SPEECH, GESTURE, AND APHASIA: TOWARDS A MULTIMODAL UNDERSTANDING OF LANGUAGE EVOLUTION

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Abstract: This study investigated the relationship between speech and gesture to further the language evolution field. Firstly, this study proposed two models: the Dual-Channel Model and the Synchronisation Model. The Dual-Channel Model suggested that if either the speech or gesture channel is impaired, the other will compensate. The Synchronisation Model suggested that if either channel is impaired, the other will also be impaired. This sheds light on whether speech and gesture linguistically evolved together or separately. To assess this, 10 case studies which focused on aphasia patients' gesture production were examined. Aphasia is a neurological disorder affecting language production and/or comprehension. 9 out of the 10 case studies concluded that gesture compensates for speech: thus, supporting the Dual-Channel Model. The results also assessed factors impacting the speech-gesture relationship, these included: the aphasia severity; the aphasia type; the task type; and apraxia (a comorbid deficiency). Overall, a multitude of conclusions emerged. Firstly, whilst the Dual-Channel Model was more accurate than the Synchronisation Model, further analysis showed that gestures are closely tied to function which highlighted the importance of the conceptualisation process. An unexpected outcome showed that iconic gestures dominated the gesture production. Finally, for language evolution, from evaluating the models, a pantomime-first theory driven by the message conceptualisation was supported. Future research should tackle the speech-gesture underlying relationship by examining a linguistically healthy participant group with one of the channels constrained.

Keywords: speech and gesture relationship, aphasia, neurolinguistics, language evolution, origins of language, pantomime origins, linguistic function, linguistic production, linguistic modelling, linguistic conceptualisation.

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Contents

1. Introduction

This study examined the relationship between speech and gesture by investigating its surface-level interaction in order to uncover it's underlying relationship. On the surface, humans use speech and gesture to varying degrees: from speech-only communication through to gesture-only communication. The underlying relationship, however, is yet to be understood. This study has two primary aims: firstly, to investigate the underlying relationship in which there were two hypotheses: a) if one system is impaired, the other can compensate; or, b) if one system is impaired, the other is also impaired. Secondly, by identifying the underlying relationship, this sheds light on linguistic evolution. If a) is accurate, then speech and gesture evolved separately. However, if b) is accurate, then speech and gesture evolved together. Thereby forwarding the dichotomous (gesture-first, speech-first) argument dominating the language evolution field.

Historically, gestures have possessed various definitions. In this study, *gestures* refer to actions when used as an utterance or part of an utterance, in other words; a co-speech gesture. Examples of gestures include referential points, shrugs, or mimes. *Speech* refers to the phonetic combinations of vowels and consonants which produce meaningful utterances. To empirically assess the speech-gesture relationship, two models have been proposed: the *Dual-Channel Model* and the *Synchronisation Model*. The Dual-Channel Model suggests a parallel speech-gesture relationship with interacting points of contact. The Synchronisation Model suggests that speech and gesture are two parts under a larger language system.

Previous research from de Ruiter (2000), McNeill (2005) and Kendon (2004) explore the speech-gesture relationship within aphasiology. Aphasia is a neurological impairment hindering speech comprehensibility and/or production. The strength of examining Patients with Aphasia (PwA) is that their speech channel is impaired; meaning that the gesture channel can be assessed to see if gesture compensates or degrades with speech. However, many aphasia studies have used one model to frame their findings: de Ruiter's (2000) *Sketch Model*. To broaden and evaluate this understanding of the underlying speech-gesture relationship, this study applies PwA's gesture production to the two new proposed models; the Dual-Channel Model and the Synchronisation Model. In doing so, this study will be the first to apply these conclusions to the linguistic evolution field.

The remainder of this study continues with the following structure. Firstly, the rest of Section 1 addresses the previous literature findings within the Speech-Gesture Debate (Section 1.1), Language Emergence (Section 1.2), and Aphasia (Section 1.3). Section 2 presents the methodology used in this investigation. Section 3 analyses the methods and results of 10 aphasia case studies centring on PwA's gesture production. Section 4 discusses and evaluates the Models and draws links to language emergence.

This study's core conclusions are: firstly, the Dual-Channel Model is accurate. But, secondly, upon further analysis, gestures are closely tied to function thereby highlighting the prominence of conceptualisation. Thirdly, PwA's gesture production is dominated by iconic gestures. Therefore, considering language evolution, this study shows support for a pantomime-first language emergence driven by the Conceptualiser, where iconicity dominates.

1.1 Gesture and Speech Debate

1.1.1 Surface-Level Speech-Gesture Relationship

There is a large volume of publications across many disciplines describing the surface-level interaction of speech and gesture. For the scope of this study, the key literature is from Kendon (1983, 2004) and McNeill (1992). In a comprehensive study of gestures, Kendon (1983) categorised gestures into four sub-types, creating *Kendon's Continuum Model* (see Figure 1). In a follow-up study, McNeill (2005) structured these based on their characteristics, which were: their relation to speech; their degree of conventionalisation; and their linguistic properties. Below (*a-d)* are the four ordered sub-types with summarised definitions (provided by McNeill, 2005) and added examples for clarity. Where *conventionalised gestures* are bound to culture, *idiosyncratic gestures* are specific to the individual.

a. *Sign Languages*: conventionalised language systems with full linguistic properties. Occurs as a replacement of speech. Example: British Sign Language.

b. *Pantomimes*: non-conventionalised imitations of motor actions holding some linguistic properties. Occurs in the absence of speech. Example: charades.

c. *Emblems*: gestures with a conventionalised relationship to the form and meaning. Occurs when accompanying speech. Example: thumbs up indicating 'good' or 'correct'.

d. *Gesticulations*: idiosyncratic gestures with a form-meaning mapping. Occurs when accompanying speech. Example: shaking fists when talking angrily.

In his extensive study, McNeill (1992) identified four characteristics of Kendon's (1983) *gesticulations*. Below *(e-f)* are these characteristics with their definitions (inspired from de Ruiter & de Beer, 2013) with added examples.

e. *Iconic*: idiosyncratic references to concrete entities with specific characteristics. Shape and manner is tightly linked, semantically and temporally, to speech. Example: squaring fingers to form a picture-frame.

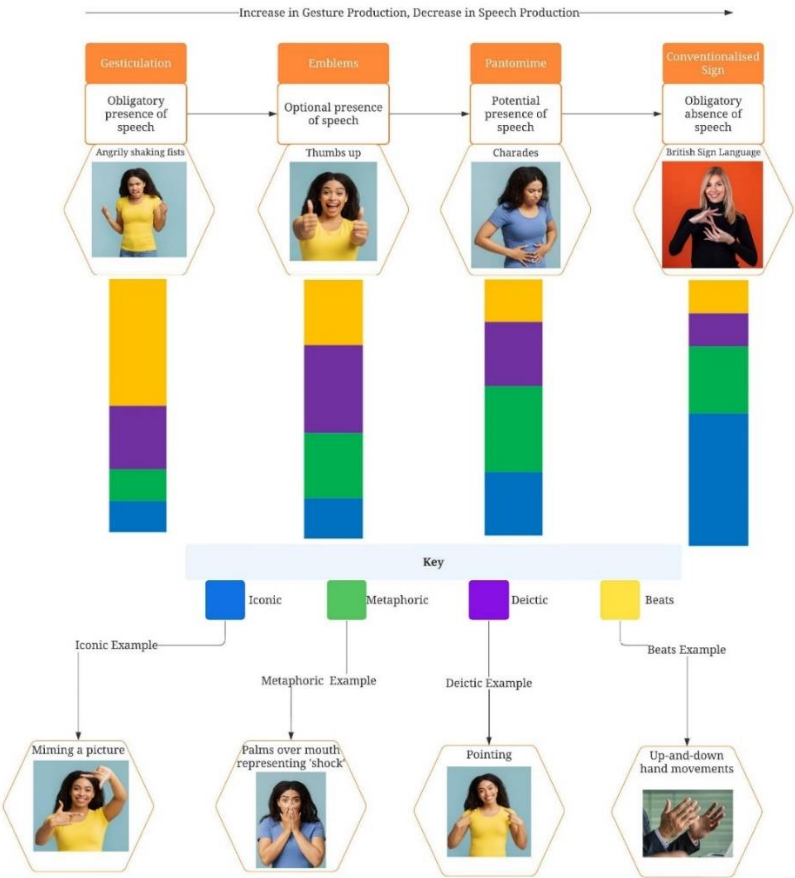
f. *Metaphoric:* idiosyncratic references to abstract entities. Example: hands covering one's mouth representing shock.

g. *Deictic*: referring to concrete or abstract entities. Often necessary for communicative discourse. Example: pointing at something on a map.

h. *Beats:* rhythmic movements not representing speech elements. Example: moving hands up-and-down whilst talking.

Together, these studies provide insight into how speech and gesture manifest. However, through exploring their conclusions, this study suggests several alterations. Figure 1 presents the breakdown of Kendon's Continuum with the alterations included. The top half of Figure 1 shows Kendon's (1983) gestural categories. The bottom half reflects McNeill's (1992) characteristics.

Figure 1- Kendon's Continuum (updated). Headings from Kendon (1983, 2004) and McNeill (1992). Pictures from iStock (photographers: Prostock Studio, 2021; ljubaphoto, 2021; vm, 2016)



The key limitation of *Kendon's Continuum* (1983) is the leap from *pantomime* gestures to fully complex *sign languages*. Not only is his use of *sign language* unsatisfactory and outdated, it has been refuted by studies proving that gestures occur within sign languages (Grosvald et al., 2012). In fact, Vigliocco et al., (2014) concluded that iconicity is 'the norm, rather than the exception in sign languages.' Thus, this paper updates this to *conventionalised sign* which, in turn, can be considered the building blocks for sign languages. Secondly, in analysing *pantomime*, Kendon (1983) concluded 'an obligatory absence of speech'. However, recent literature from Żywiczyński et al., (2021) and Zlatev et al., (2020) proved *pantomime* as multimodal, meaning that both speech and gesture are produced. Additionally, de Beer et al., (2017) concluded *pantomime* gestures can replace *and* accompany speech. Therefore, in Figure 1, *obligatory* has been replaced with *potential*.

McNeill's (1992) main limitation for his *gesticulation* characteristics is the lack of recognition that these characteristics could be applied to the other gestures on *Kendon's Continuum* (1983). Consequently, this study offers a quantifiable impression of how much these characteristics define the gesture types proposed by Kendon (1983). For example, *conventionalised signs* has the most iconicity, whereas *gesticulations* has the most *beat*-like characteristics.

Finally, these studies exposes a correlation between conventional and abstract gestures: the more conventional the speech, the more abstract the gesture, and vice versa. When speech is referring to concrete objects, there are more *beat* gestures, which are rhythmic abstract movements. However, when speech is more abstract, there are more *iconic* gestures. This subtly supports a compensatory relationship.

1.1.2 The Underlying Relationship

The previous section established the knowledge surrounding the surface-level relationship of speech and gesture. It is now necessary to explore the research on the underlying speech and gesture relationship. This topic's academic literature is filled with contrastive theories due to a lack of cross-interdisciplinary references and purely observational conclusions. Glosser and Wiener (1990) identified and evaluated four explanations for the speech and gesture underlying relationship. These are:

1. Speech and gesture are separate and unrelated communication channels. Representing several types of information, they serve different communicative functions. Speech is consciously intended, whereas gestures convey unintended emotional information.
2. Speech and gesture interact and transfer information within the same psychological structure. They are functionally related, stemming from a symbolic conceptual start point.
3. Speech and gesture rely on the same common motor systems for production and are located within the left cerebral hemisphere. They have an incidental, but not intrinsic, relationship.
4. Gestures are primarily manifestations of efforted or disrupted speech. They have a causal relationship and arise independently. Gestures occur specifically when speech is disrupted.

