



An action planning mechanism hypothesis on Broca's aphasia

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ABSTRACT

The present article proposes that the language production difficulties of Broca's aphasics may be explained by damage to the brain action planning mechanism. More precisely, the impairment to the ability for performing what Koechlin and Jubaul (2006) called the "successive selection of subordinate segments that constitute" "hierarchically higher action plans" would hamper the capacity to hierarchically combine ideas and communicative goals in the context of language production. It is also proposed how such a hypothesis could be tested by using already existent cognitive tasks in combination to traditional treatments of aphasia. The hypothesis may be framed as an attempt to give an application for the body of knowledge about the connections between language and action as well as to collect more evidence on the matter – evidence which could potentially be of fundamental importance for the field of study concerned and for the elaboration of new rehabilitation programs.

Introduction

The present article proposes that the language production difficulties faced by Broca's aphasics comprise a result of impairment to the capacity of performing what Koechlin and Jubaul [1] described as the "successive selection of subordinate segments that constitute" "hierarchically higher action plans". Such a capacity would be more effectively recovered within the domain of action through a cognitive training program that taps action planning mechanisms which, in their turn, would be re-used for the combination of meaning and ideas in the context of language production.

Such a hypothesis is based on the knowledge gathered by experimental studies on language and action, being that it departs from the integration of two ideas: the idea defended by Koechlin and Jubaul [1] that the Broca's area is responsible for the successive selection of subordinate segments that constitute hierarchically higher action plans and the Glenberg's [2] idea that the brain's action planning system supports the sensible combination of meanings across words and sentences during language comprehension. The present article's proposal extends Glenberg's [2] idea towards the context of language production and, based on the integration of the mentioned ideas, argues that the capacity to successively select subordinate segments that constitute hierarchically higher action plans is necessary for the sensible combination of ideas across words and sentences in the context of language production.

Such a proposal aims to be an application of the body of knowledge on the connections between language and action that has been accrued in the last decades, including brain imaging experiments whose results suggest that action and language processing rely on common brain circuitries and – very importantly – the idea from Glenberg [2] that language uses the brain action planning system for the purpose of combining ideas. Such a body of knowledge will be commented in the next section.

In the third section, the hypothesis will be presented and, in the fourth section, is proposed that the tests used by Koechlin and Jubaul [1] to investigate the role of Broca's area in hierarchical processing of actions could be re-used as cognitive training tasks, being that such tasks would serve for the purpose of testing the hypothesis. The hypothesis predicts that the combination of the cognitive training with a traditional treatment of aphasia would be more effective for the patients' rehabilitation than the treatment alone. The fifth (and last) section concludes the article.

Action & language

The idea that action and language are closely related to each other has received support by several experimental studies. Collectively, those studies provide "strong evidence" that the processing of action and language share brain substrates; both language and tool-use – object-directed action – are proposed to depend on a circuitry that

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stretches from temporal cortex to frontal lobe, passing through the posterior temporal cortex, inferior parietal lobule, ventral premotor cortex and the inferior frontal gyrus¹. Along this circuitry, is carried out the integration of sensorial information from action observation with motor commands, which is essential for the imitation of actions, as well as the integration of sensorial information from spoken language with speech-related motor commands, which, in its turn, is crucial for vocal imitation². Also, this circuitry is involved in the association between semantic content – “general knowledge of objects and motion” – with speech sounds and tool images and in the processing of “hierarchically structured sequential information” from language and action [4].

Within such a circuitry, the Broca’s area³ have been associated by several studies to important roles in the processing of hierarchical information from language and action; more precisely, the Broca’s area seems to be involved with the assembling of elements into hierarchical structures, being that the different components of Broca’s area – BA 44 and BA 45⁴ – support the processing of information from different levels of hierarchical structures. The BA 44 – or pars opercularis – have been reported to be involved in the combination of lexical elements in order to form sentences, distinguishing subordinate elements of object-directed actions that combine several individual motor acts⁵ and in the processing of the boundaries of simple chunks of actions, while the BA 45 is involved in the processing of higher-level – or more abstract – information; it is involved in the processing of boundaries of superordinate chunks of actions (chunks of action chunks) and in semantic unification of language content (e.g. the definition of the meaning of ambiguous words in sentences) [1,5,6–13].

