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REVIEW

Implicit Causality of Verbs on Anaphora Processing

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ABSTRACT

This paper provides a comprehensive review of research on the Implicit Causality (IC) of verbs and its role in anaphora resolution. IC refers to the inherent semantic bias in interpersonal verbs that guides readers or listeners in assigning causal responsibility, thereby influencing the interpretation of pronouns. Like in the sentence "*David betrayed John because he…*", the pronoun "*he*" is more likely to be interpreted as referring to *David*, whereas in "*David criticized John because he…*", "*he*" is more often understood as referring to *John*. This phenomenon has been observed in multiple languages and populations. The review focuses on several key areas: linguistic and non-linguistic factors affecting IC bias; the activation and persistence hypotheses of IC; research methodologies; the performance of different subject types in IC processing; and how large language models process IC information. Key findings and current challenges are discussed, including the need to refine the classification of IC verbs, to clarify the weight of multiple influencing factors, and to explore cross-linguistic and cross-population differences in IC processing. This study offers theoretical insights and practical implications for second language education, clinical language assessment, and AI-based natural language understanding.

Keywords: Implicit Causality; Anaphora Resolution; Verbs; Influencing Factors; Hypotheses; Methodology

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ARTICLE INFO

Received: 25 April 2025 | Revised: 11 June 2025 | Accepted: 23 June 2025 | Published Online: 26 August 2025
DOI: https://doi.org/10.30564/fls.v7i8.9705

CITATION

Tian, X., Fu, L., Zhao, Y., 2025. Implicit Causality of Verbs on Anaphora Processing. Forum for Linguistic Studies. 7(8): 1190–1211.
DOI: https://doi.org/10.30564/fls.v7i8.9705

1. Introduction

The concept of Implicit causality (IC) of verbs was proposed to describe a phenomenon in which certain interpersonal verbs imply the cause of an action or state[1]. This implicit semantics directly influences the resolution of anaphoras in subsequent clauses. The NP, which is in line with the IC bias, is more likely to be interpreted as the antecedent of the pronoun. IC verbs are divided into NP1-biased verbs (NP1 verbs) and NP2-biased verbs (NP2 verbs). The former causes the pronoun to tend to be attributed to NP1, the subject of the sentence, while the pronoun in NP2 verb sentences tends to refer to the object. For example:

(1) David$_i$ apologized to Mark$_j$ David because he$_i$ was the one to blame.
(2) Mark$_i$ criticized the David$_j$ because he$_j$ forgot his lines.

In example (1), the verb *apologize* is an NP1 verb, which makes *he* tend to be interpreted as the antecedent to the subject, *David*. In other words, when resolving the pronoun, readers focus more on why David apologized to Mark rather than the other way around. However, in example (2), the verb *criticize* is an NP2 verb, and more readers will think *he* refers to *David*, explaining why David is criticized.

Existing research has already been conducted across various languages and has widely confirmed the role of IC in pronoun use in both written and oral discourses[1,2]. Studies on English[1], Italian[3,4], Dutch[5], Spanish[6], Chinese[7], Finnish[8], Russian[9], Brazilian Portuguese[10,11], Croatian[12], Czech[13] and Catalan[14] have all provided evidence supporting IC's influence in this domain. Various research methodologies, including behavioral and electrophysiological approaches, have been used to explore the effect of IC on anaphora resolution among different population groups, such as typical adults, second-language learners, children, the elderly, and individuals with disabilities.

Early reviews on IC primarily focus on verb classification and the timing of IC activation[15,16]. A more recent review provided brief accounts of IC in causal inference, with an emphasis on certain linguistic influence factors and the application of the eye-tracking paradigm[17]. A systematic review of the broader range of influencing factors, methodological approaches, and participant populations relevant to IC research remains necessary.

To extend prior work, the present paper offers a comprehensive review of IC in anaphora resolution, including: (1) linguistic and non-linguistic factors influencing IC in referential resolution; (2) IC activation and persistence hypotheses, including their conflicts and integration; (3) research methodologies, their suitability, and limitations; (4) IC findings across populations; and (5) IC processing models in Large Language Models. By integrating insights from diverse perspectives, this review aims to advance theoretical understanding of IC and anaphora processing, while also identifying directions for future research. Furthermore, it highlights the broader psycholinguistic implications of IC, with practical significance for fields such as second language acquisition and language rehabilitation.

2. The Interaction of IC and Influence Factors in Anaphora Resolution

When IC is presented in isolation within a context, the antecedents of the anaphora will be the NP, which is consistent with IC bias. However, when other factors are introduced, IC may be intensified or weakened, or even disappear to varying degrees. This chapter will review both linguistic and non-linguistic factors that work together with IC in anaphora resolution (**Figure 1**).

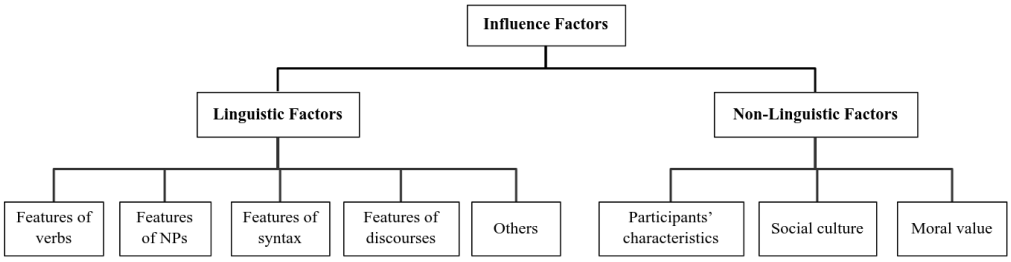

Figure 1. The linguistic and non-linguistic influence factors of IC.

2.1. Features of Verbs

Linguistic factors have received more attention, mainly including the features of verbs, nouns, and coherence relations.

2.1.1. Features of Verbs

Verb classification, which means to what extent a verb is an NP1 verb or an NP2 verb, has been a topic of discussion for a long time. Garvey and Caramazza[1] first divided verbs into two categories: those with NP1 as the agent (e.g., announce), which exhibit an NP1 bias, and those with NP2 as the agent (e.g., like), which exhibit an NP2 bias. Subsequently, many researchers found that discussing only one thematic role of an agent could not include all IC verbs and began to explore more detailed ways of categorizing verbs.

Brown and Fish[18,19] classified IC verbs into action and state verbs and argued that the former only included Agent-Patient verbs, but the latter Experiencer-Stimulus and Stimulus-Experiencer verbs. He also defined these four semantic roles, pointing out that the agent is the one who acts, whereas the patient is the role being acted upon. Stimulus is the source that creates the experience, while the Experimenter is the individual getting the experience. However, Au[20] found that action verbs can also be attributed to patients. Therefore, he dichotomized the action verbs with Agent-Patient verbs and Patient-Agent verbs, which exhibit NP1 and NP2 bias, respectively. Rudolph[21] and Rudolph and Forsterling[15] adjusted the classification of action verbs again, revising Patient-Agent verbs into Agent-Evocator verbs, in which the agent is the entity that takes action, while the evocator is the entity that causes the action or behavior. The revised classification includes four verb categories: agent-patient verbs (example 3), agent-evocator verbs (example 4), stimulus-experiencer verbs (example 5), and experiencer-stimulus verbs (example 6). Among them, agent-patient and stimulus-experiencer verbs are biased towards NP1, while agent-evocator and experiencer-stimulus verbs are biased towards NP2[6].