Glosser and Wiener (1990) ruled out (1) due to speech and gesture having highly synchronised, parallel, and interdependent content and pragmatics: albeit certain instances where they differ in meaning. Glosser and Wiener (1990) identified that (2) and (3) are opposite in the mechanisms that they rely on. For (2), whilst there is a shared conceptualisation (supported by

McNeill, 1992; Kendon, 2004; and de Ruiter, 2000), it does not account for motor control, especially in PwA. However, for (3), the opposite is true: whilst speech and gesture share the same motor control, the conceptualisation is not accounted for. Glosser and Wiener (1990) conclude (3) is unfeasible as the specific speech-gesture encoding within the left cerebral hemisphere is unknown. Glosser and Wiener (1990) refute (4) as gestures hold communicative information independent of speech. These conclusions support a model highlighting the importance of motor control and conceptualisation.

As previously highlighted, much of the current aphasia research pays attention to de Ruiter's *Sketch Model* (2000). De Ruiter's (2000) key conclusions are as follows: firstly, there are points of synchronisation between speech and gesture. Secondly, communication requires an intention stemming from a shared Conceptualiser. Finally, speech and gesture are mutually adaptive, meaning if one communicative channel is impaired, the other channel will compensate. Outside of aphasiology, other disciplines have reached similar conclusions. For example, psychologists Goldin-Meadow & Alibali (2013) concluded gestures reflect conceptualised thoughts, functioning as 'a window into the cognition process'. Similarly, Hostetter & Alibali (2008) argued gestures underlie embodied language, mental imagery and cognition. Other disciplines suggest that gestures and speech are synchronous in their underlying relationship. This includes cognitive scientists Pouw et al., (2021) who discovered a 'tight coupling' of gesture movement and prosodic aspects governed by sophisticated neural-cognitive mechanisms.

The linguistic field places conceptualisation and iconicity in the forefront for understanding the underlying relationship. For instance, Vigliocco et al., (2014) claimed that whilst language is entrenched in arbitrary symbols, the speech-gesture relationship is seen through multimodality where iconicity reflects these symbols on a continuum. Similarly, Burlak (2018) suggests that a need for a constant increase in symbols gave rise to speech and gesture: therefore, a signal-interpretation, multimodal approach is detrimental to understand the speech-gesture underlying relationship. Finally, Kendon (2017) argued language models must ensure multimodality with neither system overriding the other. Overall, these approaches support a multimodal approach where conceptualisation takes a primary focus. Considering linguistic evolution, Żywiczyński et al., (2021) offered this idea through a pantomime-first language emergence, as like Vigliocco et al., (2014), it places iconicity and communicative intention first.

Considering all this evidence, it appears that depending on the discipline, the interpretation of the speech-gesture underlying relationship differs. It is therefore critical that these observations become empirically tested through cross-discipline studies applying specific models. Correspondingly, the next section introduces the Dual-Channel Model and the Synchronisation Model.

1.1.3 Models: Dual-Channel Model and Synchronisation Model

This section offers two models encompassing the main findings discussed so far. Both of the models consist of three fundamental sections: the *Conceptualiser,* the *System Encoder,* and the *Message Production* with signals passing information through each stage. The Dual-Channel Model suggests speech and gesture are two separate parallel systems with points of contact: the *Conceptualiser* and the *Message Production*. If one of the channels is impaired, the other can compensate as it is fully functional. From the literature discussed, the Dual-Channel Model draws upon de Ruiter's (2000) *Sketch Model* closely, whilst emphasising the importance of the *Conceptualisor* and *Motor Control* from the discussion by Glosser and Wiener (1990). The Synchronisation Model, however, suggests speech and gesture work within one larger Language System with continual contact points throughout: if one of the channels is impaired, the other is impaired too. The Synchronisation Model draws inspiration from the shared transfer of information (Glosser and Wiener, 1990) and both Pouw et al.,'s (2021) and Kendon's (2017) notion of speech and gesture acting as equal systems.

Figure 2 - The Dual-Channel Model

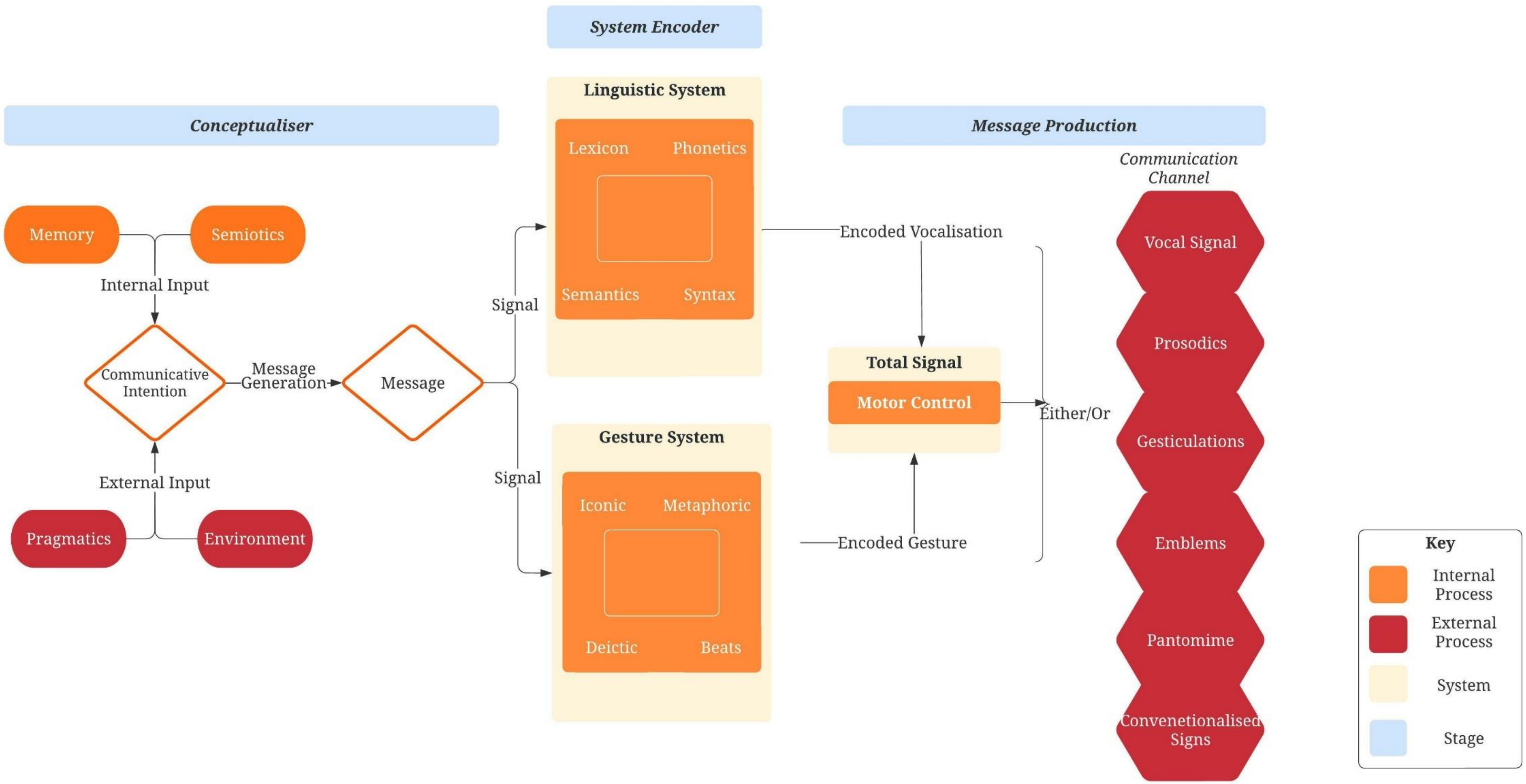
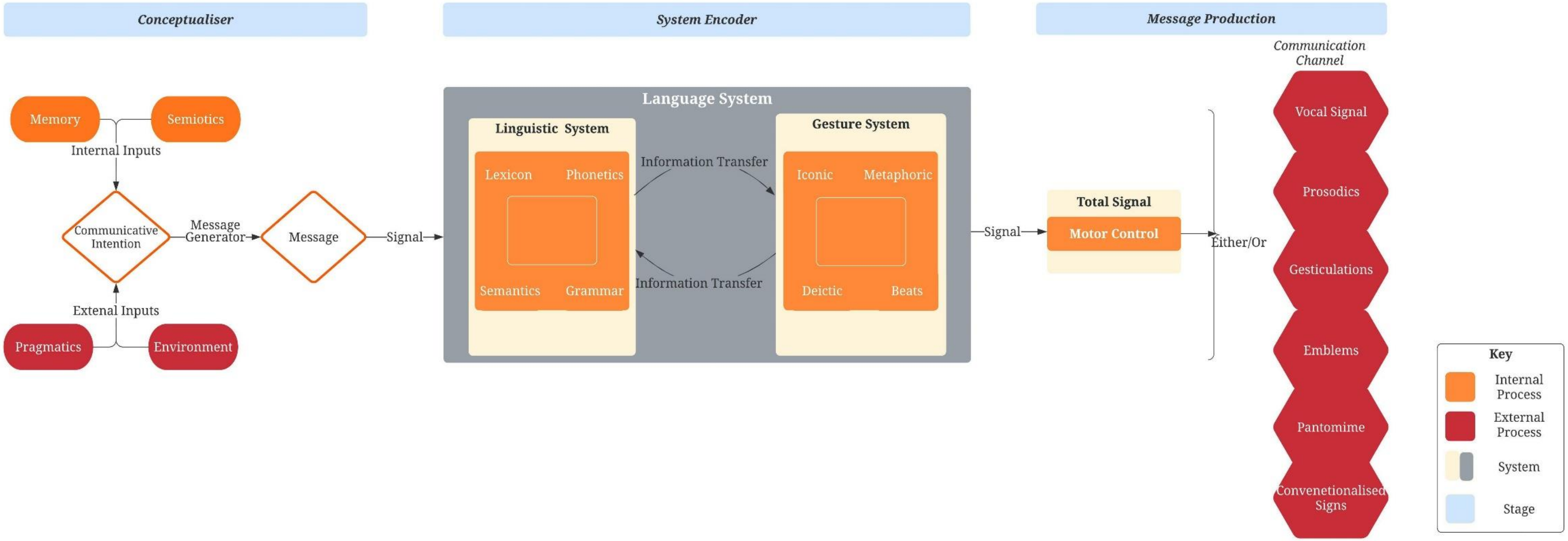


Figure 3 - The Synchronisation Model



Having discussed the two models' structure, the remainder of this section describes how the Dual-Channel Model and Synchronisation Model operate. In both models, the Conceptualiser and Message Production operate the same whereas the System Encoder differs. Within the Conceptualiser, both models start with a *Communicative Intention* built from two *Internal* and *External Inputs*. The two Internal Inputs are *Memory* and *Semiotics*. *Memory* encompasses working, spatial, personal, and propositional memory; and, discourse, and situational knowledge (de Ruiter, 2000). *Semiotics* is the need for interpreting symbols and signals (Burlak, 2018) and encodes whether the message is an abstract or material reference. The External Inputs are *Pragmatics* and *Environment*. Where *Pragmatics* encodes the social context, *Environment* encodes the speaker's physical surroundings. From there, the *Communicative Intention* forms a signal generating a *Message*. This *Message* transfers all the needed information to the *System Encoder*. This is where the two models diverge in how they operate.

