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Understanding an implicated causality: The brain network for processing concessive relations

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ABSTRACT

Concessive relations, often indicated by conjunction words such as *although*, are semantically and pragmatically more complex than causal relations (expressed using *because*), as they involve more semantic features such as implicated meaning and negation. However, it remains unclear how linguistic-level complexity is manifested through different brain activities and functional connectivities. This fMRI study investigated how the neural underpinnings of concessive relations differ from those of causal relations. Pragmatically congruent and incongruent words were embedded in causal as well as concessive sentences. The whole-brain analysis revealed that relative to *because*-congruent sentences, *although*-congruent sentences evoked increased activations in a left network including IFG, bilateral MFG, mPFC, pMTG, and TPJ. DCM analysis showed that while the functional connectivity from IFG to MFG was commonly involved in processing concessive and causal relations, functional connectivities from pMTG to IFG and from pMTG to TPJ were involved in processing causal and concessive relations, respectively.

Understanding causality is a basic principle of human perception and experience, as it is fundamental both to the representation of human knowledge and to other cognitive abilities like predicting and explaining

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frequently in natural language (Blumenthal-Dramé, 2021; König, 1985; Verhagen, 2005). Concession has been argued to be semantically and pragmatically more complex than causality (König & Siemund, 2000). A causal sentence like "*Grandma has moved from Harbin to Hainan, because she liked the warm winter there*" explicitly asserts a causal connection between a proposition *p* (people like to live in a warm place in the winter) and another proposition *q* (people move from a cold place to a warm place). The same causal connection (*p, q*), however, is implicit in a concessive sentence "*Grandma has moved from Hainan to Harbin, although she liked the warm winter there*". Therefore, inferential processes have to

interpreted as reflecting the increased processing costs of establishing and keeping a reversed (vs chronological) temporal representation (Chen et al., 2022; Münte et al.,1998; Xiang et al., 2014), it seems that readers with larger working memory span are better at retrieving and maintaining

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2.2. Design and materials

The stimulus materials consisted of 128 quartets of written Chinese two-clause sentences, which were taken from a previous ERP experiment (Xu et al., 2015). As shown in Table 1, the main clause stated that a protagonist moved from location A to location B, the subordinate clause either provided a statement addressing the cause of the movement in a *because* structure (see sentence A/B) or a statement conceding an attitude towards the movement in an *although* structure (see sentence C/D). The subordinate clause always contained a positive attitude-biased verb (it could be one of the following verbs: 嚒骔/like, 81; 弥伝/prefer, 25; 弥傴/believe, 8; 佘懊/be used to, 8; others, 6) to explain the reason for the movement. The two locations mentioned in the main clause have certain characteristics that distinguish them from each other (e.g., *warm* vs *cold*, *expensive* vs *cheap*) or have been featured by different symbols known throughout China (e.g., the *Great wall* is in Beijing), which leads to an unambiguous resolution of the locative pronoun in the subordinate clause.

Each sentence in a quartet was assigned to a different test list with a Latin square procedure, such that in each list there were 32 sentences per experimental condition. A set of 40 fller sentences were added to each list. To reduce the potential inuence induced by the positive attitude words (e.g., *like, prefer*), the subordinate clauses in half of the fllers (20 sentences) contained negative attitude words (e.g., *dislike*) or neutral words (e.g., *know*). The other half of the fllers (20 sentences) had various types of sentence structures (connected by *because* or *although*) and described a variety of situations. All of the 168 sentences in each list were pseudo-randomized, with the restriction that no more than three consecutive sentences were of the same condition and no more than three consecutive sentences were pragmatically correct or incorrect. Participants were randomly assigned to one of the four lists. The fMRI scanning was divided into three sessions, lasting approximately 15 min per session.

2.3. Procedure

are presented at this threshold unless otherwise noted.

2.5.2. The correlations between brain activations and individual differences

We used the statistical maps from the *t*-tests in the first-level analysis to examine brain activations that correlated with individual differences in pragmatic inference (i.e., AQ scores; Baron-Cohen et al., 2001) and verbal working memory (i.e., Reading span; Daneman Carpenter, 1980). In the second-level analysis, we used measures of AQ and working memory scores as covariates and activations in the contrasts '*although*-congruent vs *because*-congruent' recorded from *t*-tests in the first-level analysis as dependent variables. We also carried out a corre

3.5. Dynamic

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left IFG to the left MFG was commonly modulated by both relations.

This study examined the neural correlates and functional connectivities underpinning concessive and causal relations. Compared to *because*-congruent sentences, *although*-congruent sentences yielded increased activations in the left IFG, (bilateral) MFG, mPFC, pMTG and TPJ/AG, a brain network which is crucial for understanding implicated meaning (e.g., conventional implicature) and semantic control; none of these brain areas were significantly activated in the reversed contrast (i.e., *because*-congruent vs *although*-congruent). Meanwhile, while stronger activations were found in the right Supramarginal Gyrus/STG and the right MFG in the comparison of *because*-incongruent vs *because*-congruent sentences, no significant activations were observed in the comparison of *although*-incongruent vs *although*-congruent sentences. Importantly, the DCM analysis revealed that, while the effective connectivity from the pMTG to IFG was enhanced during the processing of causal relations, the connectivity from the pMTG to TPJ was enhanced during the processing of concessive relations. Finally, activations in the left MTG (extended to the left STG) and the left ventromedial prefrontal cortex significantly correlated with individuals' communication abilities and verbal working memory scores, respectively. These findings suggest that compared to processing causal

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This is consistent with the recruitment of MTG, alongside IFG, for demanding semantic retrieval (Davey et al., 2015; Noonan et al., 2013; Lambon Ralph et al., 2017). The left IFG, and especially pMTG, has been

4.2. Different functional connectivities for processing concessive relations vs causal relations

The differential neural substrates for concessive and causal relations are also re fected in the strength of effective functional connectivities between the involved areas in the left hemisphere. W

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