(3) Paul $_{\text{agent}}$ helped Albert $_{\text{patient}}$ because he was stronger

(4) Philippa $_{\text{agent}}$ criticized Frank $_{\text{evocator}}$ because he had behaved inappropriately.

(5) Paul $_{\text{stimulus}}$ surprised Albert $_{\text{experiencer}}$ because he completely cleaned his room.

(6) Mary $_{\text{experiencer}}$ admired Ann $_{\text{stimulus}}$ because she bought the best chocolates.

(Goikoetxea et al.[6]: p. 761)

This classification is widely used in current IC research. Researchers often categorize experimental verbs according to this classification and test participants' perceptions of different types of IC bias. For example, Goikoetxea et al.[6] found that IC bias is more obvious in the state than in action verbs. Corrigan[22] demonstrated that when attributions were directed toward the sentence subject, sentences with stimulus-experiencer verbs exhibited higher scores compared to those with action verbs. A recent empirical study found that 'agent-evocator verbs' and 'agent-patient verbs', referred to in the study as occasion verbs, permit anaphoric resolution of projective content more broadly than verb types[23].

Semin and Fielder[24] proposed the Linguistic Category Model (LCM), which further elaborated on the characteristics of different types of verbs. They pointed out that experiencer-stimulus verbs mainly express psychological or emotional states with no clear beginning and end. These verbs cannot be used in progressive tenses or imperative sentences. Stimulus-experiencer verbs are generally used to express emotions caused by actions, rather than describing specific actions. Other verbs, either descriptive action verbs (indicating an individual's actions, with constant physical characteristics and a clear beginning and end, without positive or negative semantic valence, such as meet, kiss) or interpretive action verbs (indicating a category of actions as a frame for diverse behaviors, requiring artificial determination with a distinct beginning and end, as well as positive and negative emotional valence, such as cheat, help), descriptive action verbs have a stronger subject bias, whereas interpretive action verbs do not have a clear bias.

With the growing understanding of verb classification, some scholars shifted their focus toward the underlying semantic features of these verbs rather than on verb classification itself[9]. In response to this, Hartshorne and Snedeker[9] proposed a more detailed classification of IC verbs according to their verb semantic characteristics, utilizing the verb network (verbnet[1])[25,26] and compared them with the previous classifications. The new classification outperforms earlier

[1] The website of the verbnet: verbs.colorado.edu/mpalmer/projects/verbnet.html

models in predictive effect. Specifically, verbs in category 31.1 (e.g., frighten, surprise) exhibited a significant NP1 bias, verbs in category 31.2 (e.g., praise, slander), and category 33 (e.g., court, cuddle) showed a significant NP2 bias, while verbs in category 36.2 (e.g., court, cuddle) do not have a specific anaphoric bias.

Other features of verbs, such as emotional valence, voice, word length, and frequency, have received attention in the study of IC. Verb emotional valence refers to whether a verb is positive or negative. Some scholars have found that emotional valence affects IC, with negative verbs tending to refer to NP1 and positive verbs more likely to refer to NP2 [7,27–29]. However, Rudolph and Rudolph [21] and Försterling [15] found no effect of valence in experiments with adults and children. Voice mainly affects reaction time. Participants recognize antecedents more quickly in active than passive sentences, but this does not change the IC bias [30,31]. Regarding word frequency and length, Ferstl et al. [28] found that low-frequency verbs are more likely to cause an NP1 bias than high-frequency verbs, but there is a weaker relation between word length and bias.

2.1.2. Features of NPs

Research on NPs in the context of IC mainly focuses on gender information, social status information, animacy, and their interactions.

Regarding gender information of NPs, LaFrance et al. [32] and Ferstl et al. [28] found that men are more likely to be the cause of actions, while women tend to be considered to elicit the actions of others. Some studies also revealed interactions between gender and other factors during IC processing. Mannetti and Grada [3] found significant interactions between the gender of the NP with verb type and respondents' gender. Additionally, LaFrance et al. [32] revealed that verbs with negative valence are more likely to be attributed to an NP with male information.

Social status and/or animacy of NPs affect IC attribution [3,33–36]. For example, 'argued' is a typical NP1 verb, and this NP1 bias is maintained when used in a context like "the assistant argued with his boss." However, when the sentence changes to 'the boss argued with his assistant', a weak NP2 bias appears [25]. In another example, 'like' as an NP2 verb, in the context of 'Ted likes Paul', more people will attribute causality to 'Paul'. If 'Paul' is replaced by an inanimate NP, the NP2 bias will be enhanced [34].

Research on NP properties is rarely focused on a single factor; instead, it often investigates how multiple NP properties interact with verb features. Corrigan [22,34–38] conducted a series of studies aimed at exploring these issues. The studies involved the classification and evaluations of verbs (e.g., emotional valence, behavioral traits: prosocial or antisocial behavior), the animacy, and related evaluations (social status and personality characteristics) of NPs. The results showed that there is an interaction between verb classification and noun animacy; the two NPs in sentences with actor and stimulus-experiencer verbs tend to be humans, whereas the ones in sentences with non-actor and experiencer-stimulus verbs tend to be a combination of animate and inanimate NPs [34,36]. For the attributions, stimulus-experiencer verbs showed a higher subject bias than object bias for all animacy types of NPs, whereas, in interpersonal contexts, attributions to the object surpassed those to the subject [28].

Additionally, participants' evaluations of verbs and nouns showed an interaction in IC bias: for action verbs, the interaction between the emotional valence of the verb and the identity of the noun explained 44% of the attribution [37]. However, the classification of verbs only works when the social status and personality characteristics of the nouns are the same [22]. Otherwise, the noun features determine the IC attribution. Participants were more likely to attribute prosocial behavior to NPs with positive personality traits, further illustrating the joint influence of NPs' personality characteristics of NPs and the behavior trait of verbs on IC [38]. A recent EEG study examined how gender cues, verb bias, and discourse focus affect pronoun resolution. Results showed that gender cues elicited stronger neural responses in the prefrontal and temporal regions, with faster reaction times than verb bias and discourse focus, suggesting that gender-based resolution relies on a more efficient, feature-driven process, while verb semantics and discourse cues involve slower, inference-based mechanisms [39].

2.1.3. Features of Syntax

The syntactic position of the anaphora's potential antecedent affects IC bias. Topics or subjects tend to strengthen the bias of NP1 verbs but weaken the bias of NP2 verbs [40,41]. This occurs because topics and subjects, especially topics, are more prominent than other syntactic positions, making them easier to retrieve [40,41]. Additionally, the first-mention effect also plays a role. Concepts introduced first in a sentence are

dominant in psychological representation, thus making them more easily activated [42]. Therefore, when the antecedent is a topic or subject and the verb has an NP1 bias, the sentence is more acceptable [4,40]. Moreover, participants spend less time reading, use fewer cognitive resources, encounter fewer syntactic violations and construct more NP1 referents in such contexts [40,41,43]. Furthermore, the facilitative effect of the topic is greater than that of the subject. Pronouns tend to exhibit coreference with the topic than the subject and object both in NP1- and NP2-verb sentences [40]. However, when the verb is NP2-biased, the influence of syntactic position on verb semantics yields inconsistent results across different studies. Some scholars suggest that while the NP in the topic or subject position may somewhat reduce the strength of IC bias, it does not reverse the direction of anaphora [31,44,45]. Other studies propose that the IC bias of NP2 verbs is stronger than that of NP1 verbs, thus weakening the effect of syntactic position [46–48]. However, ERP experiments by Xu et al. [41] indicated that the topic effect in Chinese is not constrained by semantic bias. Whether the verb is NP1-biased or NP2-biased, both object and subject anaphora elicited larger P600 responses than topic anaphora, with the topic always being the preferred referent.