In the Dual-Channel Model, individual signals are sent to two systems in parallel with one another: *the Linguistic System* and *the Gesture System.* Within the *Linguistic System*, there is: *lexical* (word), *semantic* (meaning), *phonemic* (sound), and *syntactic* (word-order) retrieval. In this study, where semiotics refers to higher cognitive symbolic referencing, *semantics* refers to specific lexical definitions within the individual's repertoire. Within the *Gesture System*, there is *iconic*, *metaphorical*, *deictic*, and *emblematic* retrieval, reflecting McNeill (1992) characteristics. The Model proposes that if a sub-part is missing or unacknowledged, there would be disrupted communication. From there, in the Dual-Channel Model, the *Linguistic System* and the *Gesture System* signals are sent to the *Total Signal*. This is where the final message is formulated. *Motor Control* refers to the programming of the articulators, vocal organs, facial expressions, hands, and body movements. This signal is transferred to the external *Communication Channel*, which is an extended version of *Kendon's Continuum* (1983) as it also includes *Prosodics* and *Vocal Signals*. For the Dual-Channel Model to be accurate, the following must hold: if one channel is impaired, the other channel can compensate.

In the Synchronisation Model, as aforementioned, the *Conceptualiser* and *Message Production* operates the same as the Dual-Channel Model. What differs is that *one* signal route is sent from the *Conceptualiser* to the *System Encoder*. The System Encoder is one larger *Language System* holding the *Linguistic System* and *Gesture System*. The two systems share the same sub-categories as the Dual-Channel Model, as in: the Linguistic System has lexical, semantic, phonemic, and syntactic retrieval; and the Gesture System has iconic, metaphoric, emblematic and beats retrieval. This model encourages a complementary relationship between the two systems. After the final signal is encoded in the *Language System,* it is sent to the *Total Signal:* which uses the *Motor Control* to encode the external physical message. This, like the Dual-Channel Model, sends the signal to the *Communication Continuum*. For the Synchronisation Model to be accurate, the following must hold: if one of the systems is impaired, the other system is too.

In summary, these two models embody the current knowledge of the underlying speech-gesture relationship. There are contact points found in both models: the *Conceptualiser* and the *Message Production*. Where the Dual-Channel Model suggests a parallel relationship, the Synchronisation Model suggests two systems found within a larger system.

1.2 Language Evolution

The language evolution field has a complicated history. To summarise, in 1866 the Linguistic Society of Paris banned any form of research into language evolution as it was considered to be lacking any scientific proof (Corballis, 2003). Consequently, this prohibition influenced the Western World until the late 20th century. Due to modern methods, the language evolution field has been revitalised by linguists, anthropologists, psychologists and archaeologists. This history is important because it caused wide-ranging, contrastive conclusions on how language emerged. The current field can be broadly simplified into two key approaches: gesture-first versus speech-first. However, recent studies have supported a middle-ground approach between the two theories. This section explores the two key theories and draws links relating to the Dual-Channel and Synchronisation Models.

Most gesture-first research has been carried out through deductive, comparative examination between humans and our genetically-related bonobos (*pan pansicus)* and chimpanzees (*pan troglodytes*). According to de Waal and Pollick (2011), gesture is found in all 3 species: whereby *gesture* is communication by means of hands, feet or limbs, encoded in the left cerebral hemisphere. This indicates that the shared last common ancestor (LCA) between humans, chimpanzees and bonobos had the capability to gesture, allowing researchers to hypothesise the date of language emergence. Whilst this investigates similarities between the genetically equidistant species, investigating the species' differences also presents explanations as to how and why human communication greatly diverges from chimpanzees and bonobos. Apes, such as Kanzi (Savage-Rumbaugh et al., 1993), have been taught sign language: however, their inability to produce innovative, novel utterances shows a neurological divergence compared to humans. In understanding the evolutionary linguistic path, Sykes (2020) argued that the LCA would have produced gesture but not vocalisation because, anatomically, the hominin body could allow gestural movements before the ability to create vocalisation. They concluded that since gestures are under greater cortical control than vocalisation, this points towards a gesture-first language emergence. Furthermore, Sykes (2020) explained how, even in the present day, infant humans produce gesture before vocalisation. Similarly, Corballis (1999) concluded that whilst blind humans are never taught gesture, they still produce gestures. This innate ability to use gestures suggests a gesture-first theory.

Alternatively, whilst speech-first scholars also employed observational methods, they concluded that speech must appear first in the linguistic evolutionary path. Although Sykes (2020) supported a gesture-first evolution, they recognised that the dominance of speech within modern human communication is a strong indicator for speech-first evolution. Similarly, de Waal and Pollick (2011) concluded that whilst gestures are found in humans, chimpanzees and bonobos, there is a vocalisation bias in all three species: in chimpanzees, they concluded that the vocalisation bias was 22%. Alongside this, studies by MacLarnon and Hewitt (1999) highlighted the anatomical changes found in archaeological records of Neanderthals, suggesting physical adaptations for speech. These adaptations include: an expanded thoracic vertebral canal for breath control in order to create specific phonemes, intonation and pitch. Secondly, in Humans and Neanderthals, the intercostal muscles and abdominal muscles are thoracically innervated, allowing for quick inhalations in order to produce long, vocal phrases and quiet breathing. MacLarnon and Hewitt (1999) used this as evidence supporting a speech-first appraoch since physical adaptations for gesture production can be easily refuted. However, Tallerman (2011) referred to vocal tract adaptation as 'indirect evidence' since language could have evolved before speech.

All these studies reveal the uncertainty of the underlying speech-gesture relationship. The Dual-Channel Model advocates gesture-first or speech-first whereas the Synchronisation Model supports a joint theory approach. After laying out the two opposing approaches, this paper hopes to further this discussion by uncovering the speech-gesture underlying relationship. The key limiting question, however, asks how and why the other system exists, if speech and gesture evolved separately? This debate makes progressing the field difficult. Nevertheless, studies have found that speech and gesture are not mutually exclusive. De Waal and Pollick (2011) affirmed that if a linguist argues for one hypothesis, it is impossible for them to 'rule out a scenario where speech and gesture co-occurred.' This is underpinned by the growing body of research supporting a multimodal, polysemiotic account. Neurologically, current research shows that no sole cerebral area is used for language, let alone for just-speech or just-gesture. For example, the Broca area consists of Brodmanns areas 44 and 45; where 44 is involved with speech *and* motor functions, including hand-movements and sensorimotor learning and integration (Corballis, 1999). From this, researchers, such as Żywiczyński et al., (2021) and Zlatev et al., (2020) have argued for a multimodal speech-gesture approach through pantomime, which is an empirical fossil of ancestral language.

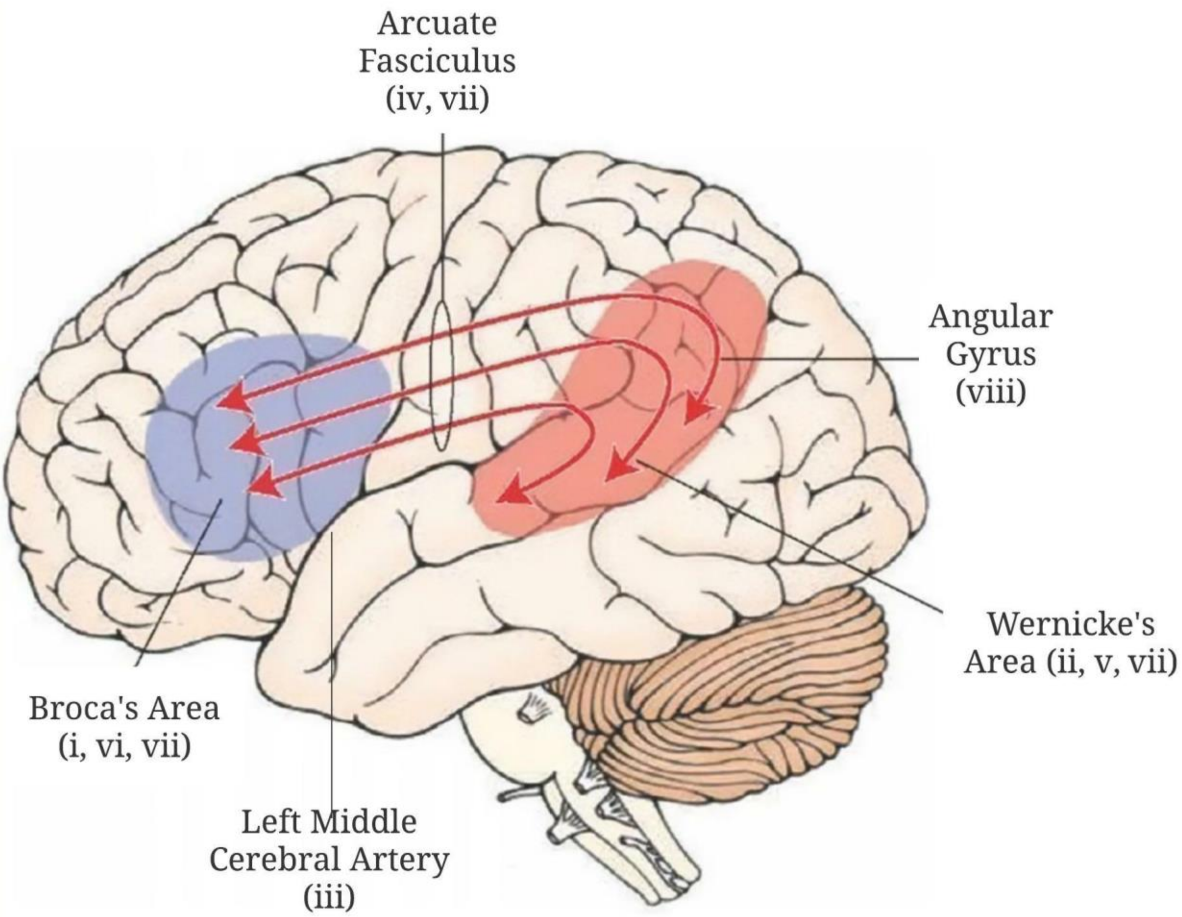
All these studies reveal the uncertainty of the underlying relationship. The Dual-Channel Model advocates gesture-first or speech-first theories because a compensatory approach indicates that the systems would have evolved separately. The Synchronisation Model displays a complementary approach whereby they must have evolved together. From this reading, one exception remains, there may be a conceptualisation-first argument: this would support both Models proposed. The Model's accuracy would then be derived by whether speech and gesture deteriorate or compensate for one another. Overall, this study promotes further interdisciplinary evaluation that will provide new insights and direction for studying language emergence, especially through a neurological lens.

1.3 Aphasia

Finally this closing introductory section explores the current research on aphasia. Aphasia is a neurological disorder affecting language production and/or comprehension (National Aphasia Association, 2022). It can be caused by numerous injuries and neurodegenerative diseases including: cerebrovascular accident, traumatic brain injury, brain mass, Alzheimer's Disease or dementia. Previously, it was highlighted that there was an inability to understand how language is neurologically processed in relation to its location. This paper uses aphasiology to try and understand this better. This is because, whether spoken or signed, the location of brain damage seems to create specific linguistic effects, for example: 'the left perisylvian regions are critical for language function' (Campbell, et al., 2008).

