2013) and is considered one of the main mechanisms underlying embodiment effects found in cognitive processing (Dijkstra & Post, 2015).

The embodiment hypothesis posits that when a behavior is associated with particular content to the extent that they generally co-occur, performance of that behavior will require fewer cognitive resources to be activated than a behavior that is not normally associated with the content in question (Förster & Strack, 1997; Glenberg, 1997; Barsalou, 1999; Glenberg & Kaschak, 2002; Gibbs, 2005; Zwaan, Madden, Yaxley & Aveyard 2004; Borghi, 2005; Gallese & Lakoff, 2005; Gibbs, 2006; Zwaan & Taylor, 2006; Borghi & Cimatti, 2009; Shalev, 2015; O'Shea & Moran, 2017). This association is generally studied through experimental designs consisting of conditions in which participants are instructed to perform behaviors compatible or not with certain stimuli, so that the recording of short response times in compatible conditions is considered indicative of a facilitation effect in cognitive processing, while longer response times in incompatible conditions are indicative of an interference effect. This is because the involved cognitive process entails a mental simulation that reactivates the same sensorimotor states that were active while experiencing the processed stimulus (Goldstone & Barsalou, 1998; Zwaan & Taylor, 2006; Zwaan & Madden, 2005; Barsalou, Santos, Simmons & Wilson, 2008; Guan, Meng, Yao & Glenberg; 2013).

Hence, the habitual movements of body parts, such as the gestures that accompany speech to express meanings, intentions and feelings, are considered to be strongly associated with cognitive, emotional and social contents (McNeill, 1992; Krauss, 1998; Kelly, Barr, Church & Lynch, 1999; Barsalou, Niedenthal, Barbey & Ruppert 2003; Niedenthal et al., 2005; Barsalou, 2008; Horstmann & Ansorge, 2011; Reimann et al., 2012). In particular, according to the recently developed "Gestures as Simulated Action" (GSA) framework (Hostetter & Alibali, 2008; 2010; 2019), gestures, as a special form of action that itself derives from sensorimotor simulation, are deemed to interact with cognitive processes to generate compatibility effects (Alibali, Boncoddo & Hostetter, 2014).

There is now considerable evidence in the embodiment literature that physical actions people perform can influence cognitive processing (generating "bottom-up" compatibility effects) and that, conversely, the cognitive processing of content can activate the simulation of compatible sensorial, motor and affective states (generating "top-down" compatibility effects) (Barsalou, 1999; 2010; Glenberg, Witt, & Metcalfe, 2013; Kaschak, Jones, Carranza & Fox, 2014; Körner, Topolinski & Strack, 2015).

Nodding and shaking of the head have a particular importance in this kind of research, because these gestures are physically embodied habits acquired in childhood (Darwin, 1872; Bates, Camaioni, & Volterra, 1975; Guidetti, 2005), which gradually assume an important communicative and social function, as they become commonly used in interactions with others, not only as backchannel responses, but in supporting of language by expressing agreement and disagreement, approval and refusal or acknowledgment and denial (Jakobson, 1972; Ekman, 1979; Morris, 1979; Poggi, D'Errico, & Vincze, 2010; Wagner, Malisz & Kopp, 2014; Horstmann & Ansorge, 2011).

However, despite their relevant functions, head nodding and shaking have mostly been investigated by social psychologists interested in the conditions in which bodily movements influence emotions and attitudes, thus generating bottom-up compatibility effects (Wells & Petty, 1980; Tom, Pettersen, Lau, Burton, & Cook, 1991; Förster & Strack, 1996; Briñol & Petty, 2003). The influence of cognition on the body via activation of sensorimotor mechanisms, i.e. top-down compatibility effects, has almost always been excluded or marginalized in investigations of head gestures, despite the fact that this direction of influence appears much more relevant if one considers simulation to be central to the study of cognition.

In an earlier study (Moretti & Greco, 2018) we addressed the dearth of research on top-down embodiment effects involving head nodding and shaking by analyzing the activation of vertical and horizontal head movements during the assessment of the truth-value of a series of conventionally true and false statements (e.g. "Sugar is sweet"; "A snail runs"). The main task required dragging sentences towards one of the four sides of a computer screen by using head movements that were translated into movement of the on-screen sentences by a motion detection software. As expected, a top-down motor compatibility effect with truth-value was observed, such that true statements were moved faster with vertical head movements and false statements with horizontal head movements.

The aim of the study presented here was to extend this result in several ways. First, we wanted to determine whether a top-down motor compatibility effect occurs when evaluating statements whose truth is subjective and dependent on personal preference (e.g. "I like chocolate"; "I dislike coffee"). This kind of evaluation is *affective*, whereas the evaluation of the *objectively* true and false statements used as stimuli in our previous study is a more *semantic* process. For this reason, our hypothesis was that more generally, accepted and refused content (both semantically and affectively) would activate the simulation of head nodding and shaking movements, respectively. Hence, we wanted to extend the approach and avoidance effects found in the processing of abstract or emotionally valenced stimuli (Solarz, 1960; Chen & Bargh, 1999) to the motion of another significant body part, the head. Researchers interested in embodied social cognition branch have almost always investigated acceptance and rejection by analyzing arm flexion and extension movements (Barsalou, Niedenthal et al., 2003; Barsalou, Simmons, Barbey, & Wilson, 2003; Neumann, Förster, & Strack, 2003; Niedenthal, 2007), whilst there have been few investigations of vertical (towards the body) and horizontal (away from the body) head movements as approach and avoidance responses.

Second, we wanted to demonstrate the reliability of the compatibility effect involving the two head movements by testing the automatic activation of their simulation in an implicit task, i.e. one that does not explicitly require participants to evaluate the stimuli. Clarifying the nature of the head gestures simulation would be relevant not only to the recent debate on the validity of embodiment effects (e.g. see Körner et al., 2015) but also to their possible manipulation in future applied social research on implicit attitudes.

The paper is organized as follows. In the next section we review previous research on compatibility effects with head gestures, first discussing early social psychological investigations and then describing the method and results of our previous study (Moretti & Greco, 2018). We then present both old and recent research showing bottom-up and top-down approach and avoidance effects, which are the basis of our experimental hypothesis. Following this we provide an overview of the three experiments devised for the present study, explaining our rationale for the choice of stimuli, the characteristics of the experimental apparatus and those of the motion capture software, and the type of analyses performed. Then the three experiments are presented in sequence. Finally, in the general discussion, we review all the results and highlight the main achievements and limitations of our investigation. We also set out future directions for research on compatibility effects with head movements and on embodiment effects more generally.

## 1.1 Previous research on head gestures

The role of the body in cognition and emotion, and especially its influence on the formation of attitudes and the use of knowledge, has traditionally been investigated by social psychologists interested in the organization of beliefs and feelings and behavioral dispositions towards social objects. Several empirical studies have examined how head gestures influence the processing of neutral stimuli and stimuli with social and emotional value.

One of the first and most famous investigations (Wells & Petty, 1980) demonstrated that nodding and shaking of the head can influence attitudes. The study was presented to participants as marketing research on a brand of earphones. Participants were divided into two groups. Those in the first group were asked to move their head up and down vertically, whilst listening on earphones to students' comments about the expense of university fees. Participants in the second group were asked to move their head horizontally from left to right, whilst listening to the same content. Both groups were subsequently asked how much they agreed with the comments they had just heard. The results showed that participants' evaluations were influenced by the head movement they had performed: the group that had nodded whilst listening expressed greater agreement with the content than the group that had been shaking the head. This compatibility effect occurred regardless of whether the comments themselves were positive or negative, in other words, regardless of the valence of the stimulus.

Later Förster and Strack (1996) found a similar effect at another level of processing using the same task. Participants had to move their head vertically or horizontally whilst learning a list of positively and negatively valenced words. The authors found that the positive words learned while nodding were remembered better than the negative ones, whereas negative words were remembered better than positive words if learnt whilst shaking one's head. The authors attributed these results to a "conceptual-motor compatibility mechanism", whereby vertical head movements - which are compatible with positive content - facilitate the generation of positive thoughts, whereas the opposite applies to horizontal movements. In the same study a double task paradigm was used to show that generating motor responses that were incompatible with the meaning of a stimulus required more resources than generating a conceptually compatible motor response. From these results the authors concluded that when a behavior is strongly associated with a certain type of thought or feeling, to the extent that they usually co-occur, the behavior requires less cognitive than behaviors that are not normally associated with the content in question (Förster & Strack, 1997).

Another study, also requiring participants to nod or shake their head while listening to a message, showed that the degree to which one is persuaded by a message is influenced by the meaning of the head movement one makes whilst listening to it (Briñol & Petty, 2003). In this study the argument contained in the message, which was about why university students should carry an identity card, was strong or weak. The strong argument mentioned the safety benefits for students, whilst the weak argument concerned the benefits for security guards. The authors found that the group that had been asked to nod was more favorable towards the proposal than the group that had been asked to shake the head. However, the attitude of the nodding group was less favorable when they listened to the weak argument. The strength of argument effect was explained as a consequence of the head movements functioning as a form of feedback, reinforcing or weakening the mover's perception of the auditory material being processed at the same time. If the argument was interpreted as strong, nodding reinforced this evaluation and increasing the influence of the argument on the nodder's opinion. Similarly, if the argument was considered weak, nodding led reinforced this evaluation and weakened the influence of the argument. In contrast, shaking of the head led to the opposite effect in both conditions. The increases and decreases in listeners' confidence in the message were thus attributed to the head movements serving as proprioceptive signals about the validity of one's thoughts.

As Förster (2004) later pointed out, however, this interpretation could only be applied to cases of persuasive communication, where the listener did not already hold a strong opinion or attitude towards the object or argument in question. Forster therefore decided to replicate the experiment, testing the influence of the two gestures on judgments of well-known objects (food products) on which participants would already have strong opinions. The experiment required participants to follow the horizontal and vertical movements of certain stimuli on a computer screen with their heads. Induction of nodding movement led to more positive evaluations of objects of which the participants already had a favorable opinion (candies) but it in no way improved evaluations of objects considered unpleasant (beef lung). Similarly, shaking the head increased the perceived unpleasantness of objects that were already judged negatively but did not influence judgments of objects considered pleasant.

The motor compatibility effect found in this type of experiment shows that gestures can influence higher-order cognitive processes such as evaluation and judgment, not only of neutral or unfamiliar stimuli but also of stimuli of which one has a pre-existing opinion. It is worth pointing out that the effect of the motor actions is considered implicit in these cases because their influence is difficult to control. In fact, in none of these experiments were participants conscious of the movement meaning, because a cover story was always given by the experimenters.

All these studies of head movement-related effects investigated bottom-up compatibility, focusing on exploiting the social and emotional implications of the two gestures and neglecting the simulative aspects related to top-down compatibility effects. Such aspects have been put in light only recently from the embodiment perspective, thanks to the important discovery of mirror neurons (Rizzolatti et al., 1988; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Fadiga, 1998; Rizzolatti & Sinigaglia, 2006). This perspective assumes that the mechanisms that give rise to sensorimotor simulations are based on previous experience and had the original function of allowing information to be represented in the absence of physical stimuli (Glenberg, 1997; Barsalou, 1999; 2010; Borghi, Glenberg & Kaschak, 2004; Gallese & Lakoff, 2005; Zwaan & Madden, 2005; Casasanto, 2009; Pecher, Van Dantzig, Boot, Zanolie, & Huber, 2010; Gallese & Sinigaglia, 2011). Therefore, top-down motor compatibility effects can be generated even when cognitive processes occur without a direct connection to the environment that had allowed the acquisition or activation of sensorimotor patterns (Niedenthal et al., 2005; Körner, Topolinski, & Strack, 2015).

In our previous research on nodding and shaking of the head (Moretti & Greco, 2018) we tested this kind of compatibility effects. In particular, we examined the relationship between the meaning of the two head movements and a higher cognitive process, such as the evaluation of the truth-value of sentences. Our hypothesis, derived from one of the main assumptions of the embodiment perspective, according to which the cognitive processing of content reactivates the experiential traces associated with that content (Zwaan & Madden, 2005; Zwaan & Taylor, 2006), was that processing true and false content activates the simulation of head nodding and shaking movements, because they typically indicate affirmative and negative responses respectively. We predicted that a facilitation effect would be observed when a vertical movement was used to indicate that a statement was true and a horizontal movement was used to indicate a false statement. In contrast, we expected to see an interference effect when the movement-evaluation pairings were reversed.

Three experiments were performed in order to investigate this top-down compatibility. The main task consisted of dragging simple objectively true and false sentences, which appeared one at a time inside a box in the center of the screen, horizontally or vertically towards one of the four sides of the screen. In the first experiment participants were required to evaluate the stimuli by dragging them with the head; motion detection software converted their head movements into mouse pointer motion. In the second experiment the same sentences were evaluated but the mouse was used to make responses instead of the head, and in the third experiment participants were not asked to evaluate the truth of sentences but to use head movements to classify them according to their subject (animals or objects). Analyses of response times only indicated a compatibility effect in the first experiment. This result suggests that performing vertical and horizontal head movements facilitates, respectively, the assessment of truth and falsity of sentences, whereas using the same movements to evaluate other properties of sentences (such as the category of the sentence's subject) or using a different motor response (e.g. moving a mouse) to indicate the truth value of the sentence does not affect performance in any way. From the results of this study it was possible to conclude that evaluation of true and false information activates the nodding and shaking gesture directional information.

However, agreeing or disagreeing with certain content also implies accepting or rejecting it, to a greater or lesser extent depending on the affective attitude towards the concerned content. Since nodding and shaking of the head are typically used to express agreement and disagreement or acceptance and rejection, and given embodiment effects relating these two gestures to higher cognitive processes such as objective evaluation (demonstrated in our previous study), we considered that it would be worthwhile to determine whether a compatibility effect occurs also in the context of subjective evaluations.

## 1.2 Approach and avoidance effects

In experimental studies that use objectively evaluable linguistic stimuli, the focus of the investigation is on the relationship between a bodily state and the conventional meaning of words or sentences. In studies that, instead, use subjectively evaluable stimuli, the relationship is between a bodily state and a subjective evaluation (judging affective meaning, pleasantness, value, etc...) of abstract concepts, words or sentences with positive and negative value.

A classic effect observed in the assessment of valenced stimuli is the approach and avoidance effect (AAE) (Solarz 1960; Chen & Bargh, 1999), which is that evaluations of positive stimuli are faster when they involve an approach movement (e.g., pulling a lever towards the body) whereas evaluations of negative stimuli are faster if they involve an avoidance movement (e.g., pushing a lever away from the body). According to the AAE model, indeed, reducing the distance between the self and the stimulus is indicative of acceptance, whereas increasing the distance is indicative of refusal. Thus the AAE generally manifests as top-down motor compatibility effect, because it occurs in tasks where body movements are used to indicate one's evaluations of stimuli, with motor responses being facilitated when they correspond to simulated actions and are hindered when there is no correspondence between the two (Dijkstra & Post, 2015).

The AAE has also manifested as a bottom-up compatibility effect in experimental paradigms where participants are asked to perform approach and avoidance actions before evaluating a stimulus.
For example, Cacioppo and colleagues (1993) observed that participants who had been asked to flex their arms towards their body whilst observing stimuli subsequently gave these stimuli more positive scores than participants who had extended their arms away from their body whilst observing them. Arm flexion and extension movements have also been shown to facilitate retrieval of compatible information from long-term memory in a name generation task (Förster & Strack, 1997): a high proportion of the names generated by participants performing approach arm

movements belonged to famous people they admired, whereas the reverse was true for participants performing avoidance arm movements.