In the context of information hierarchical processing, the Inferior Frontal Gyrus (IFG) as a whole has the important function of unifying elements or, in other words, combining elements into larger, hierarchically organized unities, being that the IFG plays such a role in the contexts of language comprehension and production as well as in the contexts of action comprehension and production. With regard to language, the data on IFG suggests that it combines phonetic and lexical elements into hierarchically organized sequences, while in the domain of action, the IFG is involved in combining action elements into hierarchically organized sequences [4,6]. Since actions are hierarchically organized by goals and sub-goals [14], the IFG – which subsumes the Broca’s area – seems to support the hierarchical combination of elements in accordance to the definition of goals (and sub-goals), being such goals either communicative goals or non-communicative ones.

Before the data on connections between language and action and based on the idea that the brain action planning system (which is responsible for producing flexible, “goal-directed combinations of parts” or elements) was available before the appearance of language, Glenberg [2] proposed that “the mechanism of action planning is the mechanism that allows us to sensibly combine meanings across words and

¹ It is proposed, based on results of several experiments, that the inferior frontal gyrus and the inferior parietal lobule contain mirror neurons, being that mirror neurons may be essential for action understanding and imitation; the mirror neurons fire when a particular action is executed or seen being executed by another individual, allowing a person to access the same representations and knowledge about an action when she is performing the action or seeing someone else doing it [3].

² It is noteworthy to highlight that speech is also a motor act and, as happens with action in general, its “execution and comprehension rely on neural circuitries integrating sensory perception and motor control” [4].

³ The Broca’s area is located on the inferior frontal gyrus [5].

⁴ It is generally agreed that the Broca’s area “comprises Brodmann’s areas (BA) 44 and 45 of the left hemisphere” [6].

⁵ More precisely, the subjects had to distinguish between three sub-actions – pictures of a video that they had previously seen – and choose which one corresponds to the middle of the action; in the words of the study’s authors, the results highlighted the role of Broca’s area (specifically BA44) “in decoding the hierarchical structure of observed actions” [7].

sentences” in the context of language comprehension. In Glenberg’s account, language would have co-opted brain mechanisms responsible for action processing⁶, being the mechanism of action planning one of them.

Such an idea is compatible with the view on Broca’s area that was defended by Koechlin & Jubaul [1]. According to such a view, the Broca’s area would comprise a “system of hierarchical control” that is responsible by initiating and terminating the “successive selection of subordinate segments that constitute” “hierarchically higher action plans” as well as by the selection and inhibition of such plans; the more anterior regions of Broca’s area would define the (hierarchically higher) plan which is to be followed, while the more posterior regions would select the subordinate segments of the hierarchical structure of the chosen plan. The Broca’s area would process “hierarchical structures in multiple domains of human cognition”, including the domain of language.

The hypothesis

The present article hypothesizes that the language production deficits which are found among Broca’s aphasics is a result of impairment to the capacity of successively selecting subordinate segments that constitute hierarchically higher action plans. Such a hypothesis departs from an integration of Glenberg’s [2] idea that the sensible combination of meanings across words and sentences in the context of language comprehension relies on the brain action planning mechanism with the idea – from Koechlin & Jubaul [1] – that the Broca’s area role on processing action plans includes the selection and inhibition of hierarchically higher action plans and “the successive selection of subordinate segments that constitute those action plans”, being such a process implemented in “multiple domains of human cognition” (including language). As a result of such an integration, the present article proposes that the sensible combination of ideas across words and sentences depends on the capacity to successively select subordinate segments that constitute hierarchically higher plans.

The hypothesis here presented extends the Glenberg’s [2] idea from the context of language comprehension towards the context of language production, positing that the impairment of the action planning mechanism hinders the speech production of Broca’s aphasics. In this line of thought, the brain action planning mechanism would support the combination of meanings across sentences not only in the context of language comprehension, but also in the context of language production, being that the tasks which were designed to evaluate action planning skills could be used as cognitive training tasks for patients with Broca’s aphasia. Such tasks would tap on action planning skills and, if such skills were exercised and enhanced, the patients’ response to speech treatments would be significantly improved.