The two key neurological factors impacting Patients with Aphasia (PwA's) gesture production are: the aphasia severity and the aphasia type. In this paper, these factors are noted in Appendix 2 alongside the patient's demographic characteristics, including: causation, onset, education, age, hemiplegia, and apraxia. Below is a list of 8 aphasia types and their linguistic effects (as defined by Le and Lui, 2021). Figure 4 shows the areas of the brain affected by aphasia, matched with the aphasia types *(i-viii)*. According to Le and Lui (2021), *paraphasia* is an aphasia characteristic where words are substituted for phonetically similar words (*phonemic paraphasia*) or for semantically similar words (*semantic paraphasia*).

Figure 4 - The brain with labels used to highlight aphasia/language localisation. (Base brain picture provided by What-When-How: Figure 26-18 Relationship of Wernicke's and Broca's area: updated as the labels added according to the aphasia's listed below; i-viii)



i. *Broca Aphasia, 'expressive aphasia' (BA):* Non-fluent, intact comprehension and unable to repeat. Content words produced to convey message. Lesions located in Broca area.

ii. *Wernicke Aphasia, 'receptive aphasia' (WA):* Fluent, impaired comprehension, unable to repeat. Speech is meaningless with phonemic and semantic paraphasia. Lesions located in Wernicke area.

iii. *Global Aphasia (GA):* Non-fluent, impaired comprehension and unable to repeat. Production of a few recognizable words with little understanding. Lesions vary in size and location; they often follow the Left Middle Cerebral Artery. This is the most severe form of aphasia.

iv. *Conduction Aphasia (CA):* Fluent, intact comprehension, unable to repeat. They recognise and attempt to correct paraphasia errors. Located in Arcuate Fasciculus.

v. *Transcortical Sensory Aphasia (TSA):* Fluent, impaired comprehension, able to repeat. Semantic paraphasia. Lesion located around Wernicke, isolating it.

vi. *Transcortical Memory Aphasia (TMA):* Non-fluent, intact comprehension, able to repeat long, complex sentences. Lesions surrounding Broca area, isolating it.

vii. *Mixed Transcortical Aphasia (MTA):* Non-fluent, impaired comprehension, able to repeat long, complex sentences. Lesions located around Wernicke, Broca, and Arcuate Fasciculus areas, isolating them. Despite severe comprehension and production, they are able to repeat long complex phases.

viii. *Anomic Aphasia (A.A):* fluent, intact comprehension, able to repeat. But, difficulties with word retrieval. Located in the Angular Gyrus. This is the mildest form of aphasia.

By investigating PwA's speech and gesture production, it is possible to gain insight into the underpinnings of speech and gesture processing (Presig et al., 2018; Le & Lui. 2021). Where other studies, such as Presig et al., (2018), focus on co-speech therapy, this study aims to focus on the underlying speech-gesture relationship using aphasia as a lens. However, three issues within aphasiology need to be addressed. Firstly, there are varying definitions for aphasia resulting in different approaches when examining how communication manifests. Caramazza et al., (1981) described aphasia as 'a semantic-linguistic impairment' underlying the comprehension and speech production. Others, such as Glosser and Wiener (1990), view it as 'a lexical access disorder'. This study refers to aphasia as a neurological impairment impacting language comprehension and/or production, with specific aphasia types being described according to Le and Lui (*i-viii*, 2021). Secondly, the aphasia severity will be investigated as it may demonstrate the degree of compensation and how it impacts gesture production. Thirdly, like severity, the type of aphasia will be investigated as it could affect gesture production, which may present more complex location-related findings.

Overall, this study examines whether the case studies refer to specific aphasia types, gesture types and aphasia severity. This will help shed light on the underlying speech-gesture relationship yielding conclusions on exactly how PwA's gesture compensate for the speech channel: or, equally how gesture degrades with speech.

2. Methodology

The next section describes this investigation's procedures which aimed to assess the accuracy of the Synchronisation Model and Dual-Channel Model in order to subsequently provide insight into the underlying speech-gesture relationship. Due to varying methodologies, both aphasia and language evolution researchers comprehended speech and gesture in contrastive ways. To this study's knowledge, no previous research had tried to uncover an understanding of speech and gesture evolution through studying aphasia case studies. To achieve this, this study proposed that the best methodology was to apply hypothesised speech-gesture models to PwA, who have an impaired speech channel. These models were the Synchronisation Model and the Dual-Channel Model, created in LucidChart (2022). If PwA's gesture deteriorated with the impaired speech channel, it supported the Synchronisation Model. If, however, gesture compensated for speech, then it supported the Dual-Channel Model. Furthermore, 3 factors affecting PwA's gesture production were investigated: severity of aphasia, type of aphasia, and type of gesture. This knowledge and process created a firm foundation which was then applied to the current field of language evolution: thereby, constructively tying empirical results to observation.

One danger that this study was vulnerable to was using an insufficient number of case studies to establish a pattern. To overcome this, 10 case studies were carefully selected to cross-reference gesture production in PwA. The case studies consisted of 511 participants, 249 of whom were PwA therefore providing a solid platform to assess the proposed models. The case studies were chosen from an academic search engine device, ConnectedPapers.com (2021), with the key words: *aphasia, speech, gesture* and *function*. Articles were selected from the following specific criteria: firstly, therapeutic strategies studies were not selected because it focused on potential gesture production rather than PwA's natural gesture production. Secondly, this study prioritised case studies investigating a range of aphasia types, aphasia severity, and gesture types. Thirdly, all papers were produced within the last 10 years reflecting recent medical knowledge. Inadvertently, most case studies referred to both de Ruiter's *Sketch Model* (2000) and *Kendon's Continuum* (Kendon, 1983; McNeill, 2005). As a result of this specific criteria, the final case studies were derived from a set of researchers who often participated in more than one case study.

After obtaining the case studies, the data was extracted and ordered into two extensive tables that held key methodological and participant information (Appendices), created using Microsoft Excel (2018). Appendix 1 is a mass overview of each individual case study's purpose, methodology and conclusions. The written description has been worded for this paper's purpose; specific quotations can be found in the original case studies. Appendix 2 provides an overview of the participants involved in each case study, this covers: total participant number, severity of aphasia, type of gestures, and demographic information. The demographic information included: age, years in education, apraxia, hemiplegia, and onset time. Not all papers provided all of this information and have thus been marked N/A where appropriate. Following the Appendices creation, this study created Tables 1-8 reflecting the key information for the Result sections. It was necessary that the Appendices were created, reviewed, and evaluated throughout this study's process.

The results explored the case studies methods focusing on the distribution of participants; gestures investigated; and aphasia investigated. From there, the next part of the Results section examined the case studies' results. Firstly, an overall conclusion highlighted which Model was supported. Next, the factors impacting gesture production were investigated, these included aphasia severity; aphasia type; task type; and effects of apraxia. Once the results were examined, the Models' accuracy and complexities were discussed. This granted conclusions to be made surrounding language evolution.

3. Results

The first set of hypotheses aimed to assess whether speech and gesture compensated or deteriorated together: therefore, 10 aphasia case studies were reviewed to further understand the underlying speech-gesture relationship. This section has 2 sub-parts; the first sub-part examined the case studies' methodology; the second focused on the case studies' results. More information surrounding the individual case studies are found in Appendices.

3.1 Case Study Methodology

3.1.1 Participants

To understand the case studies' methods, Table 1 provides information on the Patients,' Controls,' and Judges' distribution. As presented, not every case study used Controls or Judges, exemplifying the wide-ranging methods used to assess PwA gesture production. Whilst PwA were Patients with Aphasia, Controls were their healthy-speaker counterparts: often age and educationally matched. Judges were external people, often undergraduate students, assessing the communicative effectiveness or comprehension of PwA and Controls.

Table 1 – Ordered from largest sample size to smallest.

Case Studies	**Aphasia Patients**	**Controls**	**Judges**	**Total**
Kong et al., (2015)	48	131		179
Sekine & Rose (2013)	98	64		162
Rose et al., (2017)	11		67	78
De Beer et al., (2017)	10		60	70
De Beer et al., (2020)	26	46		52
Mol et al., (2012)	25	17		44
Nispen et al., (2013)	1	11	15	27
Özer et al., (2019)	6	20		26
Akhavan et al., (2018)	8	11		19
Hogrefe et al., (2013)	16			16
Total	249	300	142	511

From Table 1, Kong et al., (2015) had the highest number of participants with 179, closely followed by Sekine and Rose (2013) who had 162. Whereas Hogrefe et al., (2013) had the fewest number of participants with 16, closely followed by Akhavan et al., (2018) with 19. All studies, except Hogrefe et al., (2013), used a Control and/or Judge group creating an opportunity to assess PwA gestural communicative effectiveness. More case studies used Controls rather than Judges. Where 3 case studies incorporated Judges (de Beer et al., 2017; Nispen et al, 2013; Rose et al., 2017), only 3 case studies did not include Controls (de Beer et al., 2017; Hogrefe et al., 2013; Rose et al., 2017). Sekine and Rose (2013) investigated the most PwA whilst Nispen et al., (2013) investigated 1 PwA. Where Kong et al., (2015) used the most Controls, Rose et al., (2017) had the greatest number of Judges, followed closely by de Beer et al., (2017). An interesting find from Kong et al., (2015), who supported the Dual-Channel Model, was that PwA's gesture enriched the verbal communication double the amount compared to the Control group.

A small number of case studies investigated PwA with certain conditions. For example, Akhavan et al., (2018) investigated PwA who had auditory comprehension problems; Sekine and Rose (2013) investigated stroke-induced PwA. And Özer et al., (2019) investigated left-hemisphere focal, brain-injured individuals with significant spatial referencing impairment.

3.1.2 Aphasia Investigated

Le & Lui (2021) and Sekine & Rose (2013) concluded that gesture production was impacted by aphasia type. Table 2 portrays the investigated aphasia types from each case study. This section explored methodological patterns among assessing different aphasia types. The main findings were that, firstly: Transcortical Aphasia cases are understudied; secondly, there is a partnership between the most studied aphasia types, Broca and Wernicke.

Table 2 - Ordered from the most tested aphasia types to the least

Case Studies	Broca	Wernicke	Global	Conduction	Anomic	Trans. Sensory	Trans. Motor	Mixed Trans.	N/A / Unclassified
De Beer et al., (2020)									
Hogrefe et al., (2013)									
Mol et al., (2012)									
Sekine & Rose (2013)									
Rose et al., (2017)									
De Beer et al., (2017)									
Özer, et al., (2019)									
Akhavan et al., (2018)									
Kong et al., (2015)									
Nispen et al., (2013)									

From Table 2, the aphasia types most studied were Broca and Wernicke Aphasia. Mixed Transcortical Aphasia, however, appeared under-investigated, followed closely by the other Transcortical Aphasia types. Furthermore, whilst 9 case studies assessed multiple aphasia types, Nispen et al., (2013), who examined one PwA, could only investigate one type of aphasia. Strikingly, the top 3 case studies from Table 2, all assessed the same aphasia types: all, but the Transcortical Aphasia types. Interestingly, Broca and Wernicke Aphasia appeared to have a partnership. Where it was common to investigate both together, in instances where Broca Aphasia was not assessed, Wernicke Aphasia was: and vice versa. However, these findings demonstrated trends in aphasia research, rather than providing insight into the underlying relationship.

3.1.3 Gestures Investigated

Using the updated *Kendon's Continuum* (Figure 1; Kendon, 1983, 2004; McNeill, 1992), this section investigated the type of gestures investigated. Table 3 presents Kendon's categorisation of gestures whilst Table 4 displays McNeill's characteristics. The important findings from these tables were: the pantomime-iconic relationship; the case studies' use of *Kendon's Continuum* (Figure 1, Kendon 1983, 2004; McNeill, 1992); and the subsequent difficulty in defining 'gesture.'

