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Language and non-verbal cognition in Aphasia: insights from an eye-tracking paradigm

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Abstract

The relation between language and thought is a far from resolved question in both linguistics and cognitive science. A language disorder like aphasia can shed light on this question by using it as a model to explore cognition with impaired access to language. In this study, our research question was whether people with aphasia would succeed in a task that requires generalizing across a series of 32 reversible transitive events that exhibit visual differences, while still falling under the same general event concept (e.g. *dog pushes car* where the cars and dogs change). We explored this question with an eye-tracking paradigm. This study reports findings from an initial pilot with five people with post-stroke aphasia and 5 matched neurotypical controls. Results showed that the aphasia group was able to make the event generalization, but differed in the time course of processing, with initial insights not maintained longitudinally. We speculate that this may be due to problems with working memory. These preliminary findings suggest that while language impairment does not necessarily interfere with event generalization, may play a crucial role in information management with respect to what we perceive.

Key Words: aphasia, event generalization, language, cognition, visual perception, two place predicates.

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1. Background

1.1 Language and Thought

Are language and thought one, or are they two separate cognitive systems? This is a core question of both linguistics and cognitive science that seems to be far from resolved. In this paper, we would like to first address some of the foundational views in terms of language and thought as one or as two separate systems.

For Bickerton (1995), language and human intelligence are basically one, language being the inherent basis of human-specific intelligence. He suggests that core characteristics that distinguish us from animals are due to language, particularly our special kind of intelligence and consciousness. Human cognition has the properties it does because it came out of language and not vice versa. He denies that human inference engines, logic modules and problem-solving devices among other cognitive mechanisms came before language. A key argument in favour of language and thought as one is the concept of 'off line thinking'. According to Bickerton (1995), language is what allows us to think about things outside of our immediate environment. The representations involved in off-line thinking have two important features: first, they have recursive syntax and second, they involve a special kind of 'denatured' representations, which are not connected to any specific perceptual modality nor to any specific mode of activity (Segal 2010:125).

Bickerton's view is opposite to a standard belief in linguistics and cognitive science which is that language and thought are two different systems. This 'Cartesian' view, often in the field of psychology, sustains that language and thought can be seen as independent elements. Fodor (1986), who represents this view, argues for thought as prior to language. On this view, the language faculty would include information about phonology, morphology syntax and semantics, but differs from the systems that support our thinking. According to this interpretation, the representations we use when thinking are different than the ones represented in the language faculty (Segal 2001:125). Fodor (1986) defends a partially modular theory of cognitive processes, where certain computational mechanisms are specific to a certain domain. On this view, our human intelligent behaviour requires thought which in itself requires representation. For this we need a system of internal representation that has its own grammar and vocabulary (Dennett 1977:265). This is what he calls the Language of Thought (LoT), which would be a different system than the language we use to communicate.

Reboul (2017) also sees language as grounding human-specific thought and not just a tool for communication but makes the distinction between LoT as being for thought, and external languages for communication[1] . Hinzen (2017a) disagrees with this distinction and explains that since we humans cannot talk without producing thoughts and communicating them, and vice versa, this distinction seems irrelevant. Why can't LoT simply be an inherent aspect of language? He questions the distinction between I-language and E-language since 'there seems to be no evidence of the existence of any human like minds that have language figuring in them internally, yet do no externalise it as speech or in some other way.' In an 'Un-Cartesian view' (Hinzen 2017a), thinking needs language, and grammar is the system that supports thinking. On this view the grammar of the LoT is inherently related to the grammar of human language, meaning there would not be a difference as in Fodor's case between what he calls the LoT and the language we use to communicate or E-language.