The AAE has mostly been tested with arm movements, but it has been shown that the manipulation of other body parts, such as posture or facial expressions, can influence both the evaluation of content (Strack, Martin, & Stepper, 1988), and memory for information compatible with the meaning of the movement (Riskind, 1984).

As for head gestures, a recent study (Osugi & Kawahara, 2018) showed that observing vertical and horizontal head movements performed by another agent can generate compatible feelings and attitudes of acceptance and refusal. In this experiment the participants watched videos of 3D models of female figures that could nod or shake their heads before evaluating the attractiveness, and pleasantness of these figures and their personal willingness to approach them. The results showed that when a model nodded her head she was perceived as more pleasant and more attractive than in the condition in which she was shown shaking her head. The authors concluded that this effect was due to the ability of the two head gestures to activate a cognitive scheme containing social information regarding whether the observer could avoid or approach the interlocutor. Osugi and Kawahara concluded, in summary, that nodding and shaking of the head should be considered respectively as approach and avoidance behaviors.

The hypothesis of our work supports this conclusion. When nodding, the head moves in a longitudinal direction, the movement typically starts above the line of sight and the head then moves towards the body (Wagner et al., 2014), resulting in an approach movement. On the other hand, shaking the head from side to side could be considered analogous to the avoidance movement made to dislodge or get rid of an unwanted object (Bousmalis, Mehu, & Pantic, 2013). This interpretation is in line with Darwin’s (1872) intuition about the origin of the two gestures of the head in his famous study on the expression of emotions in men and animals. He observed that nodding might have its roots in the infant’s acceptance of the mother's breast and the maintenance of food in the mouth, whereas the gesture of shaking the head might originate from the movements the infant makes to refuse nourishment.

The starting point for our study was from the assumption that nodding and shaking of the head can represent approach and avoidance responses respectively and we investigated a potential top-down compatibility effect, i.e. an AAE, involving vertical and horizontal head movements and the evaluation of valenced stimuli.

## 1.3. Overview of the present study

As mentioned in the introduction, head nodding and shaking are relevant to the embodiment perspective because they are body movements that support cognitive processing by both conveying and facilitating the interpretation of important information during everyday interactions. Furthermore, they are among the first non-verbal behaviors acquired by newborns (together with the hand gesture used to say hello) (Darwin, 1872; Bates et al., 1975), and they are the only means by which infants of less than 16 months can communicate acceptance and rejection (Guidetti, 2005). Hence we assume that their relationship with cognition is grounded and strong.

As outlined above, we showed previously (Moretti & Greco, 2018) that the evaluation of true statements activated the simulation of the vertical oriented head movement involved in the nodding gesture, whereas the evaluation of false statements activated the simulation of the horizontal movement of shaking the head. The stimuli used were very simple sentences, whose truth-value was objective and conventionally recognized.

The research presented here stems from our previous result and uses the same apparatus, but as stimuli we used sentences that state personal preferences whose truth-value is not an objective matter, but depends on the subjective, emotional preferences of the person who is evaluating. For example, the truth-value of positive or negative statements such as "I like coffee" or "I dislike coffee" depends on the value that the object (coffee) has for the subject (the person who is evaluating them). Evaluating a positive statement as true and a negative statement as false would mean accepting their object, whereas evaluating a positive statement as false and a negative one as true would indicate a rejection of the object.

Hence using this type of sentence as stimuli in a study of the motor compatibility allows one to make an important distinction between motor-*semantic* compatibility (whether the movement is compatible with the objective meaning of the sentence) and motor-*affective* compatibility (whether the movement is compatible with the affective attitude towards the object of the statement). It is the negative statements that allow us to discriminate between the two types of compatibility, because evaluating them as true, that is agreeing with their meaning, means rejecting their object, whereas evaluating them as false, disagreeing with their meaning, means accepting it. Consider, for example, the negative statement “I dislike coffee”: if the object (coffee) has positive value for the respondent, i.e. he or she likes coffee, then the sentence would be evaluated as false, whereas if he or she dislikes coffee, it would be evaluated as true. In the case of positive statements such as “I like coffee” the respondent would evaluate the sentence as true if he or she likes coffee, and as false otherwise, so there is a congruence between truth-value and object value.

Hence, in order to determine whether the motor-semantic compatibility found in our previous study, in which participants evaluated the truth-value of objective sentences (true-vertical; false-horizontal), was actually a sub-effect of a stronger and more general compatibility effect based on the acceptance or rejection (accepted-vertical, refused-horizontal), we devised a new study based on the same paradigm, but with a series of positive and negative statements about subjectively pleasant or unpleasant foods as stimuli. The choice of this kind of sentence object was based on the fact that personal preferences about food are not a matter of particular shame or pride, so expressing such preferences was considered unlikely to be subject to biases that might distort or slow down the evaluation process.

The task, which involves using vertical and horizontal head movements to drag sentences that appear in the center of a computer screen towards one of the four sides, makes use of a custom motion capture program written in Visual Basic 6 allied to the free software 'Enable Viacam v.1.7.2' (CREA Software, released under the GNU General Public License, www.crea- si.com) that uses a standard webcam to capture head movements and convert them into mouse pointer motion[1]. Response times were recorded using the same customized program and then analyzed with the Linear Mixed Modeling (LMM) technique (Brysbaert, 2007; Baayen, Davidson, & Bates, 2008; Baayen & Milin, 2010). This is a recommended procedure for repeated measures paradigms involving linguistic stimuli since it allows the variance due to individual differences between participants and variance due to differences in intrinsic item properties (such as sentence length, the complexity of reading or the familiarity of words) to be taken into account at the same time.

The analyses were performed using the statistical software R 3.3 (http://www.r-project.org/) with the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). The *F* statistics were obtained using the Anova function of the lmerTest package (https://cran.r-project.org/package=lmerTest) and degrees of freedom were estimated with the Satterthwaite approximation; the eta-squared values were calculated using the eta_sq function in the sj_stats package (https://cran.r-project.org/package=sjstats). In all the analyses we started with the simplest model and worked

[1] E-Viacam settings were the following: 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.

through increasingly complex models to find the most suitable model for the data. In all models the dependent variable was response time, with participants and items as random factors. The fixed factors varied according to the specific hypothesis being tested and previous results. We didn't set sample sizes for our experiments a priori, since no direct sample size calculations are available with the Linear Mixed Modeling technique, and there is not a single agreement among scholars about how to determine sample size in advance with these models.

In total we carried out three experiments. The first two investigated the activation of the simulation of the two head movements in an explicit truth evaluation task. We expected to replicate the *semantic* motor compatibility effect when evaluations were made with head movements (first experiment) but not when they were made with the mouse, that is without moving the head (second experiment). We also expected to find an motor-affective compatibility between head movements and the affective value that the object of the sentence had for the respondent, such that response times would be shorter when head movements were used to move statements about liked food vertically and statements about disliked food horizontally.

The third experiment examined the simulation of the two head movements in an implicit task, that is one where participants were not explicitly required to evaluate the truth-value of the sentences. The aim was to assess the extent to which the compatibility effect was automatic and to determine whether the activation of the simulation was detectable at the initial stimulus processing stage or during subsequent stimulus evaluation. As participants were not required to evaluate the truth-value of the sentences in this latter experiment we expected to find only a motor-affective compatibility effect based on participants' affective evaluation of the sentence object.

# 2. Experiment 1

## 2.1. Method

### 2.1.1. Participants

A total of 79 students (54 women; mean age 21.46, *SD* = 4.12) participated in the experiment in return for course credits, with local ethical approval. All participants had normal color perception and normal or corrected-to-normal vision. Informed consent was obtained before the start of the experiment. Participants were randomly assigned to two groups (A = 40; B = 39).

### 2.1.2. Materials and apparatus

The computer monitor (an HP1955 LCD 19-inch color flat screen) used for the experiment was placed at a distance of about 60 cm from where the participants were seated. The webcam, which was mounted in the middle of the upper side of the screen, was a Logitech C210, with a required frequency of 30 frames per second. The experiment consisted of four phases: a practice session, followed by the main task, an explicit food preference questionnaire, and, finally, a debriefing phase.

The main task consisted of two blocks of 60 trials each (for a total of 120 trials). In the first block the "True" bars were positioned at the top and bottom of the screen and the "False" bars at the right and left sides for group A, whilst the positioning was reversed for group B. In the second block the positioning of the bars was reversed for both groups.

The stimuli were 120 simple sentences (in Italian) expressing preferences about 60 different foods. Half of the sentences had a positive formulation (e.g. "I like chocolate") and the other half a negative formulation (e.g. "I dislike chocolate"). 60 stimuli per block were shown in a different random order for each participant: 30 positive and 30 negative sentences were shown in the first block and the rest in the second block.

The final questionnaire assessed explicit preference for each of the 60 foods mentioned in sentences and was designed to detect any inconsistencies between the evaluation made with the head in the main task and the answers given to the questionnaire, and to exclude from the analysis those items to which a participant declared him or herself to be “indifferent” in the questionnaire.

### 2.1.3. Procedure

The experiment took place in a separate, well-lit, quiet room. After a short practice session, instructions displayed on the screen informed participants that the research concerned food preferences and that the task consisted of evaluating, based on their personal preferences, the truth of a series of sentences that would appear inside a black box in the center of the computer screen, by using head movements to drag them towards one of the bars placed at the four sides of the screen.

The instructions also explained that sentences with an apparently excessive intensity, such as "I love…" or "I hate…", should be interpreted as "I like…" or "I don't like…". The aim was to reduce hesitations in the case of sentences referring to foods for which the participant did not have a strong preference (e.g. "I like it but don't love it" or "I don't like it but it doesn't disgust me"). This instruction was repeated after the first eight sentences of block 1, halfway through the task (before the beginning of block 2) and after the first 8 sentences of block 2.

Participants were seated in a chair placed in front of the computer and asked to keep their torso as still as possible throughout the experiment. Initially the following instructions appeared on the screen: "In this experiment you will control the mouse pointer by moving your head. The webcam you see on the monitor is used to capture these movements and works this way: when you move your head you will move the pointer, when you are keeping your head still, the pointer will make a clicking sound".

At the beginning of the practice session the instructions asked participants to keep their gaze fixed on a cross that appeared in the center of the screen and not to move their head, to allow the software to calibrate the webcam. The calibration set the Eviacam software so that holding the pointer still would generate a left-click. When the calibration was complete, a message prompted participants to abandon the mouse (used to follow instructions up to this point) and to use head movements to control the pointer. Then a gray screen with a black box in the middle (11x3cm) appeared and the participants were instructed to move their head to position the pointer inside the box and then remain still until they heard the click sound. When the click sounded the box changed position, upwards and downwards, six times. The next screen instructed participants to drag the box horizontally and vertically. In this phase the words "This is a sentence" appeared inside the box after the click and a 15 mm yellow bar appeared on each of the four sides of the screen. Participants were asked to drag the box to one of the yellow bars and stop when they heard the click sound. Whenever the box reached one of the yellow side bars, it reappeared in the center of the screen; this enabled participants to practice moving the box in all directions (up, down, right, left) in the order they preferred. The practice session (10 trials) could continue until the participant was fully accustomed using head movements to control the mouse pointer.

Then the main task began. The instructions explained that sentences would appear inside the central black box, one at a time, which would be true or false depending on personal preference, and that the task consisted of evaluating the truth-value of the sentences by dragging them towards one of the four sides of the screen, where bars labeled "True" or "False" would appear. The bars were positioned in the same way as the yellow bars had been in the practice phase. In the compatible condition (Block 1 of Group A and Block 2 of Group B) the "True" green bars appeared at the top and bottom of the screen (on the vertical axis) and the "False" red bars on the right and left sides (on the horizontal axis); in the incompatible condition (Block 2 for Group A and Block 1 for Group B) the bar positions were reversed. Participants could freely choose the direction of their answers to evaluate the sentence truth-value.

At the end of the main task participants rated their preference for each of the 60 foods by choosing from 3 options: "I like it", "I do not like it", and "I neither like nor dislike it".

At the end of the experiment participants were asked a series of debriefing questions covering possible difficulties encountered during the experimental procedure and checking that they had not discovered the experimental hypothesis.

### 2.1.4. Data analysis

Response times (RTs) were recorded from the moment when the central box was clicked and the sentence appeared to the time at which the box reached a vertical or horizontal distance of 20 pixels from its starting point. This measure was chosen to maximize sensitivity to response movements and minimize inclusion of random movements (less than an amplitude of 20 pixels)

To clean the data the following trials were eliminated: the first 8 responses of each block were considered additional practice (13.3%) and trials with RTs < 300 ms (1.8%) or > 3000 ms (5.7%) were considered invalid. Inconsistent responses (i.e. those where the preference expressed was different on the two blocks (1.3%) or difference from the preference expressed in the final questionnaire (14.7%) and those where the initial movement was inconsistent with the final bar position (13%)) were also discarded. Trials involving foods to which the participant declared indifference in the final questionnaire (7.9%) were also eliminated. The remaining data were subjected to logarithmic transformation (the distortion of the distribution was reduced from 0.96 to 0.01) and analyzed using linear mixed models.

## 2.2. Results

The first model included the following fixed factors: Block (block 1; block 2) x Group (group A; group B) interaction; Block; sentence Type (positive; negative); sentence Truth-value (true; false), with subjects and items as random intercepts [Table 1(a)].

There was an effect of practice (i.e. Block), with RTs being shorter in block 2 than block 1 in both groups [$F(1,115) = 60.43$, $SE = 0.017$, $p < .001$]. There was also a Block x Group interaction indicative of a motor-semantic compatibility effect (true-vertical/false-horizontal faster than true-horizontal/false-vertical) [$F(1,5394) = 57.57$, $SE = 0.012$, $p < .001$] (Fig. 1). There was no Group effect [$F(1,75) = 0.41$, $SE = 0.031$, $p = .52$] but there was an effect of Type, with positive sentences being evaluated faster than negative ones [$F(1,164) = 66.72$, $SE = 0.013$, $p < .001$] There was also an effect of Truth-value, with longer RTs to false sentences [$F(1,5270) = 10.75$, $SE = 0.008$, $p = .001$].