Action plans are devised by identifying a superordinate goal and the sub-goals that must be executed to achieve the superordinate goal, being that the hierarchical relations amongst such goals determine how actions are hierarchically segmented [17–20] and adults who agree about where the action boundaries are also agree about the intentions or goals of the actors [21,22]. In the production and execution of action plans, the capacity to place breakpoints or boundaries into the stream of behaviour, reorganizing it into discrete, subordinate segments of actions – each of them being coupled with an intention or sub-goal – may

⁶ Experimental studies have demonstrated that language comprehension is affected – being facilitated or delayed – by the observation of actions and that the execution of actions can also be delayed by language comprehension; for instance, understanding a sentence that implies movement towards or away from the body interferes with how much time the person takes to release a button in order to move the finger towards or away from the body (in order to press another button to judge the sensibility of the sentence). The results of those studies suggest that the processing of language and the processing of action are underpinned by common brain mechanisms [2,15,16].

be applied to the own thoughts and knowledge previously acquired⁷. Such a process would be of crucial importance for what Koehlin & Jubaul [2] defined as the “successive selection of subordinate segments that constitute” “hierarchically higher action plans”.

In language, the hierarchically higher plan would be the overall idea to be expressed by any sentence – the superordinate goal – and, in order to express it, the person would have to successively select subordinate segments – the words and syntactical devices that compose the sentence – according to a set of sub-goals. If the production of language and the production of action plans depend on common neural mechanisms (of central importance for the hierarchical aspects of both processes), the person would only produce sentences if she was capable of reorganizing her own knowledge about an event into a hierarchical structure of events and sub-events and, at the same time, match each of those events or sub-events with a goal or intention. There was an experiment that investigated the capacity to reorganize a previously understood action into four segments, being that its results are quite relevant to the issue here discussed.

Fazio et al. [25] presented videos of events to Broca’s aphasics and each of such videos was followed by four snapshots (of the videos); the task was to establish the correct temporal order of the sub-events represented by the snapshots, but not all the events were endowed of a similar character: there were physical (unintentional) events, such as a bicycle falling on the ground (alone, with no agent interfering with it), and human actions whose comprehension depended on the decoding of agents’ goals and intentions. The performance of Broca’s aphasics at the physical event condition was very similar to the control (non-aphasic) group’s performance, but the same did not happen in the human action condition. Broca’s aphasics significantly underperformed at reorganizing correctly the snapshots of human actions, although their “understanding of the global meaning” of such actions “was mostly preserved”⁸.

By translating such results into the terms of the hypothesis here presented, the failure found by Fazio et al. [25] would be due to impairment to the capacity of reorganizing mental representations – knowledge that is already present in mind – into chunks of segments that are attached to intentions or goals – goals which are subordinate to higher-level ones and are responsible for defining the character and meaning of action segments. In other words, the Broca’s aphasics would achieve a global comprehension of actions by matching a goal or intention to the representation of the action – the action as whole – but they would not be able to attach goals and intentions to sub-actions that belong to distinct, subordinate levels of the action hierarchical structure. As a result, they would not form a hierarchical structure of goals and intentions that parallels the hierarchical structure of the action, being unable to attribute meanings to the action’s subordinate elements that make sense with the (previously understood) global meaning of the action. The skills that are necessary for such a process of hierarchical reorganization of knowledge would be crucial for the production of language and the impairment of such a capacity would help – if not be the main factor – explaining the agrammatical character of the speech from Broca’s aphasics.

Broca’s aphasia is hallmarked by abnormal or reduced grammatical forms as well as reduced phrase length (telegraphic sentences that are

⁷ It may happen because the comprehension of action hierarchical structure is not only important for understanding actions performed by other people, but also for a person to produce the own actions [17,18], being that the hierarchical segmentation of actions depends on the establishment of boundaries or breakpoints in order to form action discrete unities [14,21,23,24].

⁸ The Broca’s aphasics passed several tests that were applied to rule out patients who have further cognitive deficits (such as difficulties to attend and retrieve visual stimuli, apraxia and dementia), being forwarded to the experiment only the patients who passed such tests. The overall description of the patient’s condition included a well preserved comprehension of normal conversation [25].

usually no longer than three words and in which function words – such as prepositions and articles – are often missing, verbs are not correctly inflected and words are not correctly marked for number and case). Broca’s aphasics also present phonemic and semantic paraphasias (the replacement of the correct word by another one – existing or new – that is phonematically or semantically related with the correct word), impaired prosody and articulatory struggle [25–29].

If the reorganization of mental representations into hierarchically organized chunks whose subordinate segments are attached to goals and sub-goals is necessary for the production of sentences, the incapacity to match segments of behaviour to sub-goals would be a barrier to the production of sentences by Broca’s aphasics, preventing them from selecting linguistic segments in response to the setting of goals and sub-goals. This problem would be solved through a cognitive training program that targets the capacity to select subordinate segments that constitute *hierarchically higher action plans*.