Carruthers (2002) who stands for a Cartesian view of language and thought explains how language can be necessary to perform certain cognitive tasks, but not others, but he still sees this view as controversial. He considers that seeing language as the medium of all human conceptual thinking is too strong of a claim because undermines the cognitive abilities of pre-linguistic children and animals and earlier forms of hominid who didn't have a developed language. According to Carruthers ,'what is at stake is then the question whether language might be constitutively involved in some forms of human thinking' (Carruthers 2002:664) and if so in which ones. He brings up inner speech as possibly a tool for conscious-conceptual thinking, as opposed to conscious visio-spatial thinking (Carruthers 2002: 8). His hypothesis is that language is the medium for non-domain specific thinking, integrating a variety of domain specific conceptual faculties. Varley (2014) refers to Carruthers exemplifying the kinds of problems that might require language faculties to be solved. These would be 'ones involving long inference chains, cross-domain integration, embedding, or perhaps a degree of abstraction away from surface properties of stimuli, might mandatorily require the re- sources of the language faculty' (Varley 2014:234).

Going further into the relation of language and thought, Lupyan and Clark (2015), explore the relation between language and cognition and perception. The authors particularly note that how, 'once learned, verbal labels continue to be uniquely effective in activating conceptual content' (Lupyan & Clark 2015:282). Language is not only the tool to

[1] According to Chomsky (1965), external or E-language is different from internal or I-language, which is the primary subject of linguistic theory.

communicate our thoughts but it actually shapes them. Researchers working from the core knowledge perspective[2] claim that language is what allows humans to weave together otherwise encapsulated representations within core knowledge systems, and that this connection among representations is the gateway to higher-order, abstract representations unique to human cognition (Carey 2009).

1.2 Is language necessary for "non-linguistic tasks"?

There is a lot of experimental work that digs into the issue of language and thought and what their relation is. Dual tasks-designs as those involving verbal shadowing and evidence from child development can provide interesting insight into this matter.

Starting with dual task designs, there is evidence that language proves necessary for certain perception tasks that at first sight seem to be non-linguistic. Baldo (2005) found that healthy subjects under a verbal shadowing condition performed worst at the WCST [3](Wisconsin Card Sorting Test, a non-verbal reasoning test) than subjects under a non-verbal shadowing condition (tapping) and a group of subjects without any shadowing.

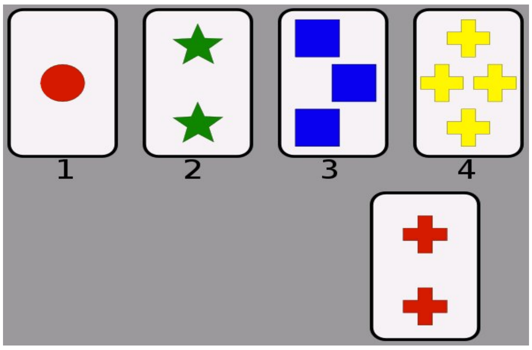

Figure 1 Example of WCST

[2] "Core cognition is articulated in terms of representations that are created by innate perceptual input analyzers. Natural selection has constructed these analyzers specifically for the purpose of representing certain classes of entities in the world, and this ensures that that there are causal connections between these real-world entities and the representations of core cognition." Carey (2009:67)

[3] The WCST is a test where the participant needs to find the pattern (it can be color, number or shape). They are guided by the examiner who tells them if they are write or wrong. The pattern stays the same for some rounds and then the examiner changes it -without telling the participant- to see if they notice it and can figure out the new pattern.

De Villiers (2014:100) also found that 'verbal shadowing is selectively disruptive for the recognition of similarity across perceptually diverse events sharing a propositional description, but not of the formation of other abstract concepts'. She presented participants (healthy adults) with a picture of a man pushing a woman in a wheel chair and then a set of pictures (3 distractors and a target) for them to match the original picture with one of them. The distractors had for example the patient-agent inverted or the correct verb but with a different participant. The target was a different man pushing a different woman on a wheelchair. The group under verbal shadowing performed worst, followed by the group under rhythmic shadowing and the group with no interference performed best. It is important to note that before the task participants had a practice round, without verbal shadowing, where they were explained the task and the right choice was pointed out if they made a mistake.