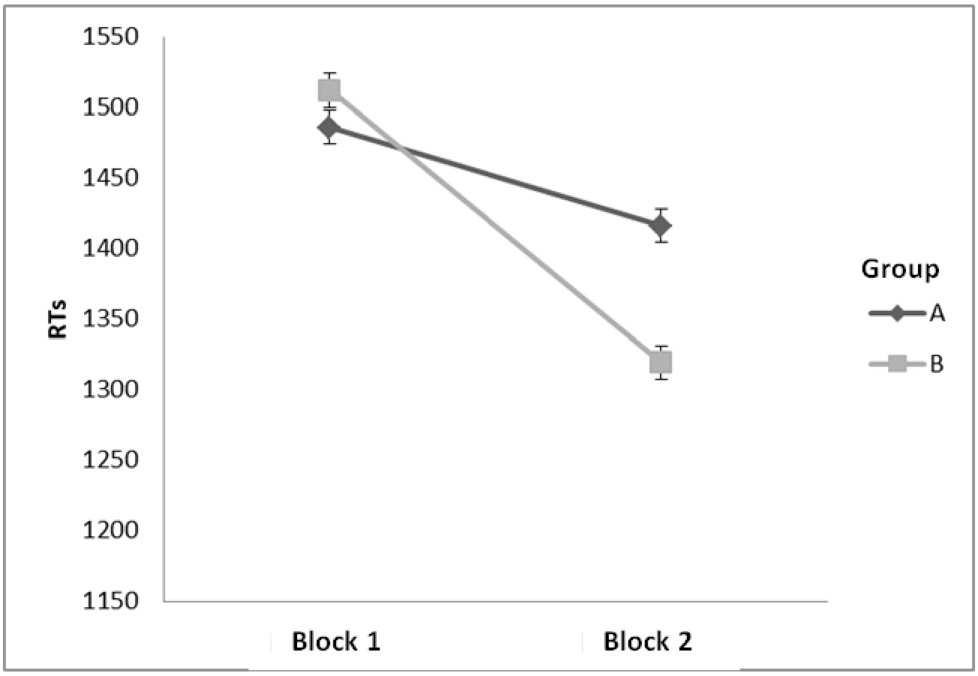


Figure 1 - Mean RTs (in ms) in Block 1 and in Block 2 for Group A and Group B in Experiment 1. Error bars indicate the standard error.

Because of the interaction between Block and Group, we checked for an effect of Compatibility (compatible conditions: Block 1 of Group A and Block 2 of Group B; incompatible conditions: Block 2 of Group A and Block 1 of Group B) in a model that included random intercepts and random slopes for the effect of Compatibility for both subjects and items. The fixed factors were Compatibility x Group interaction, Truth-value and Type [Table 1(b)].

In line with the motor-semantic compatibility hypothesis, there was an effect of Compatibility, such that RTs were faster in the compatible condition than the incompatible condition [$F(1,70) = 20.78$, $SE = 0.011$, $p < .001$] (Fig. 1.1). There were also effects of Truth-value [$F(1,5258) = 9.85$, $SE = 0.008$, $p = .002$] and Type [$F(1,165) = 38.60$, $SE = 0.013$, $p < .001$] and an interaction between Compatibility and Group (the effect of Block) [$F(1,131) = 38.60$, $SE = 0.030$, $p < .001$].

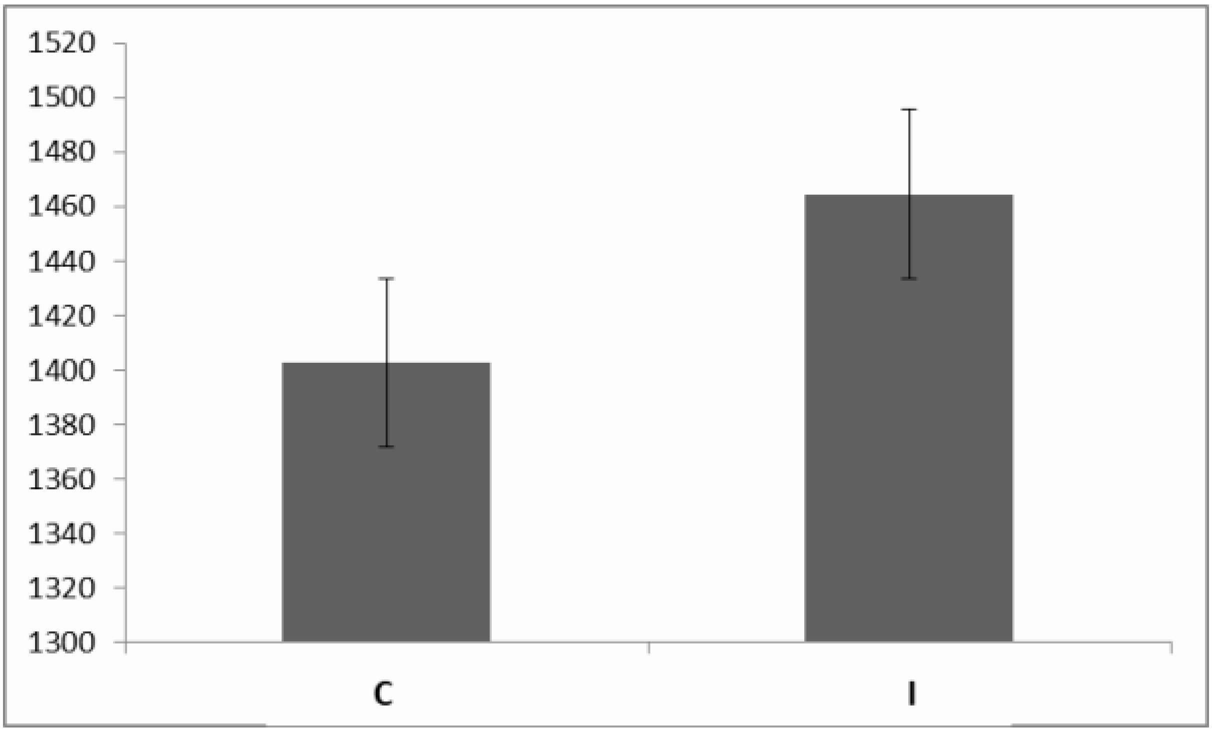


Figure 1.1 - Mean RTs (in ms) in Compatible (C) and Incompatible (I) conditions in Experiment 1

were consistent with the motor-semantic compatibility hypothesis.
Error bars indicate the standard error.

We examined the possible interaction between the effects of Truth-value, Type and Compatibility, in a third model with the Compatibility x Group x Truth-value x Type interaction, Truth-value and Type as fixed factors, and the same intercepts and random slopes as in the second model [Table 1(c)].

The significance of main factors was confirmed. There were effects of Compatibility [$F(1,108) = 19.63$, $SE = 0.011$, $p < .001$], Truth-value [$F(1,5115) = 4.01$, $SE = 0.011$, $p = .045$], Type [$F(1,175) = 91.43$, $SE = 0.014$, $p < .001$] and a Compatibility x Group interaction [$F(1,160) = 32.03$, $SE = 0.02$, $p < .001$]. There was also a Compatibility x Type interaction [$F(1,5216) = 9.27$, $SE = 0.016$, $p = .002$] such that the difference between conditions was greater on positive sentences than negative sentences (Fig. 1.2). There was no Compatibility x Truth-value interaction [$F(1,5371) = 1.77$, $SE = 0.016$, $p = .18$] although there was a Type x Truth-value interaction [$F(1,5079) = 110.07$, $SE = 0.016$, $p < .001$] such that RTs were faster to negative sentences that were evaluated as false rather than true, whereas responses to positive sentences were faster when they were evaluated as true.

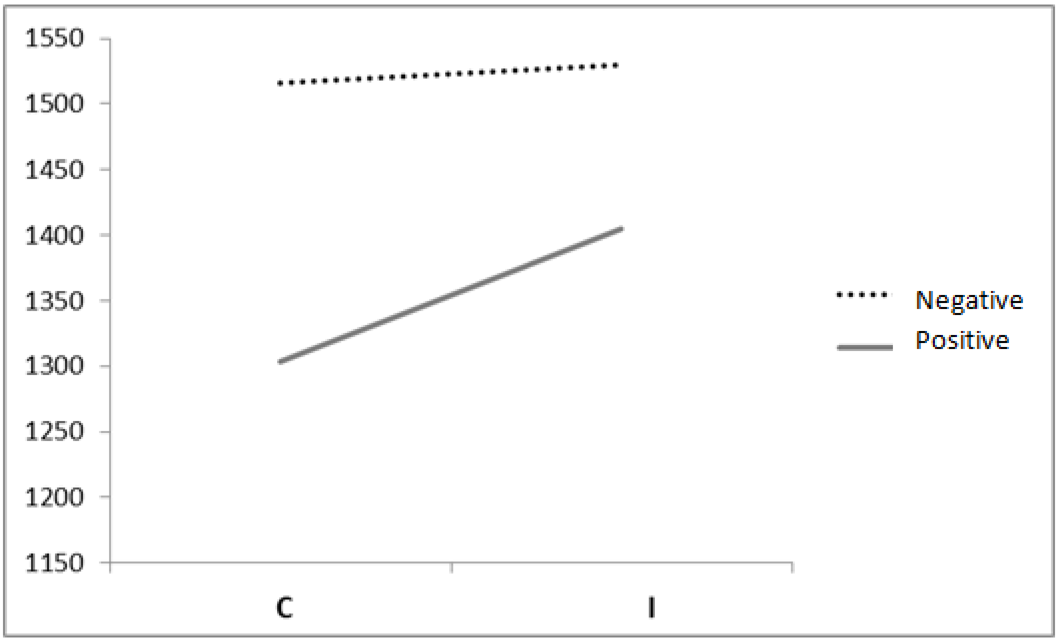


Figure 1.2 - Mean RTs (in ms) in Compatible (C) and Incompatible (I) conditions for Positive and Negative sentences in Experiment 1.

The final model included Compatibility x Group, Truth-value x Type, Truth and Type as fixed factors, random intercepts and random slopes for the effects of Compatibility, Type and their interaction for subjects, and random slopes for the effect of Compatibility for items [Table 1(d)].

There was an effect of Compatibility [$F(1,69) = 22.40$, $SE = 0.010$, $p < .001$, $\eta^2 = .09$], together with an effect of Type [$F(1,156) = 93.10$, $p < .001$, $\eta^2 = .41$], but only a marginal effect of Truth-value [$F(1,3302) = 3.62$, $SE = 0.0008$, $p = .06$, $\eta^2 = .03$]. There were also interactions between Compatibility and Group [$F(1,121) = 44.49$, $p < .001$, $\eta^2 = .14$] and between Type and Truth-value [$F(1,5014) = 104.92$, $p < .001$].

We analyzed the interaction between Truth-value and Response direction (up; down; left; right) using a repeated measures ANOVA with Response direction and the Truth-value as within-subject factors. There was a Truth-value x Response direction interaction [$F(2.18,89) = 6.09$ (Huynh-Feldt correction), $p < .01$] and post-hoc analyses (with Bonferroni correction) showed that in the case of false sentences, rightwards movements were faster than upwards movements ($p < .05$), whereas in the case of true sentences upwards and downwards movements were faster than rightwards ($p < .01$) and leftwards ($p < .05$) movements (Fig. 1.3).

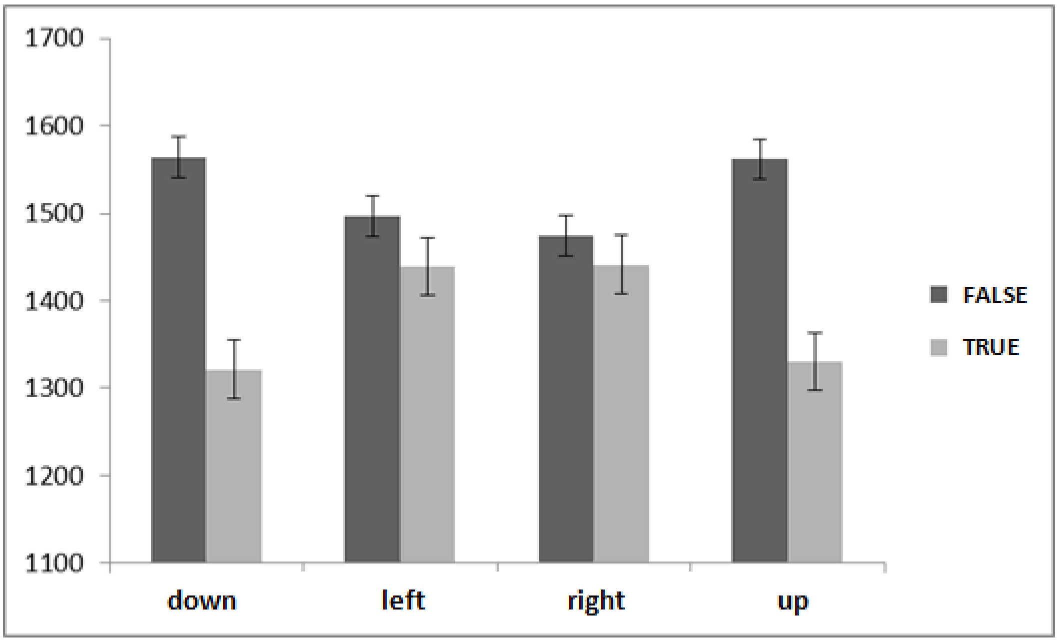


Figure 1.3 - Mean RTs (in ms) for the four Response directions of (down, left, right, up) for True and False sentences in Experiment 1. Error bars indicate the standard error.

To determine whether there was a motor-affective compatibility effect involving the object of the sentence and to compare any such effect with the motor-semantic compatibility effect, we recoded the Compatibility factor on the basis of affective rather than semantic compatibility. Trials were coded as MA-compatible (motor-affective compatible) if a sentence about a food rated as liked in the explicit questionnaire had been moved vertically or a sentence about a food rated as disliked had been moved in a horizontal direction, whilst the remaining trials (liked-horizontal/disliked-vertical) were recoded as incompatible. The model was built with MA-Compatibility, Type and their interaction as fixed factors, MA-Compatibility and Type as random slopes for subjects, and MA-Compatibility as a random slope for items [Table 1(e)].

The effect of Type remained [$F(1,95) = 88.26$, $SE = 0.017$, $p < .001$, $\eta^2 = .70$] and, more importantly, there was a main effect of MA-Compatibility [$F(1,73) = 17.13$, $SE = 0.008$, $p < .001$, $\eta^2 = .16$] (Fig. 1.4) with the effect size for the motor-affective compatibility effect being greater than that for the motor-semantic compatibility effect.

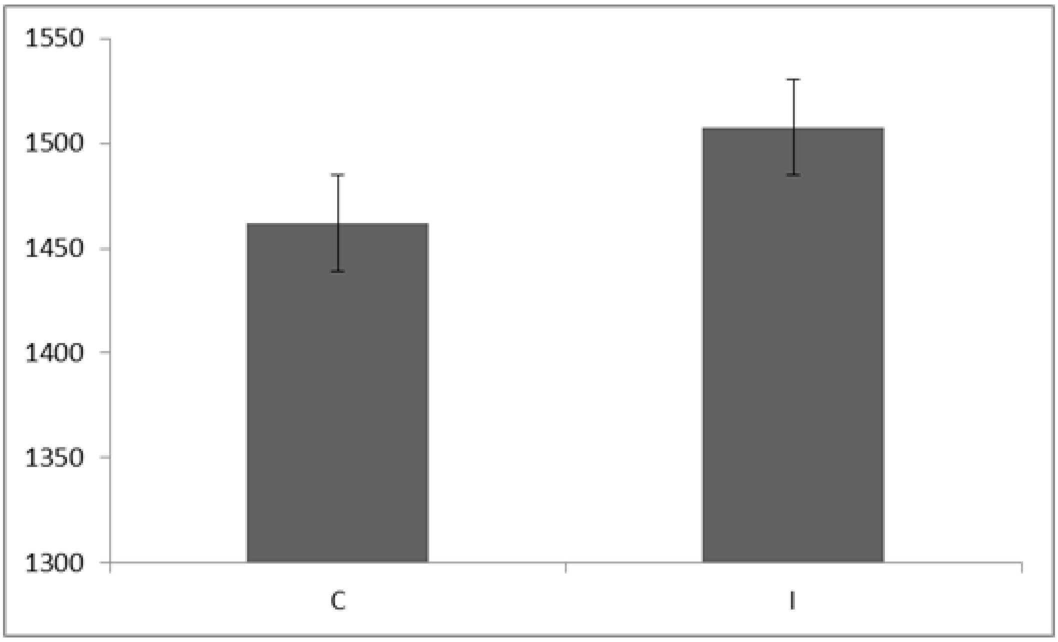


Figure 1.4 - Mean RTs (in ms) in MA-Compatible (C) and MA-Incompatible (I) trials were consistent with the motor-affective compatibility hypothesis in Experiment 1. Error bars indicate the standard error.