In addition, parallel structure effects indicate that sentences are comprehended faster when they contain parallel structures, that is, the antecedent and the anaphora are in the same syntactic position and share the same composition [49,50]. Miao [31] found that this effect only occurs when both the pronoun and the antecedent are in subject positions, leading to faster reading of the sentences in this context.

2.1.4. Features of Discourses

Coherence relations and their markers are key factors at the discourse level. Sanders et al. [51] (p. 51) define coherence relation as "an aspect of the meaning of two or more segments of discourse". This meaning cannot be described solely by the meanings of isolated segments. Coherence relations make the overall meaning of two segments greater than the sum of their parts. For instance, in the sentence 'Mike likes Anna. She's beautiful' people often interpret the second sentence as the cause of the first, thereby creating a result-cause relation between the two to maintain coherence. When the connective 'because' is inserted between the two clauses, the causal relation becomes more explicit, as the connective highlights the causal connection, reducing the cognitive load for the speaker or listener in processing the relation. In other words, establishing a coherent relation does not rely on the presence of a conjunction; instead, an explicit conjunction simply makes the relation clearer and easier to process [52,53].

When there is no explicit connective in a mini discourse containing an IC verb, the findings are inconsistent regarding whether IC affects anaphora resolution. Scholars with a negative view found that people generally tend to refer to the subject in the former clause as the antecedent of the pronoun in the latter clause [30,54]. On the contrary, scholars with a positive viewpoint note that subjects tend to produce a clause indicating the reason for the event/state in the first clause, and the antecedent of the pronoun tends to be consistent with IC [5,55–58]. However, the strength of the IC bias will weaken, and the activation speed will decrease [56].

When conjunctives are present, IC plays different roles based on their specific type. When there is a result-cause connective, such as 'because', is used, the role of IC is strengthened, and the antecedent of the pronoun typically aligns with the IC bias [5,55,58–62]. In contrast, when clauses are connected with 'so', the antecedents tend to be the NP, which is inconsistent with the IC bias, suggesting that IC has reversed [57,63].

However, the impact of other connectives on IC remains inconclusive. When the conjunction indicates contrast, such as 'but/although', there are generally two results: one is that connectives cause the IC effect to disappear, resulting in no clear preference for anaphora [5,30,64]; the other is that they may shift anaphora towards arguments that are inconsistent with the IC [63,65]. The effect of 'and' is similar to that of 'but/although', as it can either make the IC disappear or reverse [3,65]. This shift is due to 'implicit consequentiality', which contrasts with the IC and encourages pronouns to seek antecedents that align with the direction of event outcomes [47,66–71].

Different connectives and IC biases in a sentence affect the choice of anaphoric forms. Li [54] and Weatherford and Arnold [72] conducted sentence completion tasks and found that when causal markers (like 'because') are present, third-person pronouns are most likely to be chosen. In these cases, the pronouns' anaphora and the verbs' IC biases are generally consistent. Li [54] also found that when 'because' is absent and the verb is an NP1 verb, participants tend to choose more zero anaphora, with the antecedent aligning with the IC

bias. However, when the verb is an NP2 verb, zero anaphora and pronouns are chosen in similar quantities, weakening the IC effect. Järvikivi et al.[44] examined the interaction between anaphoric forms in Finnish (third-person pronoun hän [he], demonstrative tämä [this]) and verb bias through a visual world paradigm. Their results showed that, although the entities referred to by the two forms are consistent with the IC bias, the demonstrative tämä exhibited a stronger NP2 bias. The authors suggested that this might be related to the functions of the anaphoric forms themselves, as the demonstrative tämä typically refers to non-subject and less prominent antecedents in the sentence, thus referring more frequently to NP2 in the experiment.

Other linguistic factors, such as sentence type, stress, temporal structure, and implicit prosody, have also been discussed. Garvey et al.[33] indicated that both interrogative and declarative sentences can detect the IC effect. Miao and Song[30] found that in passive sentences in Chinese, speakers tend to use NP1 as the antecedent of the pronoun, which causes the IC bias to disappear. In contrast, Leng and Mo[73] revealed that the passive voice would not affect the IC bias. Shen and Yang[74] discovered that IC primarily functions when pronouns are unstressed, with the effect of stress being mainly evident in NP1 verbs. Dery and Bittner[61] added temporal nouns (e.g., 'yesterday' and 'today') into sentences and found that both temporal structure and IC influence re-mention biases of NPs, with the effect of temporal structure sometimes being more significant than that of IC. In two self-paced reading studies, participants read poem-like texts with either regular or disrupted rhyming schemes and meters, and these rhyme cues led participants to adapt their interpretative preferences and processing strategies[75].

2.2. Non-Linguistic Factors

The participants' characteristics, culture, and moral values are the main topics of discussion.

In terms of participants' characteristics, reading ability is a primary concern. Long and De Ley[46] demonstrate through sentence completion experiments that only high-level readers showed the early influence of IC in pronoun resolution, but this effect occurred in sentences with NP2 verbs. Low-level readers, on the other hand, only perceived this effect toward the end of a sentence. The results of Leng and Mo[73] differ slightly, confirming that high-level readers can immediately complete elaborate processing in conditions of NP1 and NP2 verbs, but low-level readers are also able to process sentences with NP2 verbs. For working memory capacity, Bai et al.[76] found through eye-tracking experiments that participants with high working memory capacity had shorter fixation times during IC processing compared to those with low working memory capacity. Furthermore, both groups could effectively utilize the IC of NP2 verbs, but only the former could use the IC of NP1 verbs. Mindfulness has been shown to influence self-enhancement in IC tasks (e.g., I/Lucy praised Lucy/me because ... was that kind of person). Compared to the control group, participants in the mindfulness group were less likely to take credit for positive events and more likely to attribute negatives to themselves[77].

Regarding social culture, American subjects showed no clear tendency in resolving pronouns in sentences containing verbs like 'trust', 'doubt', and 'chase', because they often chose the subject as the pronoun antecedent[1]. In contrast, Chinese subjects tended to assign the object as the antecedent in sentences with all three verbs[31]. Miao and Song[30] hypothesize that this difference is due to social culture factors, suggesting that individuals from China and the United States attribute certain events differently, which leads to variations in how they predict anaphora.

Turning to moral values, Niemi et al.[78] suggested that in some IC sentences describing harmful events, like 'Bob coerced Amy because...', people's endorsement of moral values that build and bind groups—such as ingroup loyalty, respect for authority, and preservation of purity— affects their attribution of the event's cause. Individuals highly endorsing these values are more likely to attribute the object as the pronoun's antecedent.

3. Hypotheses of IC on Anaphora Resolution

Many factors can influence IC, raising the question of which factors play a decisive role in IC activation. In other words, what is the pattern IC follows in guiding anaphora resolution. Scholars have proposed several theoretical hypotheses to address this question. This chapter will introduce and summarize these hypotheses, with a focus on the activation patterns of the IC.

3.1. Lexicosemantic Hypothesis

The *Lexicosemantic account* posits that IC originates from the event semantics inherent in the verb itself, which is an intrinsic semantic property of the word[1,6,9,15,18,19,79]. According to this theory, IC activation is primarily driven by its semantics, rather than other linguistic or non-linguistic factors. This approach classifies verbs based on their argument roles or semantic features, thereby determining whether a given verb is biased toward NP1 or NP2 (see 2.1.1.).