However verbal shadowing as a method for exploring the language-dependence of certain cognitive processes is not undisputed. Varley (2014:233) contests this evidence as showing that language is necessary for performance on these non-linguistics tasks, on the grounds that the verbal shadowing must disrupt performance in a stronger way than rhythmic shadowing to discard the interference being caused by divided attention or motor demands. She also mentions that even though there is evidence of verbal shadowing disrupting kinds of tasks like visuo-spatial orientation, false belief tasks and ToM (Hermer-Vazques 1999, De Villiers 2014, Newton& Devilliers 2007), other researchers have failed to replicate these results (Learmonth et al., 2002; Bek et al., 2010; Fouget d'Arc and Ramus, 2011; Dungan and Saxe, 2012; Bek et al., 2013).

Another interesting issue that arises here is whether verbal-shadowing can be culturally dependent. Kim (2002) had participants from different cultural backgrounds, Asian-American and European-Americans, perform a matrix reasoning test while reciting the alphabet. The results showed that European-American students performed worst under articulatory suppression, but for the Asian-American group there was no significant impairment.

A recent eye-tracking study from the Boston BabyLab (Shukla 2016: manuscript in preparation) has also found that results in perceptual generalization tasks (performing event generalizations from exclusively visual stimuli) vary when the participants are performing them with their linguistics faculties compromised (verbal shadowing condition), like repeating out loud a text they are hearing on headphones. In this condition participants showed much more difficulty correctly performing the task compared to the control group (see Figure 2 below). This could be seen as an 'artificial aphasia' condition. Preverbal infants also performed worse in this task than verbal infants which could also be evidence that access to language is needed to correctly perform these kinds of task. This task design but without the verbal shadowing variable is the one we have replicated in our study (see Figure 5 and section 3.2 for more details on the design).

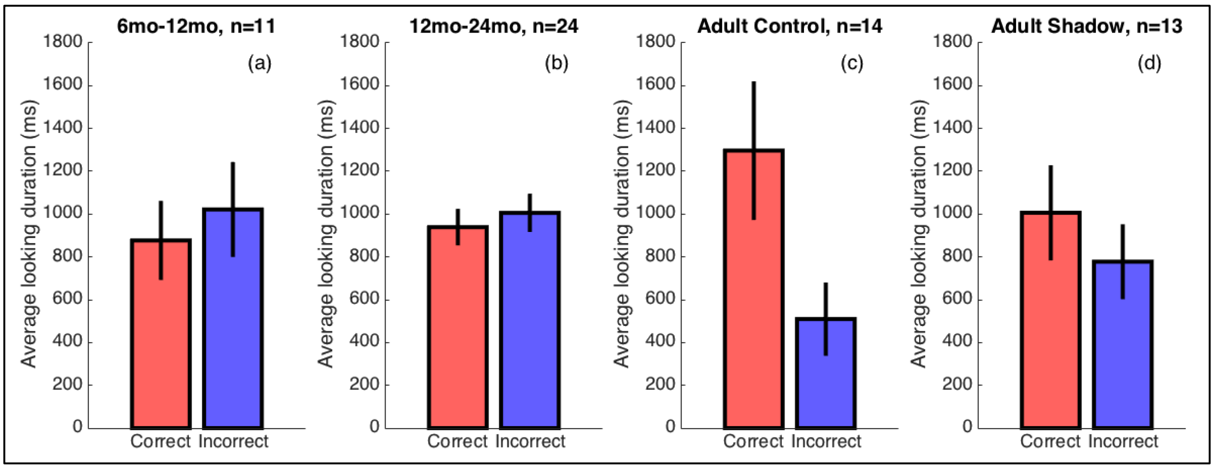

Figure Results from infants 6-12 month old (a) , children 12-24 months old (b), adults non-verbal shadowing (c), and verbal shadowing adults (d). Verbal shadowing in adults disrupts the task performance compared to the control group.