We analyzed the interaction between subjective preferences for the object of the sentences and the direction of the response using an ANOVA with Preference (liked; disliked) and Response direction (up; down; left; right) as within-subject factors. There was an effect of Preference [$F(1,22) = 22.10$, $p < .001$] but no interaction between Preference and Response direction [$F(3,66) = 1.63$, $p = .19$] (Fig. 1.5).

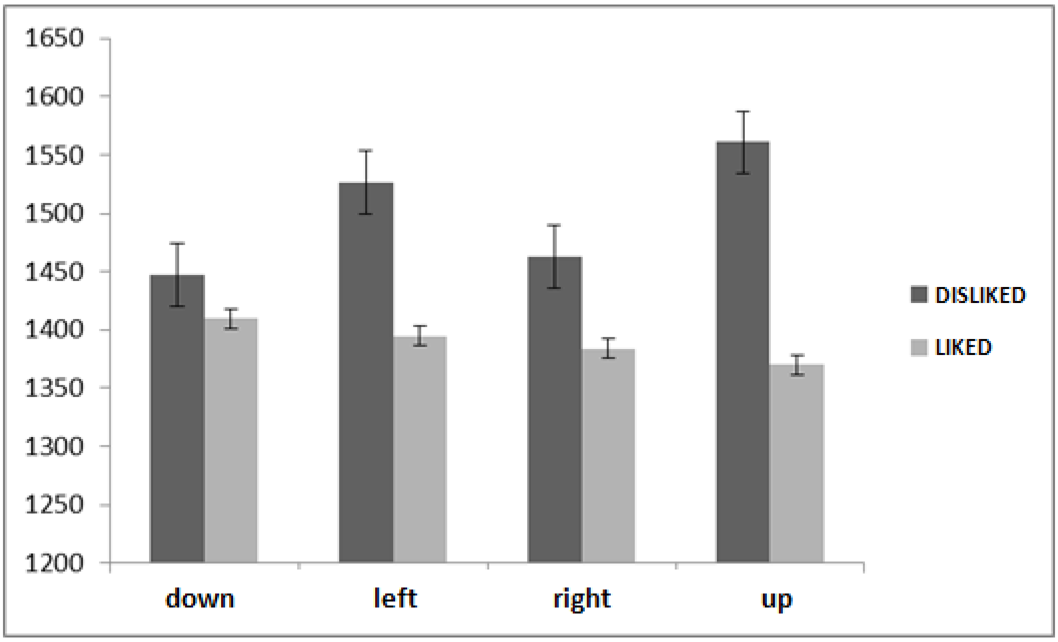


Figure 1.5 - Mean RTs (in ms) for the four Response directions (down; left; right; up) for statements about Liked and Disliked foods in Experiment 1. Error bars indicate the standard error.

## 2.3. Discussion

The aim of this first experiment was to replicate the motor-semantic compatibility effect we had previously found between head movements and objectively true and false sentences (vertical-true; horizontal-false) (Moretti & Greco, 2018), with the evaluations of subjectively true and false sentences, and to investigate a motor-affective compatibility, which we hypothesized would occur between the subjective value, positive or negative, of the object of the sentence (i.e. whether the participant liked or disliked the object) and the head movement required(vertical-liked; horizontal-disliked).

Both types of compatibility were observed: sentences evaluated as true and sentences about liked food were moved faster with vertical head movements, whereas sentences evaluated as false and sentences about disliked food were moved faster with horizontal head movements and comparison of the two effects revealed that the motor-semantic compatibility effect was smaller than the motor-affective compatibility effect.

This means that negative sentences about disliked food (e.g. "I dislike coffee") judged as true were moved faster in horizontal, even though they should have been moved faster in vertical, according to the hypothesis of semantic compatibility. Similarly, negative sentences concerning liked foods judged as false were moved faster in vertical, although they should have been moved faster horizontally.

Negative sentences were included in the study to allow a distinction between the two types of compatibility, given that for true sentences the two compatibilities are congruent. Positive sentences (e.g. "I like coffee") that were judged as true (the participant did like coffee) were moved faster in vertical (direction compatible with both the semantic valence of the sentence and the affective valence of object of the sentence). Similarly, positive sentences about disliked foods judged as false were moved faster horizontally (direction compatible with both types of valence).

This difference emerged in the analysis of the motor-semantic compatibility, where the interaction between Compatibility and Type was greater in magnitude for positive sentences, an effect that was probably due to affective compatibility.

As for longer RTs for false and negative sentences, they confirm a well-established finding about the complexity of processing negative information (Carpenter & Just, 1975; Wason, 1980; Fischler, Bloom, Childers, Roucos, & Perry, 1983; Hald, Hocking, Vernon, Marshall, & Garnham, 2013). Plus, the significant interaction between Truth value and Type suggests that content is represented in a similar way whether it accepted or rejected semantically (on the basis of whether or not it is true) or affectively (on the basis of personal, subjective evaluation of the object).

As emerged from the Anova run to identify a precise direction towards which the response movement was faster, for the semantic compatibility faster responses were almost in the directions of the first movements involved in two gestures (up for sentences evaluated as true and right for false ones) (Wagner et al., 2014). For the affective compatibility there was no specific direction towards which the response was faster, so the compatibility showed-up with both up and down (vertical) and left and right (horizontal) directions. This difference may be due to the fact that nodding and shaking of the head are communicative gestures that are performed in the context of interactions with others. So the explicit evaluation of the truth-value of the stimuli has activated the simulation of the two movements of the head as gestures having a communicative function "for the other". On the contrary, the implicit evaluation of the object value appears to have activated the two movements of the head as movements of approach and avoidance "for the self", that is as movements that increase or decrease the distance between the agent and the stimulus.

In summary, these results appear to confirm that there is a top-down motor compatibility effect based on a correspondence between the movements involved in the two gestures of nodding and shaking the head and a higher cognitive process such as the evaluation of linguistic stimuli, and that the more emotional and personal aspects come into play in the evaluation processing, the broader the motor compatibility effect.

This experiment left open the possibility that the results actually reflect a spatial-affective compatibility with vertical and horizontal space or dimensions. For example, there are studies that have found compatibility effects involving spatial responses and words with affective value (e.g. Lakoff & Johnson, 1980; 1999; Chasteen, Burdzy, & Pratt, 2010; Xie, Huang, Wang, & Liu, 2015). We therefore wanted to investigate the compatibility effect in a task in which the response did not require the movement of the head.

# 3. Experiment 2

## 3.1. Method

### 3.1.1. Participants

A total of 70 students (61 women, mean age = 21.98 years, *SD* = 6.42) took part in the experiment in return for course credit, with local ethical approval. All participants had normal color perception and normal or corrected-to-normal vision. Informed consent was obtained at the beginning of the experiment. None of the participants had been involved in the previous experiment. Participants were randomly assigned to two groups (C = 33; D = 37).

### 3.1.2. Materials and apparatus

Stimuli and apparatus were the same as in the previous experiment: 10 trials (or more if participant had not fully understood the task) in the practice session, 60 trials in the first block, and 60 trials in the second block.

To avoid possible distortion of the responses due to excessive sensitivity of the mouse, its speed was slowed down, through the SystemParametersInfo function (pvParam value = 4), included in the Windows API library user32.dll, SPI_SETMOUSESPEED parameter.

### 3.1.3. Procedure

The experiment took place in a separate, quiet, well-lit room. Instructions, practice session, and the main task were identical to those of previous experiment, except that references to head movements were replaced with references to mouse movements.

As in the previous experiment, after the practice session, the first group (Group C) began the main task with the position of "True" bars in vertical and "False" in horizontal, and with the position of the bars inverted in the second block. For the second group (Group D) the order of blocks was reversed. At the end of the main task participants were given an explicit questionnaire on food preferences.

### 3.1.4. Data analysis

The procedure was identical to that used in the previous experiment. RTs were recorded as the time between the appearance of the sentence and the time at which the box had moved 20 pixels (taken as the start of the movement). The same data cleaning criteria were used: the first 8 answers of each block (16%) were discarded, as were RTs < 300 ms (2.4%) or > 3000 ms (2%), RTs on trials where a different preference was expressed in the two blocks (1.2%), RTs on trials for which the response was inconsistent with the response given in the final questionnaire (12%), trials in which the initial direction of movement was not consistent with the final position of the response bar (13.8%) and trials involving foods to which the participant declared him or herself indifferent in the final questionnaire (7.2%).

Cleaned data were subjected to logarithmic transformation (reducing the distortion of the distribution from 1.29 to 0.33) and analyzed with the linear mixed models technique.

## 3.2. Results

As in the previous experiment, the first model included the fixed factors Group (group C; group D) and Block (block 1; block 2) and the Group x Block interaction as well as Type (positive; negative) and the Truth-value (true; false) of sentences [Table 2(a)].

There was no Block x Group interaction [$F(1,5032) = 0.88$, $SE = 0.014$ $p = .35$] (Fig. 2) and hence no motor-semantic compatibility effect. There were, however, effects of Truth-value [$F(1,5042) = 11.12$, $SE = 0.010$, $p < .001$], Type [$F(1,5055 = 111.36$, $SE = 0.010$, $p < .001$], Block [$F(1,5072) = 115.07$, $SE = 0.007$, $p < .001$] and Group [$F(1,66) = 7.06$, $SE = 0.039$, $p = .009$].

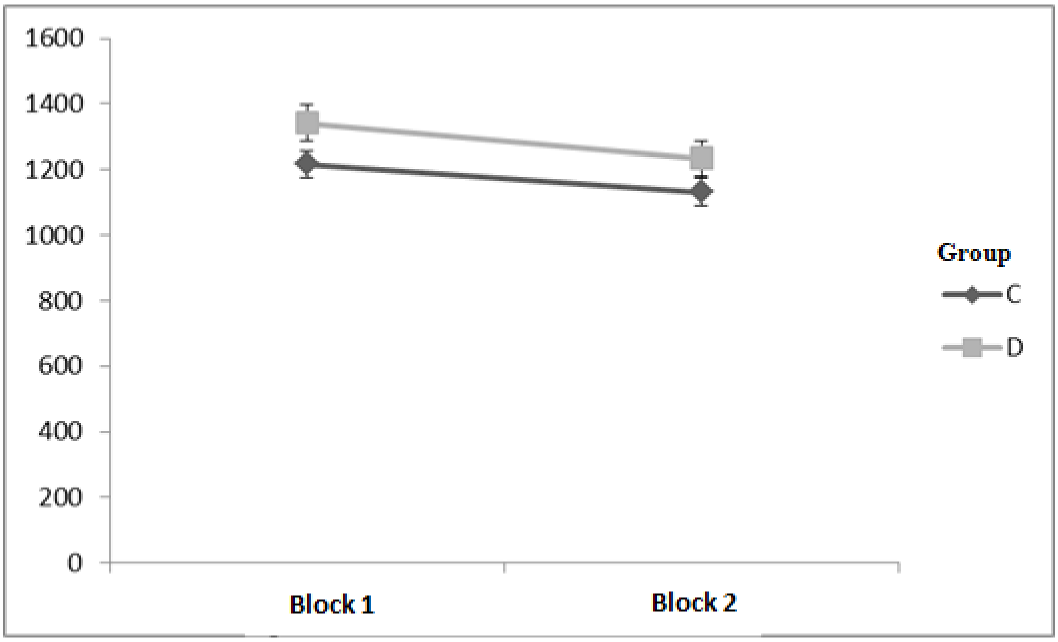


Figure 2 - Mean RTs (in ms) in Block 1 and Block 2 for Group C and Group D in Experiment 2. Error bars indicate the standard error.

As in the first experiment we tested whether a spatial-affective compatibility effect was present by building a model with the MA-Compatibility, recalculated on the basis of the preferences expressed in the questionnaire, with Type (positive; negative) and their interaction as fixed factors, their joint effect as random slopes for the subjects, and the single effect of MA-Compatibility as random slopes for items [Table 2(b)].

There was no spatial-affective compatibility effect. There was no main effect of MA-Compatibility [$F(1,57) = 0.26$, $SE = 0.010$, $p = .61$] (Fig. 2.1) and no MA-Compatibility x Type interaction [F(1,66)

= 0.01, *SE* = 0.036, *p* = .92], although there was an effect of Type [$F(1,65) = 276.02$, *SE* = 0.007, *p* <.001].

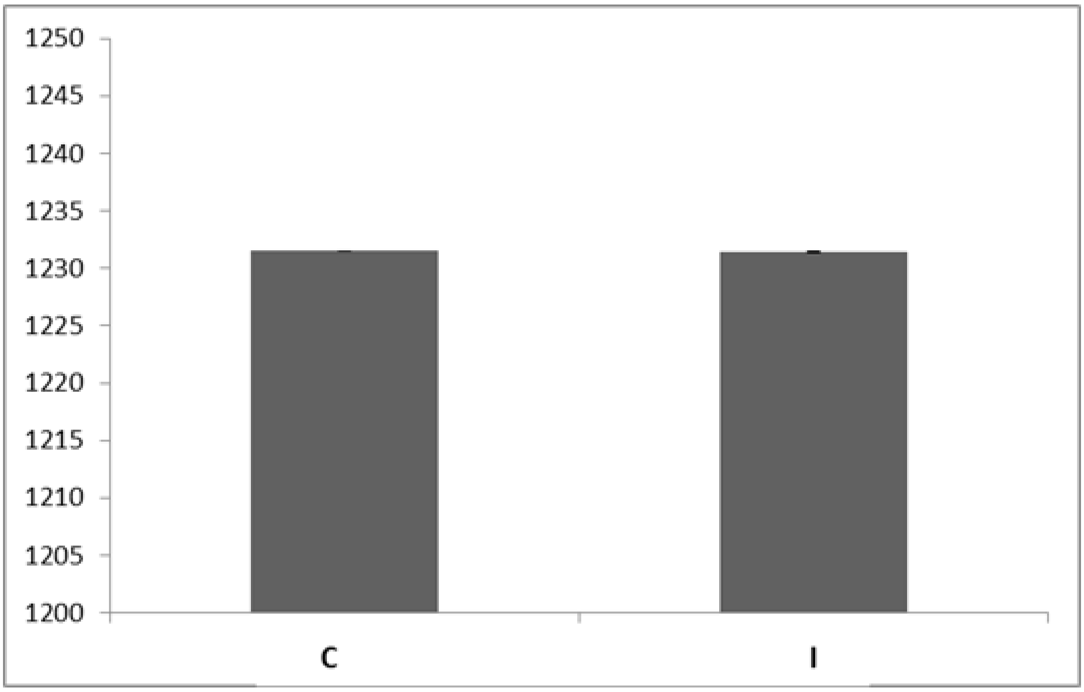


Figure 2.1 - Mean RTs (in ms) in the MA-Compatible (C) and MA-Incompatible (I) conditions were not consistent with the motor-affective compatibility hypothesis in Experiment 2. Error bars indicate the standard error.