Table 3 – Ordered from the most gestures investigated to least

Case Studies	**Gesticulations**	**Emblems**	**Pantomime**	**Conventional Signs**
De Beer et al., (2017)				
Nispen et al., (2013)				
Hogrefe et al., (2013)				
Özer et al., (2019)				
Rose et al., (2017)				
Kong et al., (2015)				
Sekine & Rose (2013)				
Akhavan et al., (2018)				
De Beer et al., (2020)				
Mol et al., (2012)				

Table 4 – Ordered from the most gestures investigated to least

Case Studies	Iconic	Metaphoric	Deictic	Beats
Kong et al., (2015)				
Sekine & Rose (2013)				
Akhavan et al., (2018)				
Özer, et al., (2019)				
De Beer et al., (2020)				
Mol et al., (2012)				
Rose et al., (2017)				
Hogrefe et al., (2013)				
De Beer et al., (2017)				
Nispen et al., (2013)				

Table 3 and 4 showed that whilst some case studies investigated a wide-range of gestures (Kong et al., 2015; Sekine and Rose 2013), others only investigated one (de Beer et al., 2020; Hogrefe et al., 2013; Mol et al., 2012). What stood out was the striking partnership between pantomime and iconic gestures. Iconic gestures were investigated and produced the most: but, when iconic gestures were not investigated, pantomimes were. The same appeared true for pantomime: however, iconic gestures appeared dominant. Rose et al., (2017) and Özer et al., (2019) investigated pantomime *and* iconic gestures indicating that the partnership was not mutually exclusive. In terms of the underlying relationship, iconic gesture were one of the main tools for gesture production supporting the proposed impression that iconicity is the dominant characteristic of pantomime, as suggested in the updated *Kendon's Continuum* (Figure 1, Kendon, 1983, 2004; McNeill, 1992).

The case studies used *Kendon's Continuum* (Kendon 1983, 2004; McNeill, 1992) in several ways. Firstly, *sign languages* were not investigated (Table 3) indicating that the modification from *sign languages* to *conventionalised sign* was reasonable. McNeill's (1992) specific *gesticulation* characteristics were investigated by every case study, except for Nispen et al., (2013) who investigated *gesticulations* independently. In a similar vein, Akhavan et al., (2018) did not examine any of Kendon's (2004) gesture categories but did study McNeill's (1992) characteristics. This also applies to Mol et al., (2012) and de Beer et al., (2020) who only investigated iconic gesture. Overall, there are more studies investigating McNeill's (1992) characteristics (Table 4) than Kendon's (2004) categories (Table 3). This shows that Kendon's and McNeill's Continuum (1983, 1992, 2004) were used as a reference point rather than a rigid framework.

Interestingly, some studies investigated different gestures by swapping, replacing, extending, or collapsing the gesture labels from Table 3 and 4, demonstrating the versatility in defining gestures. Since the case studies that adapted *Kendon's Continuum* (1983) did not use the gesture with its original intended purpose, it has not been recognised in the Tables. For Sekine and Rose (2013), *pantomime* gestures were broken down into *time* gestures and *pointing-to-self* gestures. De Beer et al., (2017) collapsed *gesticulations* into *referential gestures* (a merge of *iconic* and *deictic* gestures) to eliminate semantic content such as *beat* gestures. Whilst they collapsed gestural characteristics, others extended the gesture labels. Kong et al., (2015) extended *deictic* gestures into *abstract deictic gestures* and *concrete deictic gestures*: and, secondly, they included *interactive,* and *pragmatic* gestures. Furthermore, *iconicity* was broken down into *iconic character viewpoint* (iconic CVPT, Rose et al., 2017) and compared to an *observer CVPT (*Sekine and Rose, 2013). *Iconicity* was also broken down by Özer et al., (2019) into *dynamic iconic gestures* and *static iconic gestures.*

3.1.4 Tasks and Constraints

The tasks and constraints similarly demonstrated the diverse methods used across the case studies: visually, Table 5 presents a more varied pattern compared to previous tables. Table 5 highlighted the tasks used in each case study and which groups performed them. Table 6, however, demonstrated the constraints imposed on each task, if applicable.

Table 5 – Ordered from the most tasks used per case study to least.

Case Studies	Forced Choice	Free Description / Spontaneous	Multiple Choice	Narration	Naming	Scenario Test
De Beer et al., (2017)		Judges	Judges	PwA		
De Beer et al., (2020)		PwA, Control		PwA, Control		PwA
Nispen et al., (2013)	Judges			PwA, Controls	PwA, Controls	
Hogrefe et al., (2013)	Judges			PwA		
Kong et al., (2015)				Control, PwA		
Mol et al., (2012)	Judges					PwA
Rose et al., (2017)		PwA, Judges	Judges			
Özer et al., (2019)		PwA, Controls				
Akhavan et al., (2018)		PwA, Controls				
Sekine & Rose (2013)				PwA		

From Table 5, narration tasks were the most common for PwA. For Controls, both *narration* and *free description* were used the most. When a case study used a Control group, they did the same test as PwA. For Judges: however, the most common method was a *forced-choice* task. Some case studies required multiple tasks to be performed by one group (de Beer et al., 2017; de Beer et al., 2020; Nispen et al., 2013). Interestingly for Rose et al., (2017), PwA and Judges did the same task-type with different objectives: while PwA did a free description *explaining* a story, the Judges performed a free description task *evaluating* comprehension. For a more specific breakdown of the methods, see the Appendices. Opposingly, 3 case studies only used one task (Özer et al., 2019; Akhavan et al., 2018; Sekine and Rose, 2013). As shown in Table 6, many case studies enriched their methods by adding constraints.

Table 6- SO = Speech Only, GO = Gesture Only, SG = Speech-Gesture condition. Ordered by number of constraints used: most to least.

Case Studies'	Task-Constraints
Özer et al., (2019)	SO, GO, SG
De Beer et al., (2017)	SO, SG
Rose et al., (2017)	*PwA-only*: SO, GO SG
Sekine & Rose (2013)	Chi-square, Fisher, and Logical Regression applications
Hogrefe et al., (2013)	SO, GO
Nispen et al., (2013)	SO(+gesticulation), SG
Mol et al., (2012)	*Control-only:* SO, or SG
Akhavan et al., (2018)	N/A
De Beer et al., (2020)	N/A
Kong et al., (2015)	N/A

Table 6 presents the dominance of Speech Only (SO), Gesture Only (GO), and Speech-Gesture (SG) constraints. Case studies using all three constraints was a strength for this study because it directly tested the speech-gesture relationship. However, only Özer et al., (2019) used all three constraints. Two case studies used constraints for one specific group: *PwA-only* for Rose et al., (2017) and *Control-only* for Mol et al., (2012). Interestingly, neither Akhavan et al., (2018) and de Beer et al., (2020) set any constraints onto the tasks but *both* used free description as their primary task-type suggesting their emphasis on natural discourse. Even though Sekine and Rose (2013) did not use constraints within the task, they constrained the task analysis by applying gesture production framework analyses (e.g., chi-square) onto the narration given by PwA. Overall, looking at these tasks and constraints, if gestures were to compensate for speech in the result's section, then it points towards environment and pragmatics being encoded prior to speech-gesture production.

3.2 Case Studies Results

After establishing the case studies methods, the remainder of this section examines which case studies' results supported the Dual-Channel Model or Synchronisation Model, as summarised in Table 7. Secondly, this section explains how task, apraxia, aphasia severity, and type of aphasia affected gesture production, as presented in Table 8.

3.2.1 The Dual-Channel Model and The Synchronisation Model

The core aim for this study was to establish whether gesture compensated or deteriorated with speech when one channel was impaired, as formulated in the Synchronisation Model and the Dual-Channel Model. In directly answering this question, Table 7 established that the Dual-Channel Model was more accurate meaning that when one channel was impaired, the other compensated. As aphasia impacts the speech channel, this meant gesture compensated.

Table 7 - Ordered Alphabetically

<table>
<tr><th>Case Study</th><th>Dual-Channel</th><th>Synchronisation</th></tr>
<tr><td>Akhavan et al., (2018)</td><td style="background-color:#70AD47"></td><td></td></tr>
<tr><td>De Beer et al., (2017)</td><td style="background-color:#70AD47"></td><td></td></tr>
<tr><td>De Beer et al., (2020)</td><td style="background-color:#70AD47"></td><td></td></tr>
<tr><td>Hogrefe et al., (2013)</td><td style="background-color:#70AD47"></td><td></td></tr>
<tr><td>Kong et al., (2015)</td><td style="background-color:#70AD47"></td><td></td></tr>
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<tr><td>Sekine & Rose (2013)</td><td style="background-color:#70AD47"></td><td></td></tr>
<tr><td>Mol et al., (2012)</td><td></td><td style="background-color:#70AD47"></td></tr>
</table>

Table 7 highlighted that every case study, apart from Mol et al., (2012), supported the Dual-Channel Model. Interestingly, all case studies, including Mol et al., (2012), concluded that speech and gesture were two partly separate systems with contact points. For Mol et al., (2012), however, these contact points were throughout since speech and gesture ‘degraded’ together. This directly supported the Synchronisation Model which maintains that the Linguistic System and the Gesture System are two systems within a larger Language System: so, when one channel is impaired, the other is too. However, every other case study concluded that gesture could ‘repair,’ ‘compensate,’ or ‘retrieve’ information from the impaired speech channel. In fact, Kong et al., (2015) refuted Mol et al.,’s (2012) conclusions on the grounds that they had reached their conclusion by neglecting to disentangle the effects of apraxia, semantic impairments and aphasia severity. These factors are explored in greater detail in the next section. Overall, Table 7 supported the Dual-Channel model, in that the case studies demonstrated gesture compensating for impaired speech.

3.2.2 The Factors Impacting Gesture Production

This section examined the case studies’ findings on whether aphasia-related factors impacted gesture production. This is important as it evaluated how accurate the Dual-Channel Model’s account for compensation was. Table 8 summarises the conclusions from each case study in answering the following questions:

A. Does task affect gesture production?
B. Does apraxia affect gesture production?
C. Does severity of aphasia affect gesture production?
D. Does type of aphasia affect gesture production?

Table 8 – Sorted alphabetically due to mixed results.

Case Study	A	B	C	D
Akhavan et al., (2018)	Yes	Yes	No	Yes
De Beer et al., (2017)	Yes	N/A	No	N/A
De Beer et al., (2020)	Yes	Yes	Yes	Yes
Hogrefe et al., (2013)	Yes	Yes	Yes	N/A
Kong et al., (2015)	Yes	N/A	Yes	Yes
Mol et al., (2012)	Yes	Yes	Yes	No
Nispen et al., (2013)	Yes	Yes	N/A	Yes
Özer et al., (2019)	Yes	N/A	Yes	Yes
Rose et al., (2017)	Yes	Yes	Yes	No
Sekine & Rose (2013)	Yes	N/A	No	Yes

3.2.3 A: Task and Gesture Production

Table 8: A, undeniably supported the suggestion that task impacted gesture production as proposed in Table 5 and 6. As alluded to, this section concludes that task and it's speech-gesture programming must be encoded in the initial conceptualising point causing task to impact gesture production.