The core of the training would be the exercising of the patients’ ability to automatically set the sub-goals and the correspondent subordinate segments (among a repertoire of sub-actions and sub-goals whose associations were previously learned) in order to fit such segments into a hierarchically organized higher-level action plan and accomplish the correspondent higher-level goal (that was defined at the moment)⁹. In other words, the training tasks need to demand from the patients the flexible, goal-directed combination of action elements whose association to sub-goals would obey previously learned rules¹⁰.

In summation, in the context of action planning, a person would establish the overall goal and, then, select the subordinate segments in consonance to the setting of sub-goals. When trying to produce language, a Broca’s aphasic would be able to identify the overall goal (the global idea that she would like to express) but would not be able - or not be fast enough - to set the sub-goals to be quickly coupled with the subordinate linguistic segments. As a result, the patient would not be able to form the necessary pairs of subordinate segments and sub-goals. This impairment could be solved by tasks that train the capacity to form hierarchical structures of goals and sub-goals by demanding from the patient to select subordinate segments of actions (in accordance to learned associations between such segments and sub-goals) in order to achieve the higher-level goals of hierarchically structured action plans.

Evaluation of the hypothesis

An important aspect of the hypothesis is the idea that the patients’ difficulties regarding language production is closely related with their lack of ability for segmenting events in the occasions where the identification of such segments implies the attribution of intentions. By taking as a premise that the production of hierarchically segmented communicative behaviour occurs in response to the setting of goals and sub-goals, the Broca’s aphasic difficulties to identify the subordinate

⁹ In general, the idea of automaticity is associated to the tasks that are performed quickly and relatively autonomously [30]. More specifically, in the context of the present article, the capacity to automatically set the sub-goals and the correspondent subordinate segments refers to the idea of automaticity that was reported by Greenfield [31]: the automaticity of lower-level elements in a hierarchical organized behaviour allows for re-directing the conscious attention to the higher-level elements; in the examples of Morse code and Braille, the learners start focusing “their attention on each letter” and, after the letter selection becomes automatic, they become able to redirect their conscious attention to the level of words. As the training goes on, the selection of words becomes automatic and “the sentence or thought” becomes “the object of conscious attention”.

¹⁰ The learning of motor sequences depends on the brain-derived neurotrophic factor [32], which suggests that stimulating the production of brain-derived neurotrophic factor could be profitable for the kind of treatment here proposed. Activities or habits that promote neurogenesis may be profitable as well.

(linguistic) segments based on the selection of sub-goals would be a barrier preventing the patients from producing regular speech. By making salient the boundaries between the linguistic segments and, therefore, establishing where the segments start and end, such a barrier could be diminished and, eventually, the matching of sub-goals to the subordinate segments would be facilitated. A treatment whose probable effect is to make those boundaries salient for Broca's aphasics was experimentally studied by Stahl, Kotz, Henseler, Turner and Geyer [33].

Stahl et al. [33] investigated whether the benefits of the melodic intonation therapy¹¹ (for patients diagnosed with Broca's aphasia or global aphasia¹²) are due to the presence of rhythmicity in the therapy; in this work, the regular melodic intonation was compared to a rhythmic speech condition in order to assess whether singing was necessary to improve patients' speech production [33]. In the context of the present article's hypothesis, the rhythmicity would help the patient to place boundaries in the language's stream of sounds; this would make easier for the patient to attribute identities to the linguistic segments if the boundaries provided by the rhythm temporally corresponded to the linguistic segments' boundaries – or, in other words, if the rhythm attracted the patient's attention towards the boundaries of the linguistic segments – since the identity of actions are defined at the action boundaries¹³.

The experimental results from Stahl et al. [33] did not show any difference between the melodic intoning condition and the rhythmic speech condition, suggesting that the “benefits typically attributed to melodic intoning in the past may actually have their roots in rhythm”. Returning to the line of thought of the hypothesis here presented, the rhythm may have triggered the neural mechanisms responsible by the segmentation of the stream of behaviour – a process which generates the subordinate segments which are to be fit in hierarchically higher action plans.

The treatment may have made the boundaries of the linguistic segments salient, helping the patients to establish the identity of the linguistic segments by associating the breakpoints from the rhythm to the boundaries of the linguistic segments: once the boundaries of the subordinate elements of language's stream of behaviour were localized, it becomes easier for the patient to associate a communicative goal or intention with each segment and to organize those subordinate segments into a hierarchical structure.