## 3.3. Discussion

In this second experiment participants evaluated the truth-value of the same series of sentences as in the previous experiment, under the same conditions, but instead of indicating their evaluations with head movements they moved the mouse to control stimuli on the computer screen.

The aim was to determine whether the facilitation effect found in the first experiment was caused by compatibility with the head movements rather than by compatibility with the vertical and horizontal spatial dimensions.

In line with expectations, no compatibility effect was observed when the movement used to indicate one’s evaluation of a stimulus was not a head movement. There was evidence of a practice effect in both groups, with shorter RTs in the second block, but RTs were not influenced by compatibility.

It should also be noted that, as in the first experiment, false and negative sentences took longer to process than true and positive sentences, which confirms a general finding about processing of negative stimuli (see the Discussion for Experiment 1).

The absence of a compatibility effect in this experiment, like in the second experiment of our previous study (Moretti & Greco, 2018), supports the hypothesis that the basis of the compatibility is motor rather than spatial. In other words, the facilitation effect was due to the re-activation of the two gestures experiential traces and not to the congruence with the spatial dimensions.

However, despite the significant result of the first experiment, clarification of the compatibility effect we observed is necessary. Embodiment effects are generally thought to be automatic because they do not require awareness. Some scholars, for example, argue that the mechanism of simulation activates itself involuntarily, and precisely when the stimulus is processed, suggesting that cognition is actually a sensorimotor simulation (e.g., Moors & De Houwer, 2006; Zwaan &

Taylor, 2006; Shtyrov et al., 2014). The degree to which a higher cognitive process, such as evaluation, can be considered to be embodied, and identifying at which level of cognitive processing the activation of sensorimotor simulation occurs, remain an open question in the field of embodiment effects (see, e.g., Körner et al., 2015).

In our study, the explicit evaluation task we designed to detect the hypothesized motor compatibility did not allow us to determine the level at which the effect occurred, i.e. whether it occurred during the sentence comprehension, evaluation or the mapping of evaluation to response direction. Since RTs represent the time taken to move the sentence box 20 pixels from the starting point, i.e. as soon as participants had understood the sentence meaning, the simplest interpretation would places the compatibility effect at the first levels of sentence comprehension. In our experiments participants were not reminded about the conventional communicative meanings of the movements required by the task and, in fact, they were not explicitly asked to nod and shake their heads, but simply to read sentences on the computer screen and evaluate them through the action of their head. Moreover, since they could only move their head in one of the four directions on a given trial the association between the task-specific response and the everyday communicative gestures of nodding and shaking of the head was far from explicit. We therefore consider that the effects observed in our experiments can be regarded as automatic and implicit.

It is worth noting, however, that although participants were explicitly asked to evaluate the truth-value of the sentences, they were not asked to evaluate the valence of the object of the sentence, also this was processed and actually generated a larger compatibility effect, as we showed in the first experiment. This phenomenon is also known as "reaction to the object", a typical bias found in the explicit evaluations of the Likert scales items, that is when people evaluate the items not on the basis of the overall meaning of the sentence but according to the value that the object of the sentence has for them (Cacciola & Marradi, 1988; Giampietro Gobo, 2000; Marradi & Gasperoni, 2002).

Given this difference, we considered it relevant to re-test the motor compatibility effect in a task that did not require any type of explicit evaluation, but exclusively to drag and drop the stimuli towards one of the four sides of the screen, horizontally and vertically with the head. The aim of this implicit evaluation task was to clarify the level at which the compatibility effect occurs, i.e. whether it occurs during explicit, controlled evaluation of stimuli or during their automatic, implicit processing.

# 5. Experiment 3

## 5.1. Method

### 5.1.1. Participants

A total of 44 students (36 women; mean age = 20.65 years, *SD* = 1.42) participated in the experiment for course credits, with local ethical approval. All participants had normal color perception and normal or correct-to-normal vision. Informed consent was obtained before the start of the experiment. None of the participants had taken part in previous experiments.

### 5.1.2. Materials and apparatus

The experiment consisted of 4 phases: a practice session (10 trials or more), the main task (128 trials), followed by a recognition task (50 items), and the final explicit preference questionnaire (32 items).

Unlike previous experiments, the main task consisted of a single block in which only one response bar appeared at a time, in one of the four positions (up, down, left and right).

The stimuli were 128 subjectively evaluable sentences expressing opinions about 32 foods. Sixty-four positive sentences (16 for each of the four response bar positions) and 64 negative sentences (16 for each of the four response bar positions) were shown in a different random order for each participant.

The recognition task included filler stimuli, consisting of sentences not presented during the main task. Its purpose was to check that participants had actually read the sentences used in the main task and exclude from analyses who might have moved the sentences without reading them, since the main task simply required participants to drag and drop sentences and did not require explicit evaluation of the stimuli.

As in the previous experiments, the explicit preference questionnaire asked about personal like or dislike for the 32 foods mentioned in the main task stimuli and allowed us to exclude from analysis data from trials dealing with a food that a participant neither liked nor disliked.

### 5.1.3 Procedure

The experiment took place in a quiet, well-lit room, separated from the experimenters' room. Participants were told at the beginning of the practice session that the purpose of the research was to test the functioning of the motion capture software.

The instructions explained that the task consisted of positioning the cursor inside the black box at the center of the screen to make the sentence appear and then using head movements to move it quickly towards a yellow response bar that would appear at the same time as the sentence on one of the four sides of the computer screen. Participants were told that at the end of the drag and drop task they would be asked to identify which sentences had appeared. In the subsequent recognition task, they were asked to indicate which, from a list of sentences, they had seen before and which they had not.

After the recognition task the participants completed the explicit preference questionnaire choosing from three options ("I like it"; "I don't like it"; "I neither like nor dislike it") for each of the 32 foods. The experiment ended with a debriefing phase.

### 5.1.4. Data analysis

Response times were recorded using the same procedure as in previous experiments. Data were cleaned by discarding the first 8 trials (6.1%), trials with outlying RTs (1%), trials where the initial movement of the response bar and the final position were inconsistent (5.6%) and trials involving foods to which a participant declared indifference in the explicit preference questionnaire (9.6%). No participant was excluded for making more than 50% errors in the recognition phase.

Data were subjected to logarithmic transformation (reducing the distortion of the distribution from 2.24 to 0.84), and analyzed with the linear mixed models technique.

## 5.2. Results

We initially analyzed semantic compatibility. The first model included Compatibility (compatible; incompatible), Type (negative; positive) and their interaction as fixed factors [Table 3(a)].

There was no effect of Compatibility [$F(1,4497) = 0.00$, $SE = 0.007$, $p = .97$] (Fig. 3), although there was a Type x Compatibility interaction [$F(1,4498) = 11.55$, $SE = 0.01$, $p < .001$], such that in the case of positive sentence - but not negative sentences - RTs were, as hypothesized, shorter in compatible trials than incompatible trials (Fig. 3.1).

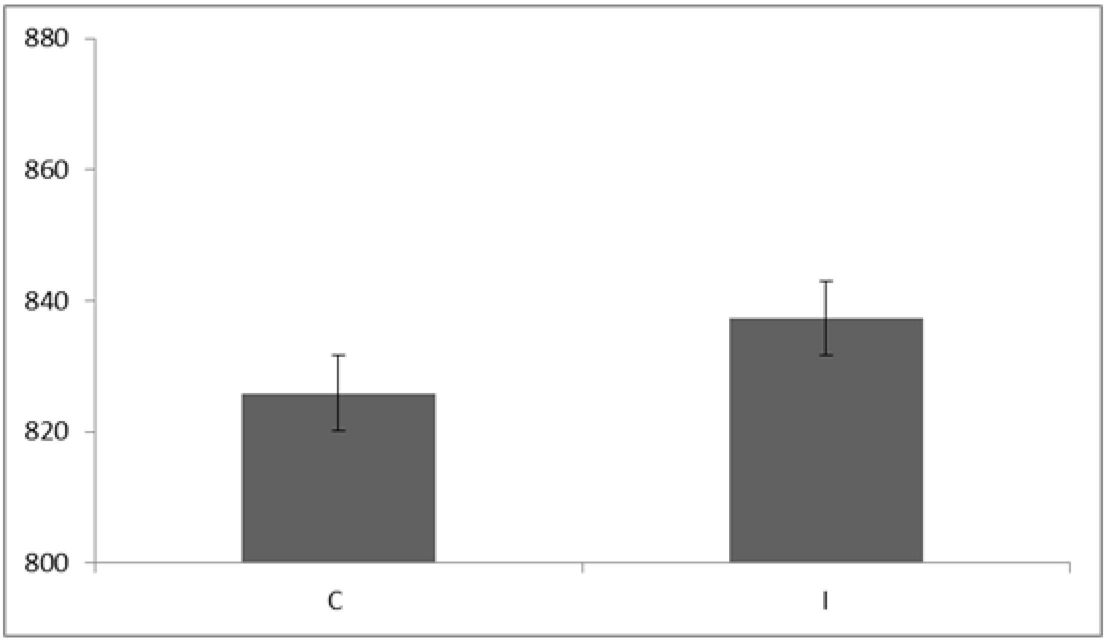


Figure 3 - Mean RTs (in ms) in Compatible (C) and Incompatible (I) trials, in accordance with the semantic compatibility hypothesis in Experiment 3. Error bars indicate the standard error.

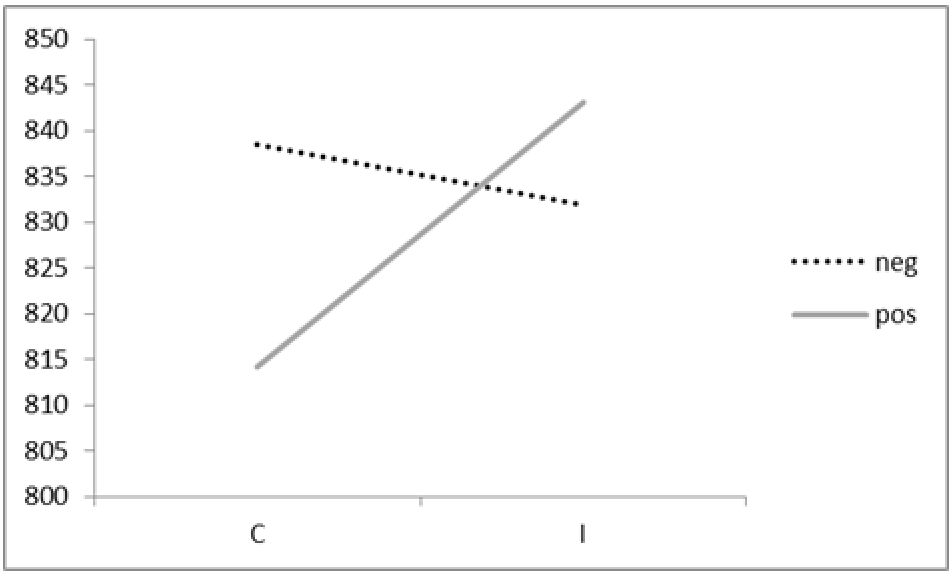


Figure 3.1 - Mean RTs (in ms) in Compatible (C) and Incompatible (I) trials for Positive and Negative sentences in Experiment 3.

This last result was in line with expectations since, as we showed in the first experiment, in the case of positive sentences motor-affective and motor-semantic compatibility have similar effects on RTs, so the difference between positive and negative sentences we observed in this experiment presumably reflected the influence of motor-affective compatibility.

As in previous experiments Compatibility was recoded as MA-Compatibility on the basis of participants' preferences about foods as expressed in the explicit questionnaire [Table 3(b)] to enable the analysis of motor-affective compatibility.

In this case, there was an effect of MA-Compatibility [$F(1,4498) = 11.55$, $SE = 0.007$, $p < .001$] that was independent of sentences type. There was no effect of Type [$F(1,59) = 0.72$, $SE = 0.008$, $p = .40$] and no interaction between MA-Compatibility and Type [$F(1,4498) = 0.00$, $p = .97$].

The MA-Compatibility effect was confirmed in a subsequent model with MA-Compatibility as a random slope for subject and items; the effect size was even larger [$F(1,45) = 5.40$, $SE = 0.009$, $p = .02$, $\eta^2 =.88$] [Table 3(c)] (Fig. 3.2).

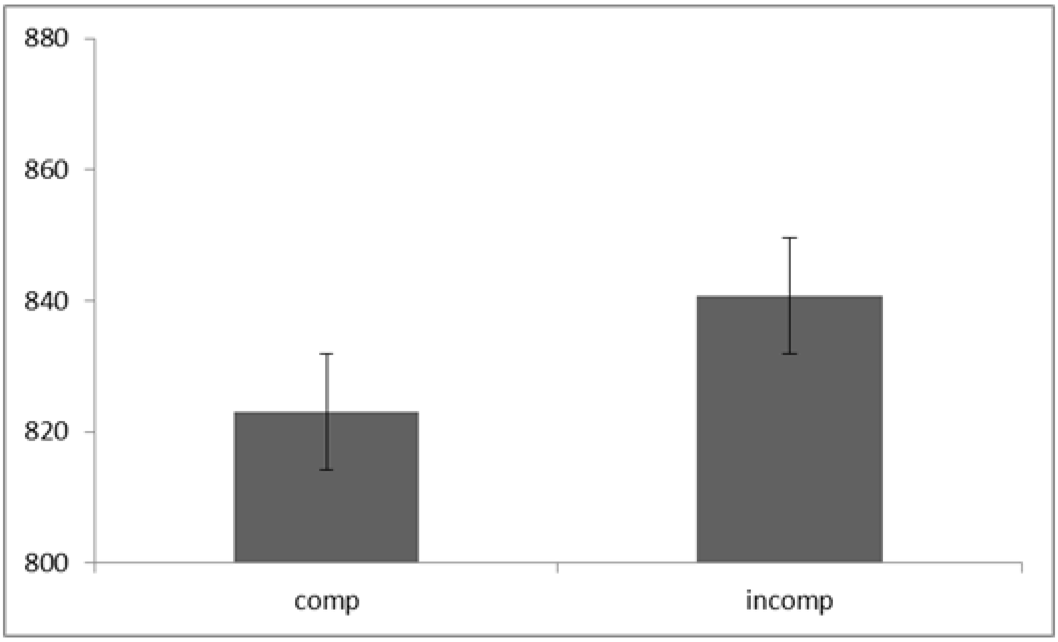


Figure 3.2 - Mean RTs (in ms) in MA-Compatible (C) and MA-Incompatible (I) trials, in accordance with the affective compatibility hypothesis in Experiment 3. Error bars indicate the standard error.

A repeated measures ANOVA was performed with Preference (liked; disliked) and Response direction (up; down; right; left) as within-subject factors was used to analyze the relationship between participants' preference and the direction of the response required. There was an effect of Response direction [$F(3,123) = 3.36$, $p < .05$] but not Preference [$F(1,41) = 0.74$, $p < .39$] and no Response x Preference interaction [$F(3,123) = 0.24$, p = .87] (Fig. 3.3).