Table 8 - Ordered Alphabetically

Case Study	A	B	C	D
Akhavan et al., (2018)	Yes	Yes	No	Yes
De Beer et al., (2017)	Yes	N/A	No	N/A
De Beer et al., (2020)	Yes	Yes	Yes	Yes
Hogrefe et al., (2013)	Yes	Yes	Yes	N/A
Kong et al., (2015)	Yes	N/A	Yes	Yes
Mol et al., (2012)	Yes	Yes	Yes	No
Nispen et al., (2013)	Yes	Yes	N/A	Yes
Özer et al., (2019)	Yes	N/A	Yes	Yes
Rose et al., (2017)	Yes	Yes	Yes	No
Sekine & Rose (2013)	Yes	N/A	No	Yes

The reason for gesture being programmed at the conceptualisation point is due to communicative effectiveness. Hogrefe et al., (2013) had two types of questions: Open Questions and Multiple-Choice Questions; and 3 constraints: SG, SO, GO. For Open Questions, they found that pantomime, emblems, and referential gestures within the SG condition were more communicatively effective compared to the SO condition in Open Questions. In the Multiple-Choice Questions, they found that the GO condition was more communicatively effective. They concluded that in all tasks, the milder the aphasia, the more easily the Judges comprehended gesture.

Secondly, those supporting that task/constraints affected gesture production also supported that gesture was a communicative repair tool. Both Sekine and Rose (2013) and Akhavan et al., (2018) found that specific gestures repaired word retrieval difficulties. Where Sekine and Rose (2013) concluded pantomimes were produced, Akhavan et al., (2018) concluded that iconic gestures were produced. Considering the updated *Kendon's Continuum* (Figure 1, Kendon, 1983, 2005; McNeill, 1992), iconic gestures are the leading characteristic found in pantomime; potentially equating the two. Further specific gesture compensations included Mol et al., (2012) who concluded iconic gestures were produced when moulding a shape. And, Nispen et al., (2013) found gesticulations were used for retelling stories and pantomime used for naming.

3.2.4 B: Apraxia and Gesture Production

Assessing apraxia allowed the assessment of the Models' Motor Control and to examine if it impacted the underlying speech-gesture relationship. Overall, as seen in Table 8: B, apraxia affected gesture, although not all case studies agreed.

Table 8 – Ordered Alphabetically

Case Study	A	B	C	D
Akhavan et al., (2018)	Yes	Yes	No	Yes
De Beer et al., (2017)	Yes	N/A	No	N/A
De Beer et al., (2020)	Yes	Yes	Yes	Yes
Hogrefe et al., (2013)	Yes	Yes	Yes	N/A
Kong et al., (2015)	Yes	N/A	Yes	Yes
Mol et al., (2012)	Yes	Yes	Yes	No
Nispen et al., (2013)	Yes	Yes	N/A	Yes
Özer et al., (2019)	Yes	N/A	Yes	Yes
Rose et al., (2017)	Yes	Yes	Yes	No
Sekine & Rose (2013)	Yes	N/A	No	Yes

From Table 8: B's data, there was an overall agreement that apraxia impacted gesture production. Whilst no case study directly opposed the conclusion, the N/As were used for two distinct reasons. For de Beer et al., (2020), apraxia was not documented at all, unlike the 9 remaining case studies who acknowledged some form of aphasia, ranging from residual to severe (check Appendix 2). For de Beer et al., (2017), Kong et al., (2015) Özer et al., (2019), and Sekine & Rose (2013), they concluded that the apraxia-gesture relationship 'remains unclear'. A surprising result from Nispen et al., (2013) showed that 'apraxia would influence purposeful gesturing, such as pantomime, but not gesticulation'. This led to their overall conclusion that gesticulation was closely related to production of speech, not pantomime. This suggests that the more conventional the gesture (i.e. pantomime), the more apraxia impacts: however, this requires future testing. Kong et al., (2015) supported this and, as aforementioned, refuted case studies, such as Mol et al., (2012), because they had not disentangled apraxia and semantic impairments from the severity of aphasia. The meant that Mol et al.,'s (2012) support for apraxia affecting gesture production was due a lack of recognition and understanding of the relationship between the Motor Control's importance and the underlying speech-gesture relationship.

3.2.5 C: Aphasia Severity

This next section investigated the severity of aphasia and answered whether an increasingly severe case of aphasia increased or decreased gesture usage; and, if it impacted the type of gesture production. The results from Table 8: C shows that 6 out of 10 case studies supported aphasia severity impacting the quantity of gestures *and* the gesture type.

Table 8 – Ordered Alphabetically

Case Study	A	B	C	D
Akhavan et al., (2018)	Yes	Yes	No	Yes
De Beer et al., (2017)	Yes	N/A	No	N/A
De Beer et al., (2020)	Yes	Yes	Yes	Yes
Hogrefe et al., (2013)	Yes	Yes	Yes	N/A
Kong et al., (2015)	Yes	N/A	Yes	Yes
Mol et al., (2012)	Yes	Yes	Yes	No
Nispen et al., (2013)	Yes	Yes	N/A	Yes
Özer et al., (2019)	Yes	N/A	Yes	Yes
Rose et al., (2017)	Yes	Yes	Yes	No
Sekine & Rose (2013)	Yes	N/A	No	Yes

To begin analysing Table 8: C, it is necessary to distinguish the N/A results. For Nispen et al., (2013), they tested one PwA and thus did not document this factor. For Sekine and Rose (2013) they concluded that they were 'unable to examine [the] impact of aphasia severity'. Even though 6 of the case studies supported the fact that aphasia severity increased gesture production, those opposing, did so strongly. For example, Akhavan et al., (2018) concluded gesture production occurred 'independent of [the] severity [of aphasia]' and de Beer et al., (2017) concluded that aphasia severity and participant communicative effectiveness had 'no remarkable correlations.'

Overall, however, the findings from Table 8 does provide support for aphasia impacting gesture production, as it was discovered that the more severe the aphasia, the more gesture acted as a communicative repair. This reflects the results from where the task/gesture relationship was investigated (Sekine and Rose, 2013; de Beer et al., 2017; Nispen et al., 2013). For Sekine and Rose (2013), pantomime was a direct substitution for verbal output communication repair. For de Beer et al., (2017) referential gestures were produced in the context of spontaneous natural discourse, whereas pantomime gestures were used to express more complex expressions. For Nispen et al., (2013), gesticulations compensated for word retrieval difficulties.

3.2.6 D: Aphasia Type

The final factor examined whether the type of aphasia affected gesture production, in which Table 8: D supports. This opened an interesting discussion point surrounding the relationship between gesture production and neurological comprehension and production processing.

Table 8 – Ordered Alphabetically

Case Study	A	B	C	D
Akhavan et al., (2018)	Yes	Yes	No	Yes
De Beer et al., (2017)	Yes	N/A	No	N/A
De Beer et al., (2020)	Yes	Yes	Yes	Yes
Hogrefe et al., (2013)	Yes	Yes	Yes	N/A
Kong et al., (2015)	Yes	N/A	Yes	Yes
Mol et al., (2012)	Yes	Yes	Yes	No
Nispen et al., (2013)	Yes	Yes	N/A	Yes
Özer et al., (2019)	Yes	N/A	Yes	Yes
Rose et al., (2017)	Yes	Yes	Yes	No
Sekine & Rose (2013)	Yes	N/A	No	Yes

Table 8: D revealed 6 out of the 10 case studies supported this aphasia type affecting gesture production, whilst 2 case studies opposed (Mol et al., 2012; Rose et al., 2017) and 2 case studies did not acknowledge this factor at all (Hogrefe et al., 2013; de Beer et al., 2017). Strikingly, on average, case studies that evaluated more aphasia types (Table 2) were more likely to oppose/not conclude whether gesture production was impacted. Hogrefe et al., (2013) who studied the greatest number of aphasia types did not conclude whether aphasia type affected gesture production. Instead, they concluded that individual, location-specific, neural substrates could impact gesture, rather than aphasia type affecting gesture production. This is a semi-plausible conclusion because, as discovered, gesture occurred regardless of aphasia. De Beer et al., (2017) assessed 3 types of aphasia and similarly, did not conclude whether aphasia type affected gesture production. De Beer et al., (2020) and Mol et al., (2012) also had the most documented aphasia types. But interestingly, they had contrastive conclusions. Where de Beer et al., (2020) concluded that aphasia type impacted gesture production, Mol et al., (2012) concluded the opposite was true. Thus, the reliability that the type of aphasia impacts gesture production is wavered. From the case studies that supported, 4 out of 6 case studies assessed 1-2 types of aphasia: meaning only 2 case studies in support of gesture production being affected by aphasia types assessed a reliable 5-6 aphasia types (Table 2). Whereas, the 2 case studies opposing assessed 4-6 aphasia-types each (Table 2).

In contrast, Sekine and Rose (2013) reported a convincing breakdown of the gesture-aphasia type relationship. They concluded Broca's PwA produced referential, emblematic, pantomime, concrete deictic, iconic CVPT, and number gestures. Statistically, Broca's PwA and Conduction PwA used more concrete deictic and iconic CVPT gestures than Anomic PwA. Conversely, Wernicke's PwA used a restricted range of vague, abstract gestures; and did not employ pantomime or iconic gestures. 71% of Transcortical Motor PwA's gestures were pointing-to-self. Finally, Sekine and Rose (2013) also documented the difference between gesture production in aphasia and non-aphasia cases: PwA, compared to the Controls, produced iconic, pantomime and deictic gestures when the Control group did not. This offers direct insight into how exactly gesture production is impacted by aphasia type, potentially alluding to neurological alignment between gesture production and aphasia type/location.

4. Discussion

This study set out to assess the underlying speech and gesture relationship through investigating PwA's gesture production, in order to further the field of language evolution. The first aim was to answer if a) speech and gesture compensated for one another, supporting the Dual-Channel Model; or, b) speech and gesture deteriorated together, supporting the Synchronisation Model. In answering this hypothesis, the case studies' results discovered that gesture compensated for speech, determining that the Dual-Channel Model was more accurate. However, upon further inspection, the factors impacting gesture production revealed nuanced links between the Models' stages. The second set of hypotheses, explored in this section, investigates how these Models link to language evolution. By identifying the more accurate model, this sheds light on how language evolved. If the Dual-Channel Model was more accurate, then it could be concluded gestures and speech evolved separately. If the Synchronisation Model was more accurate, then it points towards a joint speech-gesture evolution. As the Dual-Channel Model has been proven to be more accurate, this suggests speech and gesture evolved separately. However, the models' evaluation deepens our understanding for language evolution.

4.1 Models

This study's results showed that the Dual-Channel Model (Figure 2) had more empirical support than the Synchronisation Model (Figure 3). This means when the Linguistic Channel is impaired, the Gesture Channel compensates. Only one case study supported the Synchronisation Model: Mol et al., (2012) who argued that the vocal and gesture systems broke down together. However, generally, the case studies aligned with de Beer et al.,'s (2017) conclusion that when there were failed attempts at communicating aspects of meaning, the message shifted to the intact gestural channel. Most case studies, supporting the Dual-Channel Model, found specific types of gestures used to compensate for specific environments based on the factors explored in Table 8. Crucially, this demonstrated that gestures are not just a speech-compensation tool, they hold information outside of speech (Özer et al., 2019; Rose et al., 2017). This could be seen in both PwA and Control groups (Akhavan et al., 2018).

4.1.1 Conceptualiser

Both models start with *The Conceptualiser;* this was not disputed by any of the case studies. From the External Inputs, Environment was supported since the tasks required the physical surrounding to be encoded before producing a message. This could be seen through either the constraints, task types, aphasia severity, or apraxia affecting physical movements. Similarly, since the task's social context had to be processed, Pragmatics was supported. From the Internal Inputs, the ability to convey and compensate signals and symbols through various communicative forms showed support for Semiotics. Finally, the ability to comprehend and produce messages after participating in a task demonstrated support for Memory.