According to the hypothesis here presented, the patient would better exploit the benefits of the therapy if she exercises the capacity to organize subordinate elements into hierarchical structures or, more specifically, to integrate the successive selection of subordinate segments with hierarchically higher action plans. It was precisely what the tasks from Koechlin & Jubaul [1] required from the subjects to carry out – such tasks could constitute the way towards the solution of the problem of how to test the hypothesis.

Koechlin & Jubaul [1] developed two tasks that consisted in pressing keys on the keyboard in response to symbols appearing on a screen, being the selection of the keys dependent on previously learned sequences and on which symbols were displayed on the screen. In the simpler of those tasks – the simple chunk condition – the subject was to press the keys as a response to squares appearing on the screen: RIGHT and LEFT simultaneously for each blue or yellow square (the baseline trials) until a green one appears; the green square signals that the

subject may respond to the subsequent blue and yellow squares according to a previously learned keys' sequence – the pre-learned sequence of simple chunk trials – and stop the sequence when a red square appears¹⁴, returning to the baseline and staying on it until the next green square. The second task is more complex because the subject may look at two letters appearing simultaneously on the screen (one above the other) in order to decide which key to press on – it was the superordinate chunk condition.

In the superordinate chunk condition, the combination of two letters defines whether the subject must press on button RIGHT or on button LEFT. In the baseline task, one of the letters was always C₁, while the others could be A, B or C (placed pseudo-randomly); if A was displayed, the subject must press on RIGHT; for B, LEFT; and for C, LEFT. The baseline trials go on until a green letter appears, signalling the beginning of the pre-learned sequence of the superordinate chunk trials; within this pre-learned sequence, the letters A, B and C will continue to appear pseudo-randomly, while the straight sequence of C₁ letters is to be replaced by a pre-determined sequence that is composed by the letters C₁, C₂ and C₃; the subjects were to press RIGHT or LEFT depending on the combination of the letters¹⁵ [1].

Such tasks recruited the Broca's area (BA 44 and 45), which – as already mentioned – is also known to be recruited by the processing of hierarchical structures of language, including the task of “organizing linguistic segments that compose speech”; the Broca's area was proposed “to play a pivotal role in chunking linguistic subordinate elements into superordinate representational structures within the phonological, syntactic, and semantic dimensions of language”¹⁶. Such data and proposal seem to be compatible with what is suggested (by the experimental results) about the importance of Broca's area recruitment to the formation of action chunks¹⁷ [1]. A cognitive training program for Broca's aphasics could be devised by using such tasks as a starting point.

New possibilities could be aggregated to the task, such as adding UP and DOWN to the LEFT and RIGHT responses, resulting in four possibilities of responses – four buttons to press on – and in a greater number of possible sequences. Such an addition could also be used to create more complex and larger sequences or even to add a new level to the action architecture of the superordinate chunk condition. It could be done by making the subjects to cross information from three letters within the pre-learned sequence of chunk trials in order to define which button to press on, being that the letters would vary independently of one another.

In order to do that, it would be added a third letter that initially signals whether the subject is to press UP or DOWN independently of the other two letters in the baseline task; it means that the subject would be looking at three letters appearing simultaneously, two of them

¹⁴ The previously learned sequence consisted of pressing the following buttons: LEFT & RIGHT > LEFT & RIGHT > RIGHT > RIGHT > LEFT; each of those sequence components were to be pressed in response to a square appearing on the screen (1).

¹⁵ The combination of letters, signalling which button to press on was as follows: for C₁, A means RIGHT, B means LEFT, and C means LEFT, just like in the baseline condition; for C₂, A means LEFT, B means RIGHT, and C means LEFT; for C₃, A means LEFT, B means LEFT, and C means RIGHT. The sequence was: C₁ accompanied by another letter (A, B or C) > C₁ & letter > C₂ & letter > C₂ & letter > C₃ & letter [1].

¹⁶ Hagoort [6] proposed that the left inferior frontal gyrus is responsible by the phonological, syntactical and semantic unification in language, resulting in “multi-word utterances”.

¹⁷ Based on such a pattern of recruitment, Koechlin & Jubaul [1] proposed a model according to which the posterior parts of Broca's area and its right hemisphere homolog exhibit “phasic activations at boundaries of simple chunks” of actions, while their anterior regions “show phasic activation at boundaries of superordinate chunks”, which correspond to chunks of simple chunks (of actions).