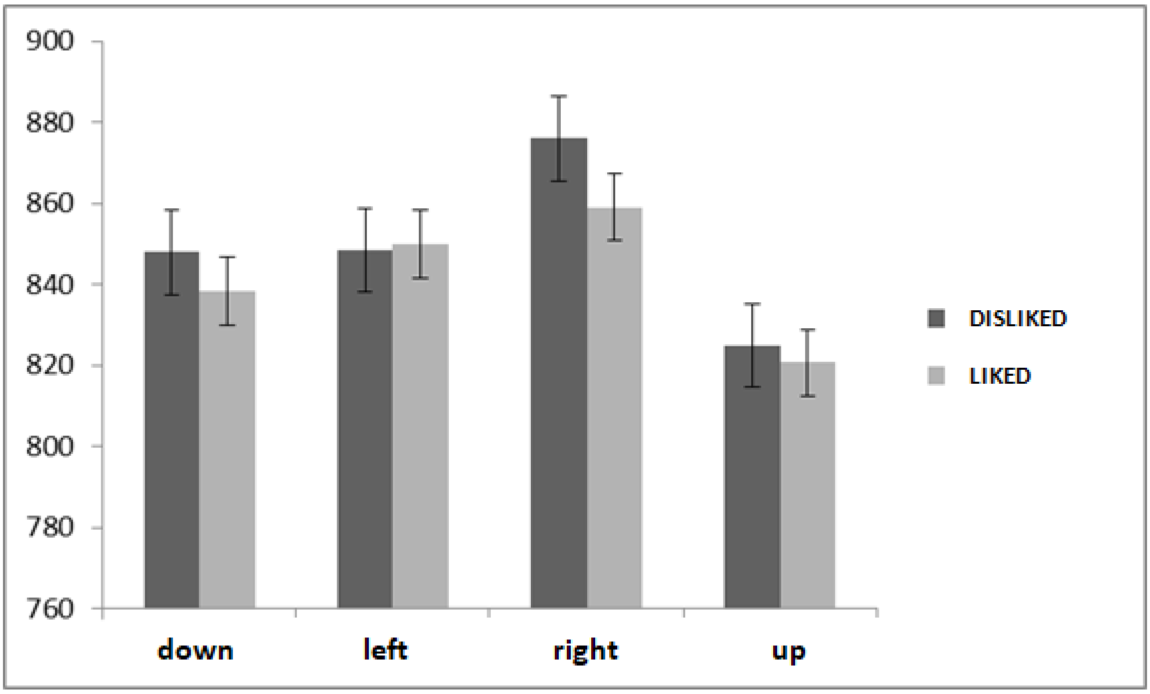


Figure 3.3 - Mean RTs (in ms) for the four Responses (down, left, right, up) for Liked and Disliked foods in Experiment 3. Error bars indicate the standard error.

## 5.3. Discussion

In this experiment the main task involved using head movements to drag a series of sentences expressing subjective opinions about different foods towards one of the four sides of the screen, horizontally or vertically; there was no explicit requirement to evaluate the sentences.

The aims of this last experiment were to determine whether the activation of the simulation of the head movements involved in the two gestures of nodding and shaking, found in the first experiment, was automatic, and to assess whether the sensorimotor simulation occurred at the level of implicit processing of stimuli or during subsequent explicit evaluation.

We found that the motor-semantic compatibility effect detected in the first experiment, where the request to assess the truth-value of sentences was explicit, did not occur in an implicit task. In contrast, the motor-affective compatibility effect found in the first experiment was observed, despite the absence of an explicit evaluation requirement, with sentences concerning liked foods being moved faster in a vertical direction and sentences concerning disliked foods being moved faster in a horizontal direction.

This result is important because it shows that the motor-affective compatibility effect involving vertical and horizontal head movements and the affective processing of content is automatic, not only because it proceeds without awareness but also because the activation of the simulation occurs at the level of the implicit processing of the stimulus.

Motor-semantic compatibility, on the other hand, was observed only when there was an explicit requirement to assess the truth-value of the stimuli, and therefore occurs at a later stage of processing, that of evaluation, which occurs after implicit processing. The automaticity of activation is corroborated by overall RTs, which were much shorter in the implicit task of Experiment 3 than the explicit tasks of the first two experiments.

Once again there was no interaction between response direction and subjective value of the object of the sentence. As explained in the discussion of the first experiment, we believe that the occurrence of affective compatibility with horizontal and vertical directions, rather than with the directions of initial movements involved in nodding and shaking the head (up and right), is due to the fact that, when the evaluation is subjective and personal the vertical and horizontal head movements function as approach and avoidance responses relative to the body, rather than as communicative gestures.

As for the absence of a difference between RTs for liked and disliked foods, it can be attributed to the kind of stimuli we used. The sentences in this research did not refer to really disgusting foods, so they did not prompt a sufficiently strong negative affective response to activate a strong avoidance response. In fact, although liked foods were, on average, moved upwards most quickly, we did not detect any differences in the speed with which disliked foods were moved in the various directions.

# 6. General discussion and conclusions

The experimental investigation presented here was conceived within the embodiment perspective, with the aim of investigating top-down motor compatibility effects involving a higher cognitive process, specifically the evaluation of linguistic stimuli, and the vertical and horizontal movements involved in nodding and shaking of the head.

Our research is based on the idea that compatibility between cognitive and bodily states is derived from the ability to activate mental (partial) simulations of previous sensory, motor or affective experiences (Stein, 1994; Barsalou, 2003; Gibbs, 2005; Niedenthal et al., 2005).

Our general hypothesis was that semantic and affective evaluations of (accepted and refused) content activates the simulation of compatible vertical and horizontal head movements, typically performed in everyday interactions to express assent or acceptance, and dissent or refusal.

This hypothesis was formulated on the basis of a motor-semantic compatibility effect we found in an earlier study investigating the relationship between the two head gestures and the evaluation of objectively true and false sentences (Moretti & Greco, 2018), and extends it to the affective evaluation of valenced objects.

To enable us to examine this compatibility in detail we implemented an innovative experimental procedure that allowed participants to control the movement of stimuli on a computer screen by moving their head, and we recorded both the speed with which movements were made and their direction in tasks involving implicit and explicit evaluation and compatibility and incompatibility between response direction and the direction of the simulated action.

Our general expectation, therefore, was that RTs would be shorter when the direction of the movement required by the experimental task coincided with that of the simulated head movement than when it did not. In particular, we expected stimuli that evoked a positive response to be moved more quickly in the vertical axis, which is the axis used in nodding, and stimuli that evoked a negative response to be moved more quickly on the horizontal axis, which is used in the head shaking gesture.

Analyses of RTs showed that the motor-semantic compatibility effect only occurred when there was an explicit requirement to assess the truth-value of the stimuli, whereas the motor-affective compatibility effect was automatic and implicit, occurring during the initial stages of stimulus processing.

These data provide further support for embodiment hypotheses based on observations of compatibility effects involving higher cognitive processes and the movement of other body parts (Chen & Bargh, 1999; Zwaan & Madden, 2005; Mahon & Caramazza, 2008; Barsalou, 2010; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Glenberg & Kaschak, 2002; 2003, Glenberg et al., 2013; Dominey et al., 2015; Körner et al., 2015). Our results also provide new data on the relationship between gestures and thought (Hostetter & Alibali, 2008; 2010; 2019; Alibali et al., 2014). In addition, the work presented here allowed us to identify the level at which the sensorimotor simulation mechanism is activated and therefore to distinguish between explicit and implicit embodiment effects.

Some empirical research with neutral or valenced material has suggested that the association between a motor response and cognitive content is not always automatic and depends on the type of task used (de la Vega et al., 2012; Phaf, Mohr, Rotteveel, & Wicherts, 2014) or the type of cognitive process implemented to address it (Tomasino & Rumiati, 2013). De la Vega and colleagues (2012), for example, argued that in order to trigger the simulation automatically it is necessary that the association between the response movement and the valence of the content is explicit. The results of our study conflict with this argument, as they demonstrate that automatic, implicit motor compatibility effects can occur.

In this regard, Barsalou (1999), in one of the first theories on the embodied processing of abstract concepts, tried to provide an analysis of the three steps involved in the processing of the truth-value of sentences. Barsalou suggested that initially, the sentence is mentally simulated by the agent, who tries to map the simulation with what is perceived in the world before, finally, the agent assesses whether the simulation accurately depicts the actual situation; if this assessment is positive, the sentence is considered true, otherwise it is considered false.

In accordance with this theory, therefore, our results show that motor-affective compatibility should be placed in the initial phase of the evaluation process, i.e. when the sentence is simulated, whereas motor-semantic compatibility effects would occur in the final phase, when the effectiveness of the mapping is being assessed, i.e. after the simulation. The difference between RTs in our explicit and implicit tasks, generally shorter in the implicit task, provides additional empirical support for this hypothesis.

Further supportive evidence is provided by differences between the truth value and the affective value of the object of the sentences in the interaction with the four response directions. During the assessment of the truth value of sentences, upwards and rightwards head movements were activated faster. These constitute the first movements involved in nodding and shaking of the head (Wagner et al., 2014), and can therefore be considered to have been activated as movements that explicitly express agreement and disagreement. During the affective evaluation, vertical and horizontal movements of the head appear to have been activated as implicit approach and avoidance responses to the object of the sentence.

Moreover, as stated before, participants were not explicitly asked to nod and shake their heads, but simply to use head movements to drag sentences towards one of the four sides of the computer screen, one at a time, so they were not explicitly aware of meaning of the movements they were performing. This is not sufficient to establish that the observed compatibility effect was automatic however, but our implicit evaluation task allowed us to distinguish between semantic and affective compatibility and show that only the affective processing of valenced content activates simulation of the movements involved in nodding and shaking of the head automatically and implicitly.

In summary, we found that:

(a) Accepted stimuli (pleasant or indicating a true state of things) were moved faster vertically than horizontally, because their evaluation activated the simulation of the vertical head movement, involved in the nodding gesture, typically used in everyday interactions to express agreement and acceptance.

(b) Refused stimuli (unpleasant or indicating a false state of things) were moved faster horizontally than vertically, because their evaluation activated the simulation of the horizontal head movement, involved in the shaking gesture, typically used in everyday interactions to express disagreement and refusal.

(c) Semantic evaluation activated the simulation of vertical and horizontal head movements as gestures having a communicative function “for the other”, whilst affective evaluation activated their simulation as approach and avoidance responses “for the self”.

(d) The greater the affective valence of the stimulus, i.e. the more strongly the individual felt about it, the more implicit and automatic the simulation.

Having found motor compatibility effects involving the two head gestures and two different types of evaluation, one semantic, explicit and based on shared meanings and knowledge, and one affective, implicit, and dependent on emotional dispositions towards valenced objects, led us to interpret our present and previous results in terms of the general Approach and Avoidance model (Solarz, 1960; Chen & Bargh, 1999). This provides evidence that supports embodied social cognition studies that have found AAEs with arm movements and subjective evaluations of abstract and valenced stimuli (Solarz, 1960; Cacioppo et al., 1993; Forster & Strack, 1997; Chen & Bargh, 1999; Wentura, Rothermund & Bak, 2000; Alexopoulos & Ric, 2007; Saraiva et al., 2013).

Since approach responses reduce the distance between the agent and the stimulus concerned, whilst refusing means increasing that distance, it seems plausible to interpret the gesture of nodding, where the head is moved vertically towards the body, as an approach response, and the gesture of shaking the head, in which the head is moved from side to side, horizontally, as an avoidance response (Darwin, 1872; Bousmalis et al., 2013; Osugi & Kawahara, 2018). Whilst the functions of the two gestures may vary according to the linguistic context in which they are performed (see Wagner et al., 2014), it is possible to identify a semantic nucleus common to their specific uses: nodding is an expression of positivity (Poggi et al., 2010) and shaking the head of negativity (Kendon, 2003).

This interpretation allows the motor-semantic compatibility to be considered as a sub-specific effect of a more general and automatic approach and avoidance effect (vertical-accepted; horizontal-refused). The head movements which originally allowed to approach or avoid a concrete stimulus, over time, might have been generalized as expressions of agreement and disagreement in the communication with others.

In light of our results, moreover, and as already demonstrated in part by the studies of Casasanto (2009), it is possible to provide a satisfactory explanation of spatial compatibility effects between abstract or valenced stimuli and the vertical and horizontal space (Meier & Robinson, 2004; Meier et al., 2007; Meteyard et al., 2007; Dudschig, de la Vega, De Filippis & Kaup, 2014; Dudschig, de la Vega & Kaup, 2015), by re-classifying them as sub-effects of a motor compatibility with the verticality and horizontality of the movements involved in approach and avoidance responses.

In fact, the absence of a compatibility effect in our second experiment, when the responses did not involve head movements, may have been due to the limits of the spatial association, since it would derive from a motor association in the first place. Conflicting results in the literature about spatial compatibility, as a single concept can be associated with multiple locations (Hurtienne et al., 2010; Casasanto & Chrysikou, 2011; Casasanto & Henetz, 2012; de la Vega, Dudschig, De Filippis, Lachmair & Kaup, 2013; Dudschig et al., 2014), constitute a further criticism for spatial compatibility effects.

We think that the approach and avoidance model currently provides the best account of our results, and that our research extends the motor compatibility effect to another important part of the body, the head, which, like the arm, can be used to perform approach and avoidance responses (see also Rougier et al., 2018 for AAE with the whole body). However, although we consider that the compatibility effect found in our research is generalizable, it cannot be considered universal, at least not yet. Different cultures use various movements of the head to indicate assent and dissent (Aksan, 2011). The most striking example of the diversity of the mapping of head gesture to meaning is the case of Bulgaria, where nodding and shaking of the head communicate the exact opposite of what they do in the West: Bulgarians generally use a vertical movement of the head to say "no" and rotate the head to the side to say "yes" (McClave, Kim, Tamer & Mileff, 2007; Andonova & Taylor, 2012). To demonstrate the universality of AAEs involving head movements it would be necessary to demonstrate such effects in cultures that use different head movements to indicate assent and dissent. For example, it would be interesting to apply our implicit evaluation task to a Bulgarian sample. In the absence of an explicit evaluation requirement we would predict that the compatibility effect would be the same as in our Western sample, reflecting the way in which head movements increase or decrease the distance between the individual and a stimulus, rather than their communicative meaning in Bulgarian culture.

Were this prediction to be confirmed, one would be encouraged to search for implicit and reliable compatibility effects. Should it not to be confirmed, the result would nevertheless be interesting and would provide a starting point for investigations aimed at clarifying the boundary between cultural and natural aspects in determining embodiment effects, and establishing their respective contribution to the activation of sensorimotor simulations.

Further studies into this and other aspects of embodiment theories are needed, because they remain somewhat controversial precisely because of the lack of sufficient empirical evidence. Similarly, the conclusions we have reached here should be interpreted taking into consideration that movements of head, a part of the body that is particularly active in everyday human interactions, have not yet been sufficiently investigated.

Some methodological limitations of our investigation should also be taken into account. For example, it should be pointed out that the motor compatibility effects we have reported are based not on the complete movements involved nodding and shaking of the head, but on the directions involved in those gestures. The RTs correspond to the time taken to start moving a stimulus in one of four possible directions. But setting the threshold for recording movements at the arbitrary distance of 20 pixels from the starting point, whilst it helped to minimize inclusion of random movements and maximize the sensitivity of the instrument to genuine responses, may have resulted in loss of information about the complete movement performed. To overcome this limitation, it might be useful to replicate our study using a motion sensor attached directly to the head of participants to provide even more precise motor data. However, since our hypothesis concerned the mental simulation of the two gestures - which are distinguished by the direction of movement - and therefore their partial reactivation, we have considered a single movement towards one of the four sides of the screen as sufficient for detection of compatibility effects.