1.2.1 Evidence from infant development

As seen in the results of the study mentioned above, a good window into the link between language and cognition is infancy, as stated by Carey when referring to childhood and conceptual development:

> The lexicon stands right in the middle of any theory of conceptual development. Words express concepts, and most of the concepts I have been concerned with are of the grain of single lexical items. How is it that language comes to be integrated with non-linguistic representations, such that it is a vehicle for expressing thought? Carey (2009:247)

Pre-verbal infants can tell us a lot about the relation of language and thought by showing us what kind of cognitive tasks require language. The domain of both object and event categorization are of much interest here because there is a lot of evidence from pre-verbal infants and young infants that shows that categorization is dependent on language. One of these studies is Ferry et al. (2010) where she presented 3 to 4-month-old babies with 8 exemplars from two different categories (either dinosaurs or fish). The babies were divided into two groups: word condition -where they heard a naming phrase when presented with the visual stimuli- or tone condition, where they heard a tone when viewing the stimuli. The researchers showed by analyzing their looking time, that 3 to 4-month-old babies formed categories when the auditory stimuli that accompanied the presentation of the objects were verbal. On the other hand, if what they were presented with were tones they failed at categorization.

The importance of categorization relies of the fact that when we identify two objects as belonging to the same category we put them on an equivalent level of representation which allows us to identify other members of that same category and to make inferences about them. Object categorization supports memory and reasoning and guides our predictions about objects we have not encounter yet and can for example warn us in dangerous situations (for example if we see a dog showing its teeth we know to avoid dogs showing their teeth without the need of getting bitten in every single encounter with them) (Perszyk 2017:235). The first step in categorization is the noun–category link, afterwards children go on to establish precise links for the predicates, including adjectives and verbs. What we observe regarding object categorization is also then the case for event categorization in infancy. This increasingly precise link between language and cognition unlocks representational capacities that distinguish human cognition from animal cognition (Perszyk 2017:237).

1.2.2 Evidence from functional neuroimaging

Fedorenko and Varley (2016) use fMRI data as evidence that language and thought are not the same thing. Based on that data they claim that there is a separability between the regions that support high-level processing and those in charge on complex thought. They take the case of arithmetic, for example, where fMRI data shows that brain regions that are active during language processing are not when solving arithmetic problems, and vice versa. Regarding executive functions, the authors come to the same conclusion, and in the case of music - which has many properties in common with language: rhythmic structure, recursion, etc. - Fedorenko and Varley say there is not an overlap in terms of neural activations of language areas while performing these tasks. Therefor they claim that both abilities are dissociated. A dissociation can also be seen in the case of people with severe language difficulties who have no problems with music perception. The case of spatial navigation seems to be different where the authors mention that language representations might be used in support of reasoning, particularly under conditions of high demand. However, they do say that there is not enough evidence in this regard since some experiments like Hermer-Vazques et al. (1999), where the authors found that healthy adults engaged in verbal shadowing had problems re-orientating themselves with just geometrical information only, have not been always successfully replicated. Fedorenko and Varley (2016) then conclude that grammar can play a central role in configuring cognitive processes, but once these processes have been established, cognition can operate without grammar.

1.3 Aphasia as a window into language and thought

An interesting way to shed light into the language and thought distinction – or lack thereof – is studying populations with either cognitive impairments or language impairments to see if it is in fact possible to have one without the other or if they are not mutually exclusive. Hinzen (2017b) extends this idea to the claim the linguistics could actually mature into a science of cognition.

> Linguistic and cognitive diversity in clinical populations thus informs linguistic theory, by illuminating the foundational question of what language is. In turn, linguistics can shed new light on cognitive disorders, potentially evolving towards a 'science of cognition' (i.e. the human cognitive type) rather than merely representing the study of a neurocognitive domain taken to be specific (a cognitive science among others) (Hinzen 2017b:4).

Aphasia is an impairment of language that can affect language production and/or comprehension and can be caused by either a stroke or head trauma affecting the left hemisphere of the brain