¹¹ Since non-fluent aphasics are often able to sing, several types of therapies have been devised in order to take advantage of it, being the melodic intonation one of them (33).

¹² The subjects of the study presented by Stahl et al. (33) were diagnosed with Broca's aphasia or global aphasia, being collectively referred to as non-fluent aphasics along the article concerned.

¹³ Experimental results suggest that the boundary of an action differs from other parts of the action because the boundary coincides with the moment when the uncertainties with regard to the character of the action are eliminated, being the action defined at such moments (24).

would function exactly as they do in the superordinate chunk condition, signalling sequences of LEFT and RIGHT buttons, while the third would initially elicit a second, independent response concerning the UP and DOWN buttons and, therefore, the subject was to click on two buttons for each set of letters that appears. However, when a start cue appears and the pre-learned sequence of chunk trials begins, the subject would have to cross information from the three letters in order to give a single response: if the third letter elicits two UP buttons or two DOWN buttons one after another, the button to be pressed on in response to the next dyad of the other two letters would change: if it was RIGHT, should become LEFT; was it LEFT, should become RIGHT. It would make the subject to cross information from the dyad of letters with a third stimulus within the pre-learned sequence of the chunk trials in order to generate a single choice, adding a new layer to the action architecture. Alterations like that one would aim to increase the demands on the patient's hierarchical processing skills by imposing the development of the capacity to process more complex structures.

In summation, a combination of a traditional treatment of aphasia with a cognitive training targeting on action planning mechanisms could be used to test the hypothesis. The hypothesis predicts that the recovery of the patients would be significantly enhanced by a cognitive training program composed by the tasks presented by Koechlin & Jubaul [1] and/or other tasks that demands the fast integration of the successive selection of subordinate segments with hierarchically higher action plans. More precisely, the patients would improve their action planning skills along the cognitive training program and the skills newly re-developed would be used in the treatment, resulting in improvements of language production which would surpass the improvements obtained with the traditional treatment alone.

Conclusion

The present article proposed a practical application for the body of knowledge that has been accrued on the relationship between language and action. Such a body of knowledge points towards the conclusion that the brain mechanisms responsible for the combination of elements into hierarchical structures with the aim of reaching goals are also the mechanisms responsible for the hierarchical processing of language. Before such a conclusion, the present article hypothesizes that the impairment to the capacity of selecting subordinate segments that form hierarchically higher action plans is the decisive factor behind the difficulties of Broca's aphasics with regard to language production and proposes that training such a capacity would contribute to the recovery of the ability for producing language of Broca's aphasics.

It was also proposed that the hypothesis could be tested by using a cognitive training program based on the tasks used by Koechlin & Jubaul [1] to investigate the role of Broca's area in the production of hierarchically organized actions. The hypothesis predicts that the combination of the cognitive training with a treatment of aphasia – preferentially a treatment that evinces the boundaries of linguistic segments – would improve the rehabilitation of the patients with Broca's aphasia (in comparison to the treatment alone).

Should the combination of the cognitive training with a treatment of aphasia be confirmed to be more effective than the treatment alone, there would be new evidence – a very strong one – in favour of the idea that language and action are closely connected, since the most likely explanation for such hypothetical results would be the re-use for communicative purposes (within the domain of language) of the connections that were originally developed within the action domain.

Such results would comprise strong evidence that the processing of language and action share brain connections that are responsible for the production of hierarchically organized behaviour instead of relying on distinct sets of connections that were adjacent to one another. More specifically, the brain connections concerned would be responsible for the successive selection of subordinate segments that constitute hierarchically higher action plans, being that such connections would be

indispensable for the effective functioning of the *mechanism that allow us to sensibly combine meanings across sentences* in the context of language production as well as to hierarchically combine goals and sub-goals in the context of action production.

In a broader perspective, such hypothetical results could stimulate the discussion on the possibility that some of the skills which are crucial for language would be more easily and effectively recovered through cognitive training programs that are constituted of non-linguistic tasks, since the results would comprise a real example of one of those (hypothetical) cases. This could help stimulate the study of the relationship between language and other aspects of human cognition with the specific aim to generate new rehabilitation programs.

Conflict of Interest:

I, Ciro Antunes de Medeiros, author of “An action planning mechanism hypothesis on non-fluent aphasia”, certify that I have no affiliation with or involvement in any organization or entity endowed of any financial interest in the subject matter or materials discussed in this manuscript.

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