As for the drag and drop task used in our research, equally valid experimental designs exist in the literature which are able to detect embodiment effects. For example, the automaticity of the simulation of the two head movements could be tested analyzing the use of cognitive resources during evaluation processes through a dual task paradigm, in which working memory is occupied by a secondary task. Alternatively one could prevent participants from moving their head and test the effects of this on the timing and the quality of evaluations (as in an investigation of the forehead muscles by Havas, Glenberg, Gutowski, Lucarelli, & Davidson, 2010).

Similarly, it would be interesting to extend our protocol by introducing a stimulus recall task after the main task in order to investigate potential compatibility effects involving the two head movements and a different cognitive process, such as memory, in a procedure analogous to that used by Forster and Strack (1997).

It must also be taken into account that the majority of our sample was female. This is noteworthy as some studies of empathy have found positive correlations between female sex and the intensity and frequency of use of non-verbal communication (Jolliffe & Farrington, 2006; Albiero, Matricardi, Speltri, & Toso, 2009).

We also consider that our research hypothesis should be tested in a longitudinal study of preschool children, as this is the age at which non-verbal behavior starts emerging (Guidetti, 2005), in order to clarify the relative contributions of biological and cultural factors to the activation of sensorimotor simulations. With such a young sample it would be necessary to replace the linguistic stimuli we used with images that have similar valence, for example, images of pleasant and disgusting food.

In this regard, it is worth repeating that we chose to use foods in the construction of our stimuli in order to avoid the distortion of the responses that often occurs when people are required to make explicit assessments of emotionally or socially charged material. However, this choice may have favored the emergence of the motor compatibility effect, because the mouth, which is part of the head, is very involved in feeding. Given, moreover, that our stimuli did not include any really disgusting foods that would be likely to activate a strong avoidance responses, it is clear that further studies involving head movements and a different type of stimulus with affective valence, are needed.

Using different kinds of stimuli can also be relevant for possible applicative aspects of the present research, which would be in line with the studies of embodied social cognition that exploit automatic sensorimotor activations, to detect implicit attitudes, such as stereotypes or prejudices. Our experimental procedure could be used to develop an implicit test that requires people to move socially relevant stimuli vertically and horizontally on a computer screen with the head and exploits the automatic activation of the approach and avoidance movements to predict positive or negative attitudes to particular social situations, objects or groups.

In conclusion, these results provide further evidence to support the embodiment hypothesis, which posits that actions people perform with their bodies, can influence cognition, as well as cognitive, affective and cultural factors can influence the acquisition and re-activation of specific motor actions (Glenberg et al., 2008; Glenberg et al., 2013; Kaschak et al., 2014; Körner et al., 2015; Barsalou, 2016). Furthermore, our investigation has shown that the two gestures of nodding and shaking of the head can interact with cognitive processing as simulated approach and avoidance responses that have assumed, over time, the important function of communicating the meaning of acceptance and refusal to others. On the basis of these results, we believe it is necessary to investigate, ever more thoroughly, the ways in which gestures can interact not only with language but also, more importantly, with cognition.

*Software for exploring head compatibility effects may be obtained free of charge from cognilab@unige.it*

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# Appendix (may be presented as Supplementary Data)

## *Table 1*

## *Experiment 1*

*Analysis of semantic compatibility*

**Mean RTs (in ms, original values):**

| Group | Block 1 | Block 2 |
|---|---|---|
| **A** | 1486 | 1512 |
| **B** | 1416 | 1319 |

| Condition | M |
|---|---|
| **Compatible** | 1403 |
| **Incompatible** | 1464 |

| Truth-value | M |
|---|---|
| **False** | 1498 |
| **True** | 1369 |

| | Direction | | | |
|---|---|---|---|---|
| **Truth-value** | **Down** | **Left** | **Right** | **Up** |
| **False** | 1564 | 1497 | 1474 | 1562 |
| **True** | 1321 | 1439 | 1442 | 1330 |

**(a) Summary of the first model for semantic compatibility:**

```
> mod1 <- lmer(LRT~block*group+block+truth+type+(1|subj)+(1|sent), data=data)
> summary(mod1)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to
  degrees of freedom [lmerMod]
Formula: LRT ~ block * group + block + truth + type + (1 | subj) + (1 |
    sent)
   Data: data

REML criterion at convergence: -80.7

Scaled residuals:
    Min      1Q  Median      3Q     Max
-6.3064 -0.6202 -0.0765  0.5603  4.4403

Random effects:
 Groups   Name        Variance Std.Dev.
 sent     (Intercept) 0.003084 0.05553
 subj     (Intercept) 0.019171 0.13846
 Residual             0.053289 0.23084
Number of obs: 5570, groups:  sent, 120; subj, 79

Fixed effects:
                Estimate Std. Error         df t value Pr(>|t|)
(Intercept)    7.243e+00  1.671e-02  9.000e+01 433.384  < 2e-16 ***
block1         9.254e-02  1.190e-02  1.150e+02   7.774 3.56e-12 ***
group1         2.042e-02  3.185e-02  7.500e+01   0.641  0.52342
truth1         2.812e-02  8.576e-03  5.270e+03   3.279  0.00105 **
type1          1.067e-01  1.307e-02  1.640e+02   8.169 7.86e-14 ***
block1:group1 -9.448e-02  1.245e-02  5.394e+03  -7.588 3.80e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Correlation of Fixed Effects:
            (Intr) block1 group1 truth1 type1
block1      -0.001
group1      -0.012 -0.002
truth1      -0.008 -0.008  0.005
type1        0.009  0.003 -0.002 -0.412
block1:grp1 -0.003  0.003 -0.001  0.044 -0.013
```

**Anova of the first model for semantic compatibility:**

```
> anova(mod1)
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       3.2203  3.2203     1  114.9  60.432 3.559e-12 ***
group       0.0219  0.0219     1   75.3   0.411  0.523418
truth       0.5729  0.5729     1 5270.3  10.750  0.001049 **
type        3.5557  3.5557     1  164.4  66.724 7.860e-14 ***
block:group 3.0682  3.0682     1 5394.1  57.576 3.797e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**(b) Summary of the second model for semantic compatibility:**

```
> mod2 <- lmer(LRT~condition*group+truth+type+(1+condition|subj)+(1+condition|sent), data=data)
>
> summary(mod2)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to degrees of freedom [
lmerMod]
Formula: LRT ~ condition * group + truth + type + (1 + condition | subj) +
    (1 + condition | sent)
   Data: data
REML criterion at convergence: -146.2
```

```
Scaled residuals:
    Min      1Q  Median      3Q     Max 
-6.3688 -0.6277 -0.0637  0.5586  4.9262 

Random effects:
 Groups   Name                Variance  Std.Dev. Corr 
 sent     (Intercept)         0.0029424 0.05424       
          conditionIncompatib 0.0005828 0.02414  0.00 
 subj     (Intercept)         0.0224551 0.14985       
          conditionIncompatib 0.0060553 0.07782  -0.40
 Residual                     0.0517046 0.22739       
Number of obs: 5570, groups:  sent, 120; subj, 79

Fixed effects:
                             Estimate Std. Error         df t value Pr(>|t|)    
(Intercept)                 7.219e+00  1.814e-02  8.700e+01 397.979  < 2e-16 ***
conditionIncompatib         5.024e-02  1.102e-02  7.000e+01   4.558 2.14e-05 ***
group1                      1.136e-01  3.628e-02  8.700e+01   3.130  0.00238 ** 
truth1                      2.690e-02  8.572e-03  5.258e+03   3.138  0.00171 ** 
type1                       1.110e-01  1.302e-02  1.650e+02   8.528 9.10e-15 ***
conditionIncompatib:group1 -1.842e-01  2.965e-02  1.300e+02  -6.212 6.49e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnI group1 truth1 type1 
cndtnIncmpt -0.394                            
group1      -0.013  0.005                     
truth1       0.000 -0.026  0.002              
type1        0.006  0.007 -0.001 -0.413       
cndtnIncm:1  0.004 -0.007 -0.476  0.006 -0.003
```

**Anova of the second model for semantic compatibility:**

```
> anova (mod2)
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
                Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
condition       1.0744  1.0744     1   69.6  20.779 2.144e-05 ***
group           0.0232  0.0232     1   75.9   0.449   0.50462
truth           0.5092  0.5092     1 5257.9   9.848   0.00171 **
type            3.7603  3.7603     1  165.2  72.726 9.104e-15 ***
condition:group 1.9954  1.9954     1  130.5  38.592 6.491e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**(c) Summary of the third model for semantic compatibility:**

```
> mod3 <- lmer(LRT~condition*group*type*truth+type+truth+(1+condition|subj)+(1+condition|sent), data=data)
> summary (mod3)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to degrees of freedom [
lmerMod]
Formula: LRT ~ condition * group * type * truth + type + truth + (1 +
    condition | subj) + (1 + condition | sent)
   Data: data

REML criterion at convergence: -233.1

Scaled residuals:
    Min      1Q  Median      3Q     Max
-6.4757 -0.6239 -0.0646  0.5642  5.0250
```

```
Random effects:
 Groups   Name                Variance  Std.Dev. Corr
 sent     (Intercept)         2.240e-03 0.047324
          conditionIncompatib 3.518e-06 0.001876 1.00
 subj     (Intercept)         2.202e-02 0.148378
          conditionIncompatib 5.590e-03 0.074768 -0.46
 Residual                     5.088e-02 0.225561
Number of obs: 5570, groups:  sent, 120; subj, 79

Fixed effects:
                                          Estimate Std. Error         df t value Pr(>|t|)
(Intercept)                                7.24568    0.01817   92.00000 398.878  < 2e-16 ***
conditionIncompatib                        0.05200    0.01174  108.00000   4.431 2.26e-05 ***
group1                                     0.10664    0.03633   92.00000   2.935  0.00421 **
type1                                      0.13961    0.01418  216.00000   9.848  < 2e-16 ***
truth1                                     0.02794    0.01154 4351.00000   2.421  0.01552 *
conditionIncompatib:group1                -0.16684    0.02948  160.00000  -5.660 6.84e-08 ***
conditionIncompatib:type1                 -0.04931    0.01620 5216.00000  -3.045  0.00234 **
group1:type1                               0.01274    0.02836  216.00000   0.449  0.65371
conditionIncompatib:truth1                -0.02172    0.01632 5371.00000  -1.331  0.18324
group1:truth1                              0.01140    0.02310 4344.00000   0.494  0.62155
type1:truth1                              -0.18026    0.02422 4264.00000  -7.443 1.18e-13 ***
conditionIncompatib:group1:type1          -0.05758    0.04817  176.00000  -1.195  0.23353
conditionIncompatib:group1:truth1          0.01514    0.03431 5073.00000   0.441  0.65894
conditionIncompatib:type1:truth1          -0.01937    0.03343 4903.00000  -0.580  0.56226
group1:type1:truth1                        0.04829    0.04833 4251.00000   0.999  0.31771
conditionIncompatib:group1:type1:truth1   -0.11995    0.07031 4569.00000  -1.706  0.08810 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

**Anova of the third model for semantic compatibility:**

```
> anova(mod3)
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
                           Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)    
condition                  0.9988  0.9988     1  107.8  19.632 2.264e-05 ***
group                      0.0276  0.0276     1   80.2   0.542  0.463884    
type                       4.6515  4.6515     1  174.7  91.426 < 2.2e-16 ***
truth                      0.2042  0.2042     1 5114.7   4.014  0.045176 *  
condition:group            1.6298  1.6298     1  160.0  32.034 6.839e-08 ***
condition:type             0.4716  0.4716     1 5215.5   9.270  0.002341 ** 
group:type                 0.0503  0.0503     1 5242.4   0.989  0.320071    
condition:truth            0.0901  0.0901     1 5371.4   1.772  0.183242    
group:truth                0.0695  0.0695     1 5413.7   1.366  0.242499    
type:truth                 5.6000  5.6000     1 5079.0 110.068 < 2.2e-16 ***
condition:group:type       0.0727  0.0727     1  175.7   1.429  0.233529    
condition:group:truth      0.0099  0.0099     1 5073.4   0.195  0.658938    
condition:type:truth       0.0171  0.0171     1 4902.7   0.336  0.562256    
group:type:truth           0.0059  0.0059     1 5431.0   0.115  0.734218    
condition:group:type:truth 0.1481  0.1481     1 4568.7   2.910  0.088099 .  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**(d) Summary of the fourth model for semantic compatibility:**

```
> mod4 <-
lmer(LRT~condition*group+type+truth+type*truth+(1+condition+type+condition:type|subj)+(1+condition|sent),data=data)
> summary(mod4)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to degrees of freedom [
lmerMod]
```

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

REML criterion at convergence: -268.7

Scaled residuals:
    Min      1Q  Median      3Q     Max
-6.3271 -0.6255 -0.0716  0.5650  4.8498

Random effects:
 Groups   Name                       Variance  Std.Dev. Corr
 sent     (Intercept)                2.131e-03 0.046165
          conditionIncompatib        1.329e-05 0.003646 1.00
 subj     (Intercept)                2.226e-02 0.149202
          conditionIncompatib        6.011e-03 0.077529 -0.46
          type1                      2.680e-03 0.051767  0.12 -0.15
          conditionIncompatib:type1 1.017e-02 0.100846  0.01  0.04 -0.89
 Residual                            5.032e-02 0.224313
Number of obs: 5570, groups:  sent, 120; subj, 79

Fixed effects:
                             Estimate Std. Error        df t value Pr(>|t|)
(Intercept)                 7.246e+00  1.806e-02  8.800e+01 401.203  < 2e-16 ***
conditionIncompatib         5.075e-02  1.072e-02  6.900e+01   4.733 1.14e-05 ***
group1                      1.147e-01  3.550e-02  8.400e+01   3.230  0.00177 **
type1                       1.182e-01  1.225e-02  1.560e+02   9.649  < 2e-16 ***
truth1                      1.628e-02  8.559e-03  3.302e+03   1.902  0.05723 .
conditionIncompatib:group1 -1.843e-01  2.764e-02  1.210e+02  -6.670 8.18e-10 ***
type1:truth1               -1.858e-01  1.813e-02  5.014e+03 -10.243  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Correlation of Fixed Effects:
            (Intr) cndtnI group1 type1  truth1 cndI:1
cndtnIncmpt -0.438
group1      -0.012  0.006
type1        0.072 -0.035 -0.002
truth1      -0.016 -0.028  0.002 -0.439
cndtnIncm:1  0.005 -0.008 -0.495 -0.002  0.006
type1:trth1 -0.145 -0.003 -0.002 -0.067  0.116 -0.002
```

**Anova of the fourth model for semantic compatibility:**