The most striking find from this research was that specific gestures replaced and compensated for specific communicative functions (Table 7). Unexpectedly, links appeared between the parallel Linguistic (lexicon, phonetics, semiotics and syntax) and Gestural (iconic, metaphoric, emblems, beats) Systems. These links were exposed when it was found that task impacted gesture production. For example, when PwA had specific word-retrieval (lexicon) difficulties, they compensated with iconic gestures (Sekine and Rose, 2013) or iconic-driven pantomime gestures (Akhavan et al., 2018). De Beer et al., (2020) found within natural spontaneous discourse (a combination of lexicon, semantics, phonetic and syntax, and pragmatic impairment), referential gestures (the collapsed iconic and deictic gestures) were used to compensate. They also found that when syntax was impaired, iconic-pantomimes were substituted for the more complex expressions. These findings raised three explanations as to how there can be a relationship in separate, parallel systems, either: a) the Conceptualiser has a more dominant role; or, b) the Total Signal has a dominant role; or c) both the Conceptualiser and the Total Signal production play much larger roles in the communication encoding. Overall, due to the indisputable support for Conceptualiser and the more ambiguous results for the Total Control, this study concludes that the Conceptualiser is the main driver for any form of communication. This means that these speech-gesture links were acknowledged prior to the signal being sent out to the System Encoder. This is supported by the seminal reading from De Ruiter (2000) who affirmed the importance of a conceptualising start point where speech and gesture are dependent on the initial programming. Thus, the core role for the underlying speech and gesture programming is to act as tools for expressing and interpreting signs and signals from the Conceptualiser (supporting Burlak, 2018).

4.1.2 System Encoder

The System Encoder is where the underlying relationship differs between the two models: but, as established, the Dual-Channel Model is more accurate. As seen in the previous section, the type of task affects the PwA gesture production and exposes specific links between the Linguistic and Gestural Systems. As for the System Encoder, this can be further investigated by evaluating the gesture production according to the aphasia type and location (according to Le and Lui, 2021). As will be found, specific links between aphasia type, aphasia location and the subsequent effect on gesture production can be drawn. Thus emphasising the importance of the Conceptualiser encoding two separate yet linked speech and gesture systems.

To begin with, as a general example, for lexical and semantically impaired PwA, iconic, metaphoric, and referential gestures were used (Sekine and Rose, 2013). However, more specific links can be drawn: for example, Wernicke Aphasia, found in the Wernicke area, affects lexical, semantic, and phonetic production. The gestures used most by Wernicke PwA were referential, metaphoric, and emblematic gestures (Sekine and Rose, 2013). Syntactically impaired PwA, as in, Broca area aphasia cases who are non-fluent, produced pantomime, emblems, concrete deictic, and iconic gestures (Sekine and Rose, 2013). Phonetically impaired

PwA, i.e. Wernicke and Conduction aphasia areas, gestured more than other aphasia types (Özer et al., 2019) but produced different gestures (Sekine and Rose, 2013). So, whilst Wernicke PwA used metaphoric and referential gestures, Conductive PwA used concrete deictic and iconic gestures. The striking difference was that Conductive PwA could correct their phonetic paraphasia (Le and Lui, 2021). This could be explained locationally; Wernicke aphasia is in the Wernicke area: whereas Conduction aphasia is found in the Arcuate Fascilicus. Overall, this supports Hogrefe et al., (2013) who concluded that individual, location-specific, neural substrates could impact gesture production.

The final interesting discovery is the dominance of iconicity. Those who supported that gesture production is impacted by aphasia severity found that: the more severe the aphasia, the more iconic gestures were produced. Furthermore, this is proven by Global PwA, the most severe form of aphasia, only producing iconic gestures to compensate (Sekine and Rose, 2013). Thus, iconicity in future models should be recognised and signalled as the dominating gesture.

Overall, these results collated and exposed important nuanced signal paths across the underlying speech and gesture stages which all stem from the Conceptualiser's initial coding. There appears to be correlations between aphasia location and the subsequent gesture produced: this provides a basis for very interesting future research centring on the neurological underpinnings.

4.1.3 Message Production

The last section of the Models is the Message Production. This holds the Total Signal and Communication Channel. The Motor Control, within the Total Signal, had simultaneously important yet ambiguous conclusions. In both the Synchronisation Model and the Dual-Channel Model, it was expected that the Motor Control would programme the external output. However, 6 out of the 10 case studies reviewed, found that comorbid deficiencies (such as, limb apraxia) affected gesture production. Whilst this shows that apraxia directly affects Motor Control, it makes evaluating the underlying speech-gesture relationship more difficult. Thus, future studies should further examine the Motor Control's relationship to speech and gesture further. The ambiguous conclusions can be exemplified by Kong et al.,'s (2015) refutation of Mol et al.,'s (2012) support for speech and gesture deteriorating together: whereby Mol et al., (2012) did not disentangle limb apraxia and semantic impairment from aphasia severity.

Overall, since the Motor Control did affect gesture production, there appears some form of significance in it's role: however, future research should further investigate this in order to provide more clarity on the underlying speech-gesture underlying relationship.

4.2 Language Emergence

The second question in this research centres on whether speech and gesture developed separately or together. Due to the Dual-Channel Model being more accurate, it appears speech and gesture evolved separately. Whilst this can be concluded, further considerations show that the strongest position is a pantomime-first theory which stems from conceptualisation.

At a minimum, the models shed light on necessary communicative aspects for language evolution which will need to be accounted for in every language model, regardless of linguistic evolutionary approach. Firstly, the models are a three-part construction: the Conceptualiser, the System Encoder, and the Message Production. Within the Conceptualisation stage, External (Pragmatics and Environments) and Internal (Memory and Semiotics) Inputs are proven to be supported: both by the results and previous seminal literature, including de Ruiter's (2000) *Sketch Model* and Burlak's (2018) signal interpretation approach. The Conceptualiser determines the underlying speech-gesture relationship. With the System Encoder, there must be a Gesture System and a Linguistic System encompassing the individual's linguistic knowledge. This closely links to the Motor Control within the Total Signal which can produce a wide-ranging form of communicative acts: from purely vocalisation through to purely gestural communication.

One consideration deepening the Dual-Channel Model's analysis on linguistic evolution is the fact that the case studies found that specific gestures compensate for specific linguistic functions. Firstly, the Dual-Channel Model supports this hypothesis as long as it places the Communicative Intentions as the driver for how the message is generated. This suggests that for language evolution, the Conceptualiser was produced first. Thomas and Kirby (2018) concluded equivalent results whereby speech and gesture are two separate channels, sensitive to the Communicative Intention. Similarly, Herrmann et al., (2007) argued that humans evolved their social-cognitive skills within the Conceptualiser allowing humans to communicate through speech and gesture within a cultural group. Additionally, Burlak (2018) argued that the need for a constant increase in symbols gave rise to speech and gesture. Thus, this signal-interpretation, multimodal approach places the conceptualisation as the main communicative driver and suggests speech and gesture are tools of expressing and interpreting signs and signals.

Next, how the signals manifested through speech and/or gesture when language first emerged needs to be addressed. From the case studies, iconicity dominated the compensation: in fact, the more severe the aphasia, the more iconic gestures were used (Table 7, C). In fact, all PwA, including those with comorbid deficiencies (Table 8, B), were able to produce iconic gestures (Sekine and Rose, 2013), or iconic-dominated pantomime gestures (Akhavan et al., 2018). Iconic gestures are a key tool for compensation and has a consistent presence even when all other linguistic systems are impaired (Sekine and Rose, 2013). This leads to the conclusion that iconicity would be the first type of gesture to occur. The most iconic-dominated theory within the linguistic evolution field, as discussed by Żywiczyński et al., (2021), is the pantomime-first theory. As proven in Tables 3 and 4, pantomime and iconic gestures have a strong partnership interlinking the two. Pantomime is multimodal, placing emphasis on Communicative Intention, and can accompany *and* replace speech with gesture (according to de Beer et al., 2014; Żywiczyński et al., 2021; Zlatev et al., 2020). Since pantomime is supported by the results and the seminal reading, it appears that pantomime is the strongest theory as long as it is driven by the Conceptualiser.

Overall, the Dual-Channel Model provides support for a pantomime-first theory that is determined by conceptualisation. This means that when langauge emerged, the communicative intention produced and signalled to the two channels an iconic-dominated message in the form of pantomime. This is because pantomime allows speech and gesture to co-occur whilst holding different communciative information. Crucially, if one of the channels is impaired, it can be compensated by the other channel. This has support from both the results and seminal reading.

5. Conclusion

Overall, this study investigated the underlying speech and gesture relationship in order to further progress the language evolution field. This study found speech and gesture are two parallel systems with a shared Conceptualiser and Motor Control. This is supported by the results of 9 case studies where PwA were evaluated on their ability to compensate for their impaired speech channel. An unexpected conclusion found that specific features were compensated for specific speech impairments. This placed priority on the Conceptualiser determining how speech and gesture would be produced based on the task. A strength of the models is that it highlighted the importance of the contact points and the communicative necessities that must have been established for language to emerge. Overall, a pantomime-first hypothesis driven by the Conceptualiser is supported and is complemented by previous findings from de Ruiter (2000), Burlak (2018) and Vigliocco et al., (2014), Zlatev et al., (2020) and Żywiczyński et al., (2021).

Through the accumulated research and analysis, this study is the first study that investigated the underlying speech-gesture relationship in PwA in order to further the field of language evolution. Thus, this paper will be of use to other researchers interested in modern, empirically driven, medical approaches to language evolution. Future research should specifically assess Speech-Only, Gesture-Only, Speech-Gesture constraints on linguistically non-impaired speakers to cross-reference the information found in this study.

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Appendices

Appendix 1

Table 9- SO - Speech Only; GO - Gesture Only; SG - Speech-Gesture; PwA - Patient with Aphasia. Ordered Alphabetically

Author (Date)	Focus	Methodology	Conclusion
Akhavan, Göksun, Nozari (2018)	Testing theories that presume the integrity of the conceptional system and absence of co-morbid conditions (limb apraxia)	PwA and Controls watched 20 clips depicting different motion events with a combination of 10 manners (hop, skip, walk, run, cartwheel, crawl, jump, twirl, march, step) and 9 paths (between, to, out of, under, over, in front, around, across, into). The participants then had to *describe* these motions.	11 control participants produced 218 full sentences in response to events in video clips. 2 trials. They had 108 gestures and 218 trials. 8 aphasia patients produced 87-event related utterances. 152 trials. They had 366 gestures and 152 trials. 7/8 people with aphasia used iconic gesture more reliably than emblems which are culturally specific. All patients with aphasia (independent of their severity), used gesture to compensate for lost speech and lexical retrieval difficulties. Gesture was often as informative as the Control's speech and took on other roles apart from compensation, for example: using interlocutors as social cues.
De Beer, Carragher, Nispen, Hogrefe, de Ruiter, Rose (2017)	Investigating how much information aphasia patients communicate and the communicative effectiveness	From AphasiaBank, PwA performed two *narrative tasks*. Firstly, they retold their stroke story: secondly, they retold an important event in their life. Their gestures were noted by their referential, emblematic and pantomime gestures. Judges watched 15 audio and 15 visual clips of around 2-10 seconds long to assess the PwA comprehensibility. They then performed *forced choice* tasks where they answered open questions and multiple-choice questions in SG and SO conditions.	Speech-gesture condition had a higher comprehensibility score than speech-only. Students scored higher in speech-gestures than speech-only when the patient used pantomime, emblems, referential gestures Gesture production is used (consciously or unconsciously) to compensate for reduced linguistic resources. This is due to the speech and gesture being closely co-ordinated yet separate processes.
De Beer, Hogrefe, Hielscher-Eastabend, de Ruiter (2020)	Investigating how people with aphasia use gestures communicatively and compensation.	*Spontaneous conversation* about four topics of daily living. PwA performed a *narration task* where they had to retell Sylvester *and Tweetybird cartoon Canary Row*. In total, it took approximately 20 minutes per task. No prompts were used to aid PwA.	The narration task evoked a higher gesture-to-word ratio than spontaneous conversation. Higher communicative constraints from tasks lead to more iconic gesture production by people with aphasia.