Support for the *Lexicosemantic account* theory mainly comes from studies investigating the timing of IC activation. If IC activates early enough before other discourse factors have fully unfolded, it is more likely that IC activation depends on its inherent semantics. The *Focusing account* suggests that IC activation has a focusing effect, rapidly directing the reader's attention to the object that denotes the reason for the event as soon as the verb appears and is processed. This object then becomes the focus of the reader's mental representation, making it more accessible during pronoun resolution than other potential antecedents. Many studies have verified the *Focusing account* through methods such as self-paced reading and eye-tracking[5,8,44,55,58,74,80,81]. Pyykkönen and Järvikivi[8] employed the visual world paradigm with eye-tracking to detect IC activation timing, revealing that participants were able to predict the pronoun's antecedent within 900 ms of the verb's onset, which is the earliest time IC activation has been detected so far. Notably, within this time window, conjunctions and pronouns had not yet folded.

However, the *Lexicosemantic account* has been challenged by several studies. Stewart et al.[82] pointed out that some agent-patient verbs, which should be NP1-biased, often refer to NP2 or exhibit no clear bias (e.g., question). Cozijn et al.[81] found that the IC effect appears after the presentation of conjunctions and pronouns, suggesting that IC activation may depend on discourse relations. These findings have prompted scholars to reconsider the role of discourse relations in IC activation.

3.2. Coherence Driven Hypothesis

The *Coherence Driven account* holds that IC is a probabilistic abstraction related to the subject of the cause of verb events, and is considered a byproduct of speakers' construction and anticipation of causal relations between events. It includes two specific processing steps: (i) expectations about how the discourse is likely to continue with respect to coherence relation, and (ii) the likelihood that a pronoun will mention a certain referent, contingent on the occurrence of that coherence relation[60]. This account suggests that discourse coherence relations are the decisive factor in IC activation, with causal relations being the only ones capable of activating IC. *Coherence Driven account* primarily examines IC activation in sentences without connectives and those with different types of connectives. The results indicate that IC facilitates pronoun resolution only in sentences that contain causal connectives, such as 'because', or when readers interpret the short discourse without explicit conjunctions as conveying a causal relation.

Support for this theory is mainly drawn from the *Integration account*. Millis and Just[83] proposed that readers cannot immediately use IC when encountering the verbs; instead, this semantic meaning becomes accessible only once the reader completes the integration of the sentence at the final stage of sentence processing. This account implies that relying solely on verb semantics is insufficient for IC activation, challenging the IC focus effect. It is supported by many studies[43,46,48,76,82,84].

However, a corpus study by Asr and Demberg[85] found that the proportion of sentences with a causal relation in non-IC verb sentences (65%) was higher than that in IC verb sentences (61%). Further production experiments revealed that the match between pronominal anaphora and IC bias was weaker than expected. On the contrary, the first-mention effect seemed more influential, and participants tended to refer to NP1 as the antecedent of the pronoun[30,54]. These findings suggest that relying only on discourse causal relations may not be sufficient to facilitate IC activation.

3.3. Verb-Coherence Hypothesis

Based on the discussions in Sections 3.1 and 3.2, neither verbs nor causal relations can independently trigger IC activation. Tian and Zhao[58] investigated IC activation in native Chinese speakers and Chinese learners when they encountered various categories of IC verbs (NP1 verbs, NP2 verbs, neutral verbs) and connectives (causal connective 'yinwei' [because] and full stop) using an eye-tracking visual-world experiment and a sentence-completion task.

The eye-tracking results revealed that IC was activated

between 1300 ms and 1600 ms after the verb onset, before connectives or pronouns had unfolded. This suggests that the verb's semantics play a critical role in IC activation. In the sentence completion task, the study first analyzed the coherent relations that participants used to complete sentences without any connectives. They found that the result-cause relation occurred most frequently, followed by the additive, result, and negative relations. Next, the study examined the antecedents of pronouns across different coherent relation conditions, discovering that the antecedent of pronouns aligned with the IC bias only in the result-cause condition. This suggests that IC activation is dependent on the presence of causal relations. To further verify this result, Tian and Zhao[58] assessed pronoun antecedents in sentences with 'yinwei (because)', and found that IC was activated, which reinforced the results observed in the full stop condition. Thus, IC activation occurs only when the verb carries IC semantics, and a causal relation is present.

3.4. World Knowledge Hypothesis

The *World Knowledge account* points out that IC is inferred from learned distributional facts about situations to which the verb is typically applied. Its activation is based on non-linguistic knowledge about who tends to cause certain types of events, rather than directly from the verb's meaning.

The likelihood of an event's cause being attributed to NP1 or NP2 largely depends on the speakers' or listeners' world knowledge. For instance, factors such as the gender and social status of the NP can influence this attribution[22,37,38] (see 2.1.2. for details). In the sentence 'John questioned Mary', if 80% of people interpret the cause as related to 'John,' this reflects an 80% NP1 bias. Conversely, if 20% attribute the cause to 'Mary,' a 20% NP2 bias is present. This suggests that, when asked to explain the event, the majority would associate the cause with 'John', while fewer would associate it with 'Mary'.

3.5. Empty Slot Theory

The hypotheses mentioned above focus on the determinants of IC activation but do not explain the process by which IC is activated by these factors. To address this gap, Bott and Solstad[86] proposed the Empty Slot Theory, a linguistic framework to account for the IC phenomenon. According to this theory, IC verbs create a unique "slot" for a specific causal context or 'explanation' type. When essential information cannot be inferred from the current or preceding context, the IC verb fills this 'slot' in subsequent discourse, guided by its expected IC bias. Essentially, when an IC verb appears, if a clear causal explanation is present, like example (7) and (8), anaphora typically follows this causal thread. However, without such an explanation, for example (9), the IC bias guides the interpretation. Different IC verbs trigger expectations for distinct causal explanations—such as simple causes, internal reasons, external reasons, or background reasons—which subsequently affect anaphoric bias. These expectations are shaped by the verb's semantic properties, including its argument structure.

(7) Peter annoyed Mary with his loud singing.
(8) Peter annoyed Mary by singing loudly.
(9) Peter annoyed Mary early in the morning because ...

(Bott and Solstad[86]: p. 385)

Bott and Solstad[86] tested the Empty Slot Theory through three experiments. Experiment 1, an ontological test, examined whether manipulating these "slots" systematically changes discourse expectations and anaphoric tendencies. The slots were modified by varying causal clauses, for example, changing the causal connective 'because' with 'by' in example (10), and by including different verbs, such as NP1-biased stimulus-experiencer verbs and agent-patient verbs. Participants were required to complete sentence fragments, and the results confirmed that under the 'because' condition, stimulus-experiencer verbs more frequently produced simple causes, while agent-patient verbs were more likely to lead to background, internal, and external reasons. In the 'by' condition, both verb types primarily produced simple causes. Additionally, internal and straightforward causes tended to trigger NP1 anaphora, while internal causes often resulted in NP2 anaphora.

(10) Lucy frightened Tom because/by ...

(Bott and Solstad[86]: p. 389)

Experiments 2 and 3, respectively, explored stimulus-experiencer verbs with NP1 bias, as in example set (11), and verbs presupposing a prior event with an NP2 bias, as in example set (12), to assess how explanation types and

anaphoric tendencies shift when the "slots" are modified. The results corroborated those of Experiment 1, confirming that slot modifications indeed influenced anaphoric type. When a slot required filling by an IC verb, the verb's semantic characteristics determined discourse interpretation expectations, which in turn shaped anaphoric tendencies.