```
> anova(mod4)
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
                Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
condition       1.1272  1.1272     1   68.8  22.402 1.144e-05 ***
group           0.0263  0.0263     1   75.8   0.524   0.47154
type            4.6843  4.6843     1  155.7  93.096 < 2.2e-16 ***
truth           0.1821  0.1821     1 3302.1   3.618   0.05723 .
condition:group 2.2385  2.2385     1  120.6  44.488 8.182e-10 ***
type:truth      5.2794  5.2794     1 5013.6 104.924 < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Effect size:**

```
             term    df sumsq meansq statistic etasq partial.etasq omegasq cohens.f power
            <chr> <dbl> <dbl>  <dbl>     <dbl> <dbl>         <dbl>   <dbl>    <dbl> <dbl>
1       condition     1 1.443  1.443    28.686 0.090         0.215  -0.179    0.523 0.069
2           group     1 0.001  0.001     0.019 0.000         0.000  -0.247    0.013 0.050
3            type     1 6.645  6.645   132.071 0.412         0.557   0.064    1.122 0.122
4           truth     1 0.501  0.501     9.960 0.031         0.087  -0.223    0.308 0.057
5 condition:group     1 2.253  2.253    44.771 0.140         0.299  -0.141    0.653 0.079
6      type:truth     1 5.279  5.279   104.924    NA            NA      NA       NA    NA
```

*Analysis of affective compatibility*

**Mean RTs (in ms, original values):**

| Condition | M |
|---|---|
| **MA-Compatible** | 1462 |
| **Incompatible** | 1508 |

| Type | M |
|---|---|
| **Positive** | 1353 |
| **Negative** | 1523 |

| | Direction | | | |
|---|---|---|---|---|
| **Object value** | **Down** | **Left** | **Right** | **Up** |
| **Liked** | 1410 | 1395 | 1384 | 1370 |
| **Disliked** | 1447 | 1526 | 1463 | 1561 |

**(e) Summary of the model for affective compatibility:**

```
mod1a <-lmer(LRT~compatibility+type+compatibility*type+(1+compatibility+type+compatibility*type|subj)
+(1+compatibility|sent),data=data)

> summary(mod1a)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to degrees of freedom [lmerMod]
Formula:
LRT ~ compatibility + type + compatibility * type + (1 + compatibility +  type + compatibility * type | subj)
+ (1 + compatibility | sent)
   Data: data
REML criterion at convergence: -156.6
```

```
Scaled residuals:
    Min      1Q  Median      3Q     Max 
-6.4045 -0.6279 -0.0738  0.5641  4.8339 

Random effects:
 Groups   Name                             Variance  Std.Dev. Corr             
 sent     (Intercept)                      3.925e-03 0.062653                  
          compatibilityIncompatib          4.762e-06 0.002182 -1.00            
 subj     (Intercept)                      1.982e-02 0.140797                  
          compatibilityIncompatib          2.027e-03 0.045024 -0.17            
          type1                            8.357e-03 0.091419 -0.12 -0.08      
          compatibilityIncompatib:type1 3.611e-02 0.190023  0.15  0.03 -0.96
 Residual                                  5.093e-02 0.225684                  
Number of obs: 5570, groups:  sent, 120; subj, 79

Fixed effects:
                                Estimate Std. Error         df t value Pr(>|t|)
(Intercept)                     7.228356   0.017433  92.050000 414.641  < 2e-16
compatibilityIncompatib         0.033206   0.008023  73.370000   4.139 9.21e-05
type1                           0.173234   0.017716 132.690000   9.779  < 2e-16
compatibilityIncompatib:type1  -0.099824   0.024848  52.110000  -4.017  0.00019
                                 
(Intercept)                   ***
compatibilityIncompatib       ***
type1                         ***
compatibilityIncompatib:type1 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Correlation of Fixed Effects:
            (Intr) cmptbI type1
cmptbltyInc -0.245
type1       -0.053 -0.050
cmptbltyI:1  0.113  0.039 -0.672
```

**Anova of the model for affective compatibility:**

```
                   Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
compatibility      0.8725  0.8725     1 73.373  17.129 9.208e-05 ***
type               4.4955  4.4955     1 95.002  88.263 3.331e-15 ***
compatibility:type 0.8220  0.8220     1 52.114  16.140 0.0001898 ***
```

**Effect size:**

```
      term    df sumsq meansq statistic etasq partial.etasq omegasq cohens.f power
           <chr> <dbl> <dbl>  <dbl>     <dbl> <dbl>         <dbl>   <dbl>    <dbl> <dbl>
1compatib      1 1.084  1.084    21.289 0.165         0.569   0.036    1.148 0.125
2type          1 4.655  4.655    91.396 0.709         0.850   0.519    2.380 0.254
3compatib:type 1 0.822  0.822    16.140    NA            NA      NA       NA    NA
```

## *Table 2*
## *Experiment 2*
*Analysis of semantic compatibility*

**Mean RTs (in ms, original values):**

| Group | Block 1 | Block 2 |
|---|---|---|
| **C** | 1217 | 1343 |
| **D** | 1133 | 1234 |

| Condition | M |
|---|---|
| **Compatible** | 1225 |
| **Incompatible** | 1237 |

**(a) Summary of the model for semantic compatibility:**

```
> mod1.2<-lmer(LRT~block*group+block+truth+type+(1|subj)+(1|sent),data=data)
> summary(mod1.2)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: LRT ~ block * group + block + truth + type + (1 | subj) + (1 |      sent)
   Data: data

REML criterion at convergence: 1226.3

Scaled residuals:
    Min      1Q  Median      3Q     Max 
-4.4715 -0.6722 -0.1072  0.5660  4.2015 
```

```
Random effects:
 Groups   Name        Variance Std.Dev.
 subj     (Intercept) 0.025630 0.16009
 sent     (Intercept) 0.003324 0.05765
 Residual             0.069220 0.26310
Number of obs: 5158, groups:  subj, 70; sent, 60

Fixed effects:
                Estimate Std. Error         df t value Pr(>|t|)    
(Intercept)      7.06500    0.02088   84.06433 338.348  < 2e-16 ***
block1           0.07949    0.00741 5072.53536  10.727  < 2e-16 ***
group1          -0.10362    0.03900   66.31214  -2.657 0.009862 ** 
truth1           0.03427    0.01027 5042.07404   3.335 0.000858 ***
type1            0.10881    0.01031 5054.86706  10.553  < 2e-16 ***
block1:group1   -0.01379    0.01471 5032.01313  -0.938 0.348484    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) block1 group1 truth1 type1
block1       0.000                           
group1       0.001 -0.003                    
truth1      -0.006  0.000 -0.005             
type1        0.013  0.014  0.004 -0.695      
block1:grp1 -0.002  0.007  0.000 -0.014  0.009
```

**Anova of the model for semantic compatibility:**

```
> anova(mod1.2)
Type III Analysis of Variance Table with Satterthwaite's method
            Sum Sq Mean Sq NumDF  DenDF  F value    Pr(>F)    
block       7.9651  7.9651     1 5072.5 115.0698 < 2.2e-16 ***
group       0.4887  0.4887     1   66.3   7.0608 0.0098622 ** 
truth       0.7700  0.7700     1 5042.1  11.1238 0.0008584 ***
type        7.7083  7.7083     1 5054.9 111.3597 < 2.2e-16 ***
block:group 0.0609  0.0609     1 5032.0   0.8791 0.3484839    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

## *Analysis of affective compatibility*

**Mean RTs (in ms, original values):**

| Condition | M |
|---|---|
| **MA-Compatible** | 1232 |
| **Incompatible** | 1231 |

| Type | M |
|---|---|
| **Positive** | 1156 |
| **Negative** | 1317 |

**(b) Summary of the model for affective compatibility:**

```
> mod2.2<-
lmer(LRT~compatip+type+compatip*type+(1+compatip+type+compatip*type|subj)+(1+compatip|sent,data=data)
> summary(mod2.2)
```

```
Linear mixed model fit by REML t-tests use Satterthwaite approximations to degrees of
  freedom [lmerMod]
Formula: LRT ~ compatip + type + compatip * type + (1 + compatip + type +
    compatip * type | subj) + (1 + compatip | sent)
   Data: data

REML criterion at convergence: 1109.1

Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.8544 -0.6687 -0.1054  0.5534  4.3372

Random effects:
 Groups   Name            Variance  Std.Dev. Corr
 subj     (Intercept)     0.0284425 0.16865
          compatip1       0.0024008 0.04900  -0.25
          type1           0.0005991 0.02448   0.33 -0.23
          compatip1:type1 0.0789649 0.28101   0.39 -0.13  0.16
 sent     (Intercept)     0.0034071 0.05837
          compatip1       0.0015004 0.03873  -0.04
 Residual                 0.0652222 0.25539
Number of obs: 5158, groups:  subj, 70; sent, 60

Fixed effects:
                 Estimate Std. Error        df t value Pr(>|t|)
(Intercept)      7.065461   0.021837 83.990000 323.550   <2e-16 ***
compatip1        0.005433   0.010593 56.670000   0.513     0.61
type1            0.129855   0.007816 65.010000  16.614   <2e-16 ***
compatip1:type1  0.003704   0.036622 65.510000   0.101     0.92
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Correlation of Fixed Effects:
            (Intr) cmptp1 type1
compatip1   -0.135
type1        0.126 -0.039
cmptp1:typ1  0.332 -0.049  0.056
```

**Anova of the model for affective compatibility:**

```
> anova(mod2.2)
Analysis of Variance Table of type III  with  Satterthwaite
approximation for degrees of freedom
               Sum Sq Mean Sq NumDF  DenDF F.value Pr(>F)
compatip       0.0172  0.0172     1 56.670   0.263 0.6101
type          18.0029 18.0029     1 65.007 276.024 <2e-16 ***
compatip:type  0.0007  0.0007     1 65.514   0.010 0.9198
```

***Table 3***

***Experiment 3***

*Analysis of semantic compatibility*

**Mean RTs (in ms, original values):**

| Condition | M |
|---|---|
| **Compatible** | 826 |
| **Incompatible** | 837 |

**(a) Summary of the model for semantic compatibility:**

```
> mod1.3<-lmer (LRT~compatib+type+compatib*type+(1|subj)+(1|sent),data=data)
> summary(mod1.3)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to
  degrees of freedom [lmerMod]
Formula: LRT ~ compatib + type + compatib * type + (1 | subj) + (1 | sent)
   Data: data

REML criterion at convergence: -244.6

Scaled residuals:
    Min      1Q  Median      3Q     Max
-5.0670 -0.6532 -0.0761  0.5819  4.7693

Random effects:
 Groups   Name        Variance  Std.Dev.
 sent     (Intercept) 0.0004493 0.0212
 subj     (Intercept) 0.0544548 0.2334
 Residual             0.0524570 0.2290
Number of obs: 4589, groups:  sent, 62; subj, 44
```

```
Fixed effects:
                  Estimate Std. Error         df t value Pr(>|t|)    (Intercept)      6.668e+00  3.545e-02
4.300e+01 188.128  < 2e-16 ***
compatib1       -2.855e-04  6.775e-03  4.497e+03  -0.042 0.966386
type1            7.351e-03  8.653e-03  5.900e+01   0.850 0.398990
compatib1:type1  4.613e-02  1.357e-02  4.498e+03   3.399 0.000683 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cmptb1 type1
compatib1   0.000
type1       0.000  0.027
cmptb1:typ1 0.003  0.001  0.002
```

**Anova of the model for semantic compatibility:**

```
> anova(mod1.3)
              Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
compatib      0.00009 0.00009     1 4497.3  0.0018 0.9663861
type          0.03787 0.03787     1   58.8  0.7218 0.3989903
compatib:type 0.60590 0.60590     1 4497.7 11.5504 0.0006832 ***
```

## *Analysis of affective compatibility*

**Mean RTs (in ms, original values):**

| Condition | M |
|---|---|
| **MA-Compatible** | 823 |
| **Incompatible** | 841 |

| Type | M |
| --- | --- |
| **Positive** | 829 |
| **Negative** | 835 |

| | **Direction** | | | |
| --- | --- | --- | --- | --- |
| **Object value** | **Down** | **Left** | **Right** | **Up** |
| **Liked** | 838 | 850 | 859 | 821 |
| **Disliked** | 848 | 848 | 876 | 825 |

**(b) Summary of the first model for affective compatibility:**

```
> mod1a.3<-lmer (LRT~comp+type+comp*type+(1|subj)+(1|sent),data=data)
> summary(mod1a.3)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to
  degrees of freedom [lmerMod]
Formula: LRT ~ comp + type + comp * type + (1 | subj) + (1 | sent)
   Data: data

REML criterion at convergence: -244.6

Scaled residuals:
    Min      1Q  Median      3Q     Max
-5.0670 -0.6532 -0.0761  0.5819  4.7693

Random effects:
 Groups   Name        Variance  Std.Dev.
 sent     (Intercept) 0.0004493 0.0212
 subj     (Intercept) 0.0544548 0.2334
 Residual             0.0524570 0.2290
Number of obs: 4589, groups:  sent, 62; subj, 44
```

```
Fixed effects:
              Estimate Std. Error         df t value Pr(>|t|)
(Intercept)  6.668e+00  3.545e-02  4.300e+01 188.128  < 2e-16 ***
comp1       -2.306e-02  6.786e-03  4.498e+03  -3.399 0.000683 ***
type1        7.351e-03  8.653e-03  5.900e+01   0.850 0.398990
comp1:type1  5.711e-04  1.355e-02  4.497e+03   0.042 0.966386
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) comp1  type1
comp1       -0.003
type1        0.000 -0.002
comp1:type1  0.000  0.001 -0.027
```

**Anova of the first model for affective compatibility:**

```
> anova(mod1a.3)
           Sum Sq Mean Sq NumDF  DenDF F.value    Pr(>F)
comp      0.60590 0.60590     1 4497.7 11.5504 0.0006832 ***
type      0.03787 0.03787     1   58.8  0.7218 0.3989903
comp:type 0.00009 0.00009     1 4497.3  0.0018 0.9663861
```

**(c) Summary of the second model for affective compatibility:**

```
> mod2a.3<-lmer(LRT~comp+type+(1+comp|subj)+(1+comp|sent),data=data)
> summary(mod2a.3)
Linear mixed model fit by REML t-tests use Satterthwaite approximations to
  degrees of freedom [lmerMod]
Formula: LRT ~ comp + type + (1 + comp | subj) + (1 + comp | sent)
   Data: data

REML criterion at convergence: -265.4
Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.9875 -0.6490 -0.0815  0.5781  4.7337
```

```
Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 sent     (Intercept) 0.0004453 0.0211
          comp1       0.0011699 0.0342   0.46
 subj     (Intercept) 0.0543676 0.2332
          comp1       0.0014672 0.0383   0.18
 Residual             0.0517874 0.2276
Number of obs: 4589, groups:  sent, 62; subj, 44

Fixed effects:
             Estimate Std. Error        df t value Pr(>|t|)
(Intercept)  6.668669   0.035415 43.470000 188.301   <2e-16 ***
comp1       -0.022984   0.009891 45.240000  -2.324   0.0247 *
type1        0.007229   0.008530 58.620000   0.847   0.4002
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
      (Intr) comp1
comp1  0.116
type1  0.000 -0.001
```

**Anova of the second model for affective compatibility:**

```
> anova(mod2a.3)
       Sum Sq  Mean Sq NumDF  DenDF F.value  Pr(>F)
comp 0.279630 0.279630     1 45.244  5.3996 0.02469 *
type 0.037192 0.037192     1 58.622  0.7182 0.40019
```

**Effect size:**

```
   term    df sumsq meansq statistic etasq partial.etasq omegasq cohens.f power
  <chr> <dbl> <dbl>  <dbl>     <dbl> <dbl>         <dbl>   <dbl>    <dbl> <dbl>
1  comp     1 0.279  0.279     5.394 0.883         0.883   0.685    2.741  0.29
2  type     1 0.037  0.037     0.718    NA            NA      NA       NA    NA
```