Hogrefe, Ziegler, Wiesmayer, Weidinger, Goldenberg (2013)	Testing whether speech and gesture are a single bimodal production process or two independent tightly coordinated processes that have a trade-off relationship	PwA *recalled* events under 2 conditions from seven 30-90second long video clips from *Mr Bean* and Tweetybird and Sylvester. The first condition was SO: the other, GO. 18 Judges determined the comprehensibility of gestures	Two participants conveyed more clearly information via gesture than speech suggesting that speech and gesture are separate but intricately linked processes. Not all PwA exploited the full communicative potential through compensation. This suggests that whilst speech and gesture have a trade-off relationship, they are two separate, tightly coordinated communication channels located in similar area in the left hemisphere.
Kong, Law, Wat, Lai (2015)	Investigating the impact of aphasia severity with a close analysis of gesture forms and functions	From AphasiaBank, control and PwA groups performed *Narrative Tasks:* Monologue narration of *The Hare and the Tortoise* and *The Boy who Cried Wolf* Presentation of picture cards and sequential description of making a ham and egg sandwich.	35% control group produced no gestures through discourse task. 10% (1 transcortical motor, 4 anomic) showed an absence of co-verbal gestures. A higher proportion of content-carrying gestures serving to reinforce speech prosody, or speech flow. Control group produced 3242 gestures, while PwA produced 3249 gestures. Higher frequency of gestures compensates for language deficits among those with more severe aphasia. Gesture compensation is common but not compulsory. The field needs a better definition of gestural compensation as it would lead to a more sophisticated understanding of the role of gestures in aphasic language production.
Mol, Krahmer, van de Sandt-Koenderman (2012)	Investigating how gesture in aphasia patient tends to degrade with spoken language	PwA and Control performed two *Scenario Tests*: the sweater task and the accident task under three conditions GO, SO, SG. The Judges then performed a *forced choice* task on whether the person in the video wanted to buy a sweater. There were three movies for the forced choice task: PwA in all conditions; Control Speakers in SO; Control speakers in GO.	PwA without apraxia were as informative as the control group. Those with apraxia could not fully comprehend due to disruption in communicative intention. Speech and gesture are more likely to break down together even though they are separate yet closely related processes: suggesting a shared underlying process.

Nispen, Sandt-Koenderman, Mol, Krahmer (2013)	Investigating whether gesticulation and pantomime are comprehensible, and how little is known about the difference with people who have aphasia	PwA and Controls performed two tasks: a *naming* task of 20 objects and a storytelling task of Tweetybird and Sylvester cartoon. This was performed twice: once SO and once SO. In a *forced-choice task*, Judges evaluated the comprehension of both pantomime and gesticulation.	For naming task: The patient's pantomimes, which were more shape-based, were frequently interpreted correctly by the Judges. Pantomimes were more comprehensible than gesticulation. For retelling the story: gesticulation was more comprehensible than pantomime and was used more by PwA than Control group. Pantomime and Gestures are different processes and are used to compensate for different functions. Gesture modes should be considered separately for different communicative settings.
Özer, Göksun, Chatterjee., (2019)	Examining gesture in speakers with and without speech impairments and how spoken spatial expressions changes when gesture was restrained	PwA watched 39 3-4 second long video clips depicting 15 different motion events (hop, skip, walk, run, cartwheel, crawl, jump, twirl, march, step, slide, roll, balance, and tiptoe) and 15 different paths (in front, under, though, across, downstairs, onto, over, along, upstairs, down, around, to, behind, on, in, up, into). They rated the familiarity of each action. The participants watched the 13 trials in the conditions SG, GO, SO. They then *described* the actions from the video.	PwA used more gestures compared to Controls. Gestures served both as a communicative and restorative function: whereas Controls only used gestures for communicative purposes. PwA produced selective compensation gestural methods to restore lost linguistic information. For some of the participants, the Controls named path prepositions more in SO: whereas PwA used manner verb less when in SO compared to SG. Iconic gestures are used as a restorative function in patients that have word-retrieval difficulties. This shows that gesture production is multifunctional and serve different functions for different environments.

Rose, Mok, Sekine (2016)	Focusing on whether meaning-laden gestures have any communicative effectiveness	From AphasiaBank, 15 audio-visual recordings of 13 aphasia participants in *conversational discourse* taken from Sekine et al., (2013). 9 Judges watched 3 manipulated 10-20-second-long extracts (SO, GO, SG). Then the Judges were asked to do a *free-description* task and a *multiple-choice task*	Regardless of the task: the milder the aphasia, the more fluent the aphasia participants in the speech environment. In the speech-gesture condition, the milder the aphasia, the better the message comprehension in the free description task. The less fluent the participant, the greater the message accuracy in the gesture condition. PwA compensate gestures for communication difficulties, especially when there is reduced speech fluency. PwA used pantomime with free speech when talking to the researcher. Pantomime and speech combined to create a strong communicative effectiveness.
Sekine, Rose (2013)	Investigating whether gesture is vital for message transfer. Examined whether patterns of gesture production associated with specific types of aphasia	From AphasiaBank, PwA performed a spontaneous *narrative task* of Retelling the story of Cinderella after viewing a picture book. No time limit was imposed on either task. Prompts were used when necessary and gestures were noted according to Kendon's Continuum (1983).	92/98 subjects with aphasia and 47/64 of the control subjects produced a gesture at least once. People with aphasia produced full range of gesture type, whereas control only produced deictic pointing-to-self, pantomime, and letter gestures. There was specific production of gesture based on the type of aphasia. All types of aphasia had usage of deictic gestures and emblems. Broca's patients had the highest use of pantomime gesture. Conduction patients had produced iconic observer viewpoint. Wernicke's aphasia used iconic observer viewpoint (100%), but none used pointing-to-self (0%). Anomic aphasia had lower gesture use than others but more closely reflected the control group. Transcortical motor aphasia reflected the control group but had high concrete deictic and pointing-to-self gestures. Aphasia patients used pantomimes during word retrieval difficulties and during communication repair attempts. Different functions that gesture serves during aphasic discourse When linguistic coding fails in aphasia, individuals rely more heavily on the gesture channel. People with aphasia gesture more than control participants.

Appendix 2

Table 10 - ANELT - Amsterdam Nijmegen Everyday Language Test; WAB-Q - Western Aphasia Battery-Quotient; WAB-R Western Aphasia Battery-Revised; CAB-AQ - Cantonese Aphasia Battery-Aphasia Quotient; AAT - Aachen Aphasia Test; FAST -Florida Apraxia Screening Tas; PwA – Patients with Aphasia. Ordered Alphabetically

Author (Date)	Subjects	Severity of Aphasia	Type of Aphasia (PwA, if given)	Type of Gesture	Age (Mean years)	Education (years)	Apraxia (PwA affected)	Hemiplegia/Stroke (PwA affected)	Onset (months)
Akhavan, Göksun, Nozari (2018)	19 subjects 8 PwA (preserved auditory comprehension) 11 Controls	WAB-AQ 42.5-95.8	Broca, Anomic	Iconic, Beat, Deictic	58.18	12-16	85+	Y (all)	22-69
De Beer, Carragher, Nispen, Hogrefe, de Ruiter, Rose (2017)	10 PwA 60 Judges	WAB-R 49-88	Broca (5), Conduction (3), Wernicke (2)	Referential, Pantomime, Emblem	Judges 22.72 PwA 55.51	N/A	N/A	Yes (all)	12-108
De Beer, Hogrefe, Hielscher-Eastabend, de Ruiter (2020)	52 subjects. 26 aphasia patients. 46 Controls.	Mild-Severe	Broca, Wernicke, Global, Anomic, Not Classified, Conduction	Iconic	56.38 PwA 56.31 control	N/A	Yes (3)	35 cerebral infarctions 1 traumatic brain 1 hypoxic	6-318
Hogrefe, Ziegler, Wiesmayer, Weidinger, Goldenberg (2013)	16 aphasia patients	AAT – 61.75 (comprehension); 2.31 (spoken)	Wernicke, Broca, Global, Anomic, Temporal, Residual, Non-Classifiable	Pantomime,	48.68	N/A	Yes (2 – severe; 2 residual)	Yes (6 hemiparesis; 4 residual) No (5)	2-124

Kong, Law, Wat, Lai (2015)	179 subjects. 131 Controls 48 PwA. 36 were fluent, 12 were non-fluent.	CAB-AQ 81.31/100	Broca, Wernicke	Iconic, Metaphoric, Deictic, Emblems, Beats	56.13	8.65	Yes Mild	All PwA Stroke-induced	6+
Mol, Krahmer, van de Sandt-Koenderman (2012)	44 subjects. 13 with moderate aphasia 12 with severe aphasia 17 Controls	22.12 ANELT	Global Wernicke, Non-Classifiable, Broca, Conduction, Anomic, Unknown	Iconic	56.92	6-17	20.72 ANELT (All PwA)	None, moderate, severe 4 weeks post stroke	1-152
Nispen, Sandt-Koenderman, Mol, Krahmer (2013)	12 subjects 1 PwA 11 Controls 15 Judges	AAT – 82 (comprehension) ANELT – 12/15 (spoken)	Wernicke	Pantomime Gesticulation	68 years	N/A	Yes (all – ideomotor apraxia)	No (all)	3

Özer, Göksun, Chatterjee., (2019)	26 subjects 4 PwA (1 dementia patient excluded) 20 control	WAB-R 65.3-94.9 (M= 88)	Wernicke, Transcortical Motor Aphasia, Expressive, Optic, Unclassified, Primary Progressive	Iconic (Dynamic, Static), Deictic, Target, Conflated, Pantomime	64.6	14	Y (all FAST: 75.5)	Y (all)	100-210
Rose, Mok, Sekine (2016)	78 subjects 67 Judges 11 PwA	17-89.5 WAB-AQ (speech)	Conduction, Broca, Transmotor, Anomic	Iconic Pantomime	67.6	12-20	Yes (7 PwA), No (4 PwA), Unknown (4 PwA)	No (2 PwA) Right-hemiparesis (4 PwA) Right hemiplegia (4 PwA)	12-360
Sekine, Rose (2013)	162 subjects. 98 individuals (stroke) 64 Controls	WAB-AQ 3 PwA = 0-25 9 PwA = 26-50 37 PwA = 51-75 38 PwA = 76-93.8	Broca (24), Wernicke (8), Global (3), Transcortical Sensory (1), Transcortical Motor (6), Conduction (11), Anomic (41)	Referential, Concrete Deictic, Pointing, Iconic Observer Viewpoint, Iconic Character Viewpoint, Pantomime, Metaphoric, Emblem, Time, Beat, Letter, Nnumber	57 - Controls 63 - PwA	N/A	Yes – Mild, Moderate, Severe	N/A	6+/-