(11) a. Peter fascinated Linda by impressive travel reports because...
b. Peter fascinated Linda by impressive travel reports ...
c. Peter fascinated Linda because...
d. Peter fascinated Linda ...
(12) a. Peter thanked Mary for the financial support because...
b. Peter thanked Mary for the financial support ...
c. Peter thanked Mary because ...
d. Peter thanked Mary ...

(Bott and Solstad[86]: p. 393)

Additionally, alternative theories, such as the *Mixed account*, have been proposed. Stewart et al.[82] introduced this account based on two initial assumptions, suggesting that the influence of IC on pronoun resolution is related to both the *Focusing* and *Integration accounts*. To evaluate these frameworks, Stewart examined the congruency effect[2] and the interaction of different referential forms (pronoun vs NP). His findings indicated that the *Focusing account* could only predict congruency effects during pronoun resolution, whereas the *Integration account* could account for congruency effects in both pronoun and NP resolution. The *Mixed account* hypothesis showed similar predictive power to the *Integration account* for pronoun resolution, though its effectiveness was comparatively weaker in NP contexts. Stewart did not empirically test the *Mixed account* in his study, and subsequent research has rarely revisited or expanded upon it.

Nevertheless, many studies support Stewart's view that IC's effect on pronoun resolution relates to both the *Focusing account* and the *Integration account*. These two accounts are not fundamentally opposed; instead, they emphasize different aspects of the IC phenomenon[5,8,56]. The *Focusing account* primarily addresses when and how IC information is activated, while the *Integration account* focuses on IC persistence, explaining how different factors affect IC functioning as the sentence unfolds progressively.

4. Methodology of IC Research

4.1. Research Paradigms

Experiments investigating the role of IC in pronoun resolution primarily include comprehension and production tasks, with comprehension experiments employing a wider range of paradigms (**Figure 2**).

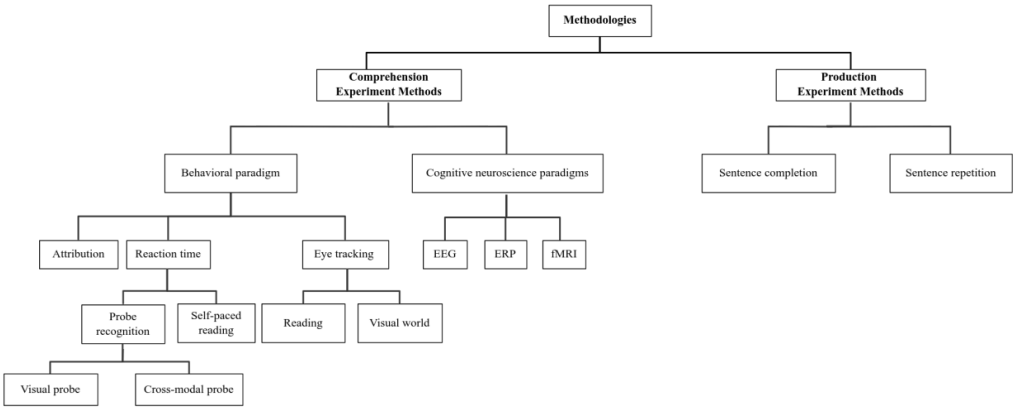

Figure 2. Methodologies in IC research.

[2] The "congruency effect" illustrates how pronoun resolution is generally faster and more accurate when the antecedent aligns with the IC verb's bias.

4.1.1. Comprehension Experiment Methods

In comprehension paradigms, early research primarily utilized offline methods, such as attribution tests. With technological advancements, a growing number of studies have shifted toward online paradigms, including reaction time, eye-tracking measures, and event-related potentials (ERP). These behavioral and neurophysiological approaches allow researchers to examine both the real-time processing of participants during comprehension and their resulting outcomes.

The attribution test has been a commonly used paradigm in early research on IC. In this method, the experimenter presents a sentence containing an IC verb, then asks participants to identify the cause of the event, in other words, the pronoun's antecedent, through a question-and-answer format, as in example (13)[3,6,18,87,88]. This method effectively measures participants' attributions of causality, thereby providing insights into the role of IC in pronoun resolution. However, the attribution test primarily captures participants' judgment outcomes and does not allow for the observation of their real-time processing. While early studies predominantly relied on this paradigm, recent research has integrated it with online methods such as reaction time and eye-tracking to provide more dynamic indicators of the reading process[89].

(13) Sentence: Sally frightened Mary because she is a dax.
Question: Who is the dax?
Options: Sally Mary
(Hartshorne et al.[87]: p. 4)

The reaction time test is one of the earliest methods used to investigate real-time processing in IC research. It includes two main paradigms: the probe recognition paradigm and the self-paced reading paradigm.

The probe recognition paradigm has two variations: the visual probe and the cross-modal probe paradigms. In the visual probe paradigm, a probe word appears suddenly during the participant's reading of an experimental sentence, typically structured as 'NP1 + verb + NP2, connective + pronoun + …'. The participant is asked to judge whether the word appeared in the preceding sentence quickly. Typically, the probe word is inserted at three positions: before the pronoun, after the pronoun, and at the end of the sentence[43,48,59,74,89,90]. To precisely pinpoint when the probe word appears, sentences in this paradigm are usually presented word by word. The cross-modal probe paradigm adds auditory stimuli to the visual probe task. In this variation, the experimental sentences are presented auditorily, and at a specified point in the sentence, a probe word appears visually on the screen for the participant to respond to as quickly as possible. This paradigm is frequently used to examine the congruency effect, as well as the *Focusing* and *Integration accounts*. Participants' reaction times to the probe word at different positions provide insights into when they begin to use IC information to process the pronoun and how IC works in congruency or incongruency contexts. However, inserting probe words into sentences is somewhat intrusive, as it interrupts natural reading and comprehension processing, potentially impacting experimental outcomes. Despite this limitation, the probe recognition paradigm offers the advantage of capturing both the process and the result of comprehension, representing a step forward in investigating real-time language processing.

Self-paced reading tests allow participants to control their reading speed and can include both visual and auditory modalities[80,82,91,92]. In IC research, sentences are typically divided into two parts for presentation: the main clause and the subordinate clause. Participants first read or hear the main clause, which contains NP1, NP2, and an IC verb, and then press a key to advance to the subordinate clause, which includes a conjunction, a pronoun, and other context. This paradigm examines reading times for sentences in which the IC bias either aligns with or conflicts with pronoun anaphora, allowing researchers to infer the IC's impact on pronoun resolution. By measuring reading durations under these conditions, this approach provides insights into how IC bias influences cognitive processing in pronoun interpretation. A notable improvement in this method is that the presentation begins at the clause level rather than word-by-word, offering a more natural reading experience. Additionally, reading time, as a key index, provides a more nuanced approach to examining comprehension processing.

The eye-tracking technology offers several advantages over reaction time tests. First, it provides higher precision in both temporal and spatial resolution. Second, it gathers more comprehensive indices, such as saccades and various categories of fixations or gazes. In IC research, the primary eye movement paradigms include the reading paradigm and

the visual world paradigm.

In the reading paradigm, the experimental sentence is presented in its entirety on the screen, and participants are required to read it naturally. After part of the sentence disappears, comprehension questions appear to test whether the subject has understood the sentence. This paradigm allows researchers to track fixation times and saccade trajectories in areas of interest, as well as reaction times and accuracy in response to comprehension questions, to assess participants' cognitive processing states[5,76,91]. In contrast, the visual world paradigm displays images representing NP1 and NP2 on a screen while participants listen to experimental sentences. This allows researchers to track participants' looks to visual stimuli in different time windows as the sentence information unfolds, enabling them to visualize which NP the subjects predicted as the antecedent of the pronoun[8,44,58,81].

Unlike the reading paradigm, which causes eye movement changes only when IC cues and other information conflict (e.g., gender ambiguity or semantic violations), the visual world paradigm allows eye movement responses to be observed regardless of whether the participant encounters information violations in the sentence. As a result, Pyykkönen and Järvikivi[8] emphasize that it is especially suited to examining the effects of IC on pronoun resolution. Wei and Knoeferle[17] also emphasized that tracking participants' looks on visual stimuli to measure which areas of the visual objects capture the most attention provides evidence for the dynamics of mental representations that support the inference of causes and consequences.

Currently, eye-tracking paradigms are frequently used to test *Focusing* and *Integration accounts*[5,8,44,76,81]. Additionally, this paradigm has been employed to investigate how coherence relations and readers' differences[5,58,93] impact IC. However, while the eye-tracking paradigm provides valuable behavioral data, it is limited in capturing electrophysiological responses linked to cognitive processing states, which constrains its capacity to explain underlying neural mechanisms.

The use of ERP and fMRI techniques has provided insights into the neural mechanisms of IC in language processing. Van Berkum et al.[94] employed ERP to examine participants' responses to mini-stories with a structure like 'NP1 verb-ed NP2 because...', where NP1 and NP2 were of different genders. When the antecedent did not align with the IC bias, the pronoun elicited a P600 component, indicating a syntactic violation. Xu et al.[57] used the Nref component of ERP to explore how different conjunctions influence IC. The Nref, associated with referential ambiguity, appears as a negative component approximately 300–400 ms after the ambiguous word, over the front of the head, and without an obvious peak[95]. Their study found that pronouns in sentences connected by 'though' produced a significantly greater Nref response compared to those with 'so', 'and', or sentences separated by a full stop, suggesting increased anaphoric processing difficulty with 'though'. In addition, Wang[96] explored self-serving bias in IC using fMRI. Self-serving bias is the tendency to attribute positive outcomes to oneself, whereas negative outcomes to external factors to achieve self-protection[97]. The study revealed that the activation of the dorsal medial prefrontal cortex may play a role in inhibiting self-serving bias during IC processing. Specifically, when participants evaluated self-related negative events, particularly when they acted as recipients, activation in dorsal medial prefrontal cortex increased with the duration of evaluation, indicating a stronger neural response in handling self-directed negative attributions.

4.1.2. Productive Experiment Methods

Research on IC production primarily employs sentence completion and sentence repetition tasks, in which participants are asked to extend sentence fragments with IC verbs and two NPs, or remember the given sentence before the complement.

The most common type of sentence completion introduces causal conjunctions and third-person pronouns simultaneously, such as 'NP1 verb NP2, because he/she_____', which clarifies causal relations and allows participants to determine attribution by completing the sentence. This approach is widely used to test the semantic biases of different IC verbs[7,30,31]. The second type of sentence fragments involves modifying or removing conjunctions, e.g., 'NP1 verb NP2, full stop/because/so/and/but/when…he/she_____'. When conjunctions are omitted, researchers can examine the types of coherence relations that participants preferentially produce, as well as the relationship between the pronominal antecedent and IC bias in different coherence relations[5,57,58,60]. Sentences containing non-causal conjunctions are used to investigate the influence of other coherence relations on IC

activation[5,57,58]. The third type omits pronouns, like 'NP1 verb NP2, because _____', which is commonly used to measure the re-mention likelihood of NP1 or NP2 and examine how different referring expressions, including NPs, pronouns, and zero anaphoras, influence IC bias[54].

Only presenting one clause, like 'NP1 verb NP2', before completion may lack sufficient discourse context. To address this, they add background sentences prior to the IC clause to enrich the context[5,72]. For instance, Weatherford and Arnold[72] provide the background context, like 'The maid and the cook put the dishes on the top shelves' before the main sentence, 'The cook appreciated the maid, because…'. Similarly, Koornneef and Sanders[5] added a background sentence with 'they' after introducing two characters, like 'David and Linda were both driving pretty fast. At a busy intersection they crashed hard into each other.' Before the critical sentence, 'David apologized to Linda because he…', ensuring that both NPs receive equal focus and minimizing first-mention or syntactic-position biases.

A recent study adopted a sentence repetition paradigm, in which participants were asked to repeat spoken or written sentence prompts from memory and then produce a complement. The aim was to explore how language users respond to mispredictions. The study found that pronouns from congruent sentences were repeated more accurately than those from incongruent ones. This pattern held regardless of participants' age of English acquisition or bilingual background, suggesting that re-mention biases shape the encoding and recall of referential information[98].

In summary, online paradigms for comprehension experiments in IC research are among the most varied, especially with the advancement of technological tools. The introduction of eye-tracking, EEG, ERP, and fMRI has made this type of research more refined and naturalistic. Researchers increasingly combine multiple methods to obtain a more comprehensive view of IC processes. For example, some studies integrate eye-tracking with the probe recognition paradigm[48] or self-paced reading with probe recognition[73]. These multi-method approaches allow researchers to observe multiple performance facts simultaneously, thereby enhancing our understanding of IC. However, research into the brain mechanisms underlying IC remains limited, and studies that combine comprehension and production paradigms are still needed. Future studies could benefit from focusing more on methodological choices and incorporating a broader range of approaches to deepen insights into IC processing and the underlying cognitive mechanisms.

4.2. Participant Types

In recent years, research on IC has expanded beyond the typical adult native-speaker population to include diverse groups, such as children, older adults, individuals with special needs, and those with disabilities. With the advancement of technology, scholars have expanded the research subjects from humans to Large Language Models (LLMs), aiming to explore the similarities and differences between AI and humans in IC processing. This section reviews IC studies categorized by participant groups (**Figure 3**).

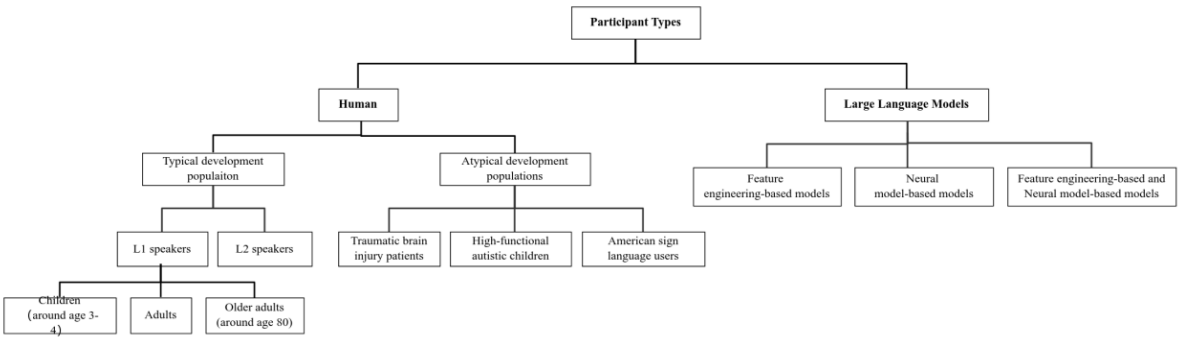

Figure 3. Research subjects in IC research.

Focusing on children and older adults, these studies primarily examine whether IC influences pronoun resolution in a manner similar to that observed in adults. Research indicates that even children as young as three exhibit sen-

sitivity to IC when predicting pronoun antecedents[6,20,38]. However, children show a weaker NP1-bias effect with NP1 verbs, and give more NP2 bias in state verbs compared to adults[6]. In the case of older adults, there is a tendency to produce more NP2 references in NP1 verb contexts and more NP1 references in NP2 contexts[99]. Bittner suggests that these differences may arise from variations in the social environments of younger and older individuals, leading to differing perspectives on interpersonal events[99].

Research on atypical development populations has primarily focused on individuals with traumatic brain injuries[100], High-functioning autistic children[101], and American Deaf signers[102], with a central emphasis on whether the activation of IC bias is different in these groups.

Dresang and Turkstra[100] investigated the impact of IC among individuals with traumatic brain injuries using a sentence-completion task with the structure 'NP1 verb NP2 because…' where the gender of the two NPs differed within the same sentence. The results indicated that this group exhibited a weaker IC bias than typical adults and made more mistakes in assigning causality to a sentence.

Yu et al.[103] examined the effects of context and IC on pronoun processing in Chinese-speaking children aged 5–7 with high-functioning autism. In the task, the experimenters played sentences in which both NPs shared the same gender, such as 'Xiaohong disturbs Xiaolan because she is singing loudly', and asked the children, "Who is 'she' ?" to judge the pronoun reference. The results showed that children with high-functioning autism performed weaker IC effect in pronoun processing compared to typical children, although contextual information helped both groups in determining pronoun antecedents. This difference is potentially due to difficulties in the semantic representation of IC verbs.

Frederiksen and Mayberry[102] investigated IC bias in eight native American Sign Language (ASL) users. Participants were introduced to two characters and asked to visualize them as protagonists within a situational context. After watching a signed video equivalent to the English phrase 'Name Verb Name because…', participants completed the sentence in ASL. The results indicated a stronger NP2 bias among Deaf signers than hearing populations. The researchers suggest that this finding may be attributed to the absence of stimulus-experiencer verbs in ASL, which could influence the distribution of IC bias within sign language contexts.

Research on second language (L2) learners has primarily investigated whether L2 speakers, like native speakers, use IC to guide pronoun disambiguation. Cheng and Almor[101,104] argue that even among intermediate to advanced Chinese speakers of English, a weaker NP2 bias and a stronger first-mention effect persist compared to native speakers. Their 2019 study supports these findings in pronoun conditions such as 'NP1 verb NP2, because he…' but in non-pronoun conditions like 'NP1 verb NP2 because…', L2 speakers demonstrated a re-mention bias similar to native speakers. Some other researchers suggest that bilinguals and native speakers exhibit similar IC biases in pronoun resolution. Some studies[93,105–108] have examined IC bias in English learners of Korean, Spanish-English bilinguals, and Chinese learners of English. They found that bilinguals can utilize IC to disambiguate pronouns in a way similar to native speakers, with consistent IC biases across both groups. Kim and Grüter[93] further observed that learners' native language would not affect their IC bias.

Regarding the speed and strength of IC processing, Liu and Nicol[92] as well as Kim and Grüter[93] found that IC effects emerged later and with lower intensity for L2 speakers than for L1 speakers in an eye-tracking visual-world experiment. However, another eye-tracking study by Contemori and Dussias[106] indicated that high-proficiency Spanish-English bilinguals showed no delay in IC processing compared to English monolinguals.

In addition, several studies have explored various factors that influence IC processing in L2 learners. Xu et al.[57] and Tian and Zhao[58] examined the impact of different connectives on IC bias. Xu et al.[57] conducted an ERP experiment to investigate IC processing in English learners of Chinese while reading sentences such as 'Lily disappointed Nina, so/and/although/full stop she quit the business.' They found that, compared to 'so', 'and', and 'full stop' conditions, the pronoun in 'although' sentences elicited a larger Nref in both L1 and L2 groups. Moreover, the L2 group showed larger Nrefs than L1 readers when reading sentences connected by 'so', 'although', or 'full stop'. Different kinds of verbs elicited different degrees of Nref responses. In the 'so' and 'full stop' conditions, sentences with NP2 verbs evoked larger Nref than sentences with NP1 verbs. Tian and Zhao[58], using an eye-tracking visual-world paradigm,

explored the effects of conjunctions 'yinwei (because)' and 'full stop' on IC processing in Korean learners of Chinese. They found that learners could activate the verb IC both in 'because' and 'full stop' conditions. Additionally, Wu and Wu[105] investigated the roles of IC and NP gender in pronoun resolution among English learners of Chinese. Their findings showed that IC did not significantly influence pronoun antecedent choice when gender cues were present; however, in the absence of gender cues, IC had a significant impact and showed a 'congruency effect'. Research on L2 speakers' differences has identified that language proficiency, vocabulary knowledge, and working memory capacity affect IC processing[93,108]. Second language proficiency can affect IC processing speed. An eye-tracking study of Chinese English learners found that, compared to low-proficiency learners, high-proficiency speakers spent less time making pronoun anaphoric inferences with IC information[109].

The research on IC mining through LLMs in texts is primarily categorized into three main approaches: feature engineering-based methods, neural model-based methods, and hybrid methods that combine both approaches[110–114]. A joint event relation identification model proposed by Zhang et al.[114] employs the first method. The model integrates contextual semantic and multiscale local semantic features of text to derive meaning using bidirectional gated recurrent unit (Bi-GRU) and a multiscale convolutional neural network. They also incorporate encoders and decoders to capture event temporal and causal relations, enabling the acquisition and interaction of event temporal and causal semantic features.

Davis[111] (2022) used Long Short-Term Memory networks (LSTMs)[115] and transformer models (e.g., GPT-2XL), which are neural model-based methods, to investigate the extent to which discourse structure, determined by IC verbs, can be acquired. The result showed that the LSTMs were unable to demonstrate knowledge of IC, while the transformer models were able to represent an IC distinction through training partially. However, this ability is unstable across languages. For example, the models performed well in English and Chinese but not in Spanish or Italian. Liang et al.[112] developed a novel causality detection model called the Multi-level Causality Detection Network model (MCDN), which combined feature engineering-based methods (multi-head self-attention) to acquire semantic features at the word level and neural model-based methods (Self Causal Relation Network, SCRN) to infer causality at the segment level. This model is designed to simulate the causal reasoning process and has been validated for its effectiveness and robustness in causality detection.

In machine learning, Toth et al.[113] established a primitive information processing elements (PRIMs) cognitive architecture. Through extensive and continuous language input and optimization, the model eventually learned to use IC information for pronoun resolution prediction. Additionally, this architecture also learned to predict antecedents based on the type of anaphora, tending to predict the subject as the antecedent in pronoun anaphora sentences and the object as the antecedent in proper noun anaphora sentences. This model suggests that seemingly complex linguistic behavior can be explained by cognitively plausible domain-general learning mechanisms.

5. Discussion and Conclusion

Based on the above review, significant progress has been made in understanding the IC effect in anaphoric resolution, both in theoretical frameworks and empirical findings. Advances in technology have enabled the use of increasingly sophisticated and ecologically valid research paradigms, facilitating deeper investigation into IC processing and its interactions with various linguistic and non-linguistic factors. Additionally, these advances have expanded the scope of research to include a broader range of participant types. However, lots of issues remain for further exploration, which we outline in this chapter to provide a foundation for future research directions.

5.1. Research Theory

Regarding the mechanisms underlying IC activation, most studies summarize theoretical approaches by identifying factors determining IC activation. Some hypotheses propose that various types of world knowledge jointly contribute to IC activation, while numerous studies have shown that several factors influence IC activation and play a role in anaphoric resolution. It is theoretically expected that one or more of these factors should be determinative, while others may serve as supporting contributors. Recent research has often focused on two primary factors: verb semantics and causal coherence relations. However, it remains unclear

whether both factors are equally crucial for IC activation or if one holds greater importance, warranting further investigation.

Additionally, we can discuss IC activation theory in conjunction with theories from other fields, such as the Cognitive Approach to Coherence Relations [53], the *Risky Reading Hypothesis* [116–118], and the *Resource Limitation Hypothesis* [119]. Sanders [53] introduced the *Causality-by-default Hypothesis*, suggesting that readers aim to construct a coherent mental representation of information, with causal relations being particularly effective in achieving this. According to his hypothesis, when readers encounter two discourse segments without explicit coherence markers, they are likely first to assume a causal relation between the discourses, which is processed more quickly. When a causal relation cannot be established, alternative relations are then considered. If this hypothesis applies to IC processing, causal relations may have a cognitive processing advantage. Consequently, a greater frequency of causal contexts might not solely result from expectations tied to the IC meaning [60], but rather from the inherent prominence of causal relations. This perspective challenges the *Coherence Driven account*. Future research could explore these insights by testing conditions with full stops and non-IC verbs. The competition between multiple theories would provide a more comprehensive IC activation mechanism and enhance the credibility of our explanations.

In terms of language types, current IC research primarily focuses on alphabetic languages, while studies on non-alphabetic languages, such as Chinese, Korean, and Japanese, remain relatively limited. Due to differences in language typology and cultural influences, IC biases for the same verb may vary across languages [30], and the impact of other factors may also differ. For instance, in Dutch, real-time IC processing is slower and weaker in the absence of conjunctions compared to when 'because' is used [56]; however, this difference does not appear in Chinese [58]. In Chinese, a Topic-Prominent Language that prioritizes semantic coherence over syntax, conjunctions are often omitted when the semantics are clear [120]. In contrast, Subject-Prominent Languages, such as English and Dutch, have stricter syntactic rules and rely more on explicit connectives. Speakers of these languages are more sensitive to the presence or absence of conjunctions, which affects their processing of IC.

In addition, sign language is influenced by the distribution of vocabulary. Stimulus-experiencer verbs are less common in sign language, resulting in weaker IC effects. Furthermore, sign languages have distinct branches, such as Chinese Sign Language (CSL) and American Sign Language (ASL), and it remains to be explored whether IC effects are consistent across these languages. Unlike spoken languages, sign language conveys some linguistic information, such as stress and emphasis on meaning, through gestures, facial expressions, body posture, and hand positions. These features may also affect IC biases. Moreover, the deaf community has a unique cultural identity and sense of community, which may also shape IC processing in distinct ways.

5.2. Influencing Factors

Research on the classification of IC verbs has advanced significantly, evolving from the initial binary categorization based on thematic roles [1] to a four-part classification system [15,21], and more recently to analyses of finer-grained semantic features beyond thematic roles [9]. Despite these developments, current research still largely focuses on summarizing the characteristics of "collected" IC verbs. This raises essential issues: the definition of an IC verb involves determining the boundaries of the IC verb category. The prevailing definition broadly encompasses 'interpersonal relationship' verbs [1], but this category is overly inclusive, encompassing many non-IC verbs. To refine this definition, a more precise set of necessary and sufficient conditions is required. Once the boundaries are clarified, it could establish a continuum of core and peripheral members within the IC verb category, allowing for an analysis of both family resemblances and distinct differences among the members of this continuum. Additionally, the classification of verbs should account not only for semantic features but also for grammatical and pragmatic aspects.

There are numerous factors affecting IC, ranging from linguistic to non-linguistic levels. However, a more systematic approach could enhance the study of how these factors comprehensively influence IC. For instance, meta-analyses could be employed to assess the effect sizes and relationships among various factors, revealing which are essential for IC activation and which merely exert a secondary influence. Making these distinctions is crucial for gaining a comprehensive understanding of IC as a linguistic phenomenon and differentiating its characteristics in its activation versus

persistence states.

5.3. Research Methods

Innovative research paradigms are essential for advancing our understanding of IC and related phenomena. Precise behavioral techniques, such as the eye movement paradigm, as well as neuroscientific approaches, like ERP and fMRI, have enhanced spatiotemporal sensitivity, index diversification, and observational accuracy. These methods have deepened our knowledge of time-locked language processing and neural mechanisms underlying the impact of IC on anaphora resolution. However, this does not imply that traditional experimental methods, especially offline approaches like attribution tests and sentence completion tasks, should be disregarded. Rather, selecting appropriate methodologies based on specific research questions, combining offline and online techniques, integrating comprehension and production measures, and merging new paradigms with established ones will more effectively support researchers in finding answers.

Regarding the research subjects, apart from typically developed adults, more and more studies focus on how children, the elderly, and atypical development populations process IC. Evidence suggests that different groups may attribute the same verbs in different ways. Whether sociocultural influences or neurological mechanisms drive these differences, and how factors such as language proficiency, language typology, and community environment shape this phenomenon, are essential questions that require further exploration. Additionally, applying these future research findings to guide language teaching and rehabilitation will hold substantial social value.

With technological advancements, IC processing by LLMs has gained significant attention in recent years. These studies have profound implications for simulating human language acquisition, language teaching, natural language processing, and the ongoing development of AI systems. However, the challenge of training models that are both effective and robust remains an area for further exploration.

Additionally, a comparative analysis of the processes involved in human language acquisition—including both L1 and L2 acquisition, as well as machine language learning—may provide valuable insights into their similarities and differences. The diversity of languages, with their unique types and characteristics, presents both opportunities and challenges for these models. Moreover, when IC interacts with a variety of linguistic and non-linguistic factors, understanding whether and to what extent machine and human languages align in anaphora resolution, as well as identifying the factors that hinder the development of machine language models, are critical areas of investigation.

The study of IC in verbs not only helps to reveal the mechanisms of causal reasoning and discourse processing during language comprehension but also holds a wide range of potential applications in several practical areas. In language teaching, IC research offers an effective training path for second language learners to improve the accuracy and coherence of pronoun use. In language disorder assessment and child language development, IC processing ability can serve as a key indicator of individual pragmatic competence, providing a theoretical foundation for early diagnosis and intervention. In the field of natural language processing, IC information contributes to tasks such as anaphora resolution and event relation identification, thereby enhancing the discourse comprehension capacity of artificial intelligence systems.

Future research could extend cross-linguistic analyses of IC verbs in multilingual contexts, focusing on developmental processes such as language acquisition and use across different populations, as well as language generation in large language models (LLMs). A key direction is to examine whether the prediction of anaphoric antecedents in AI aligns with human performance when IC interacts with multiple linguistic and non-linguistic factors, and which are the primary factors that hinder AI language learning, offering valuable insights for both theoretical modeling and practical advancements in cross-cultural communication and intelligent language technologies.

Author Contributions

Conceptualization, X.T.; writing—original draft preparation, X.T.; writing—review and editing, X.T., L.F., and Y.Z.; project administration, Y.Z. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by the sub-theme “Research on Localization of International Chinese Education” of the

major program of National Social Science Foundation of China under "Research on the Innovation of Second Language Acquisition Theory in Comparison with International Chinese Education" (23&ZD320).

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not available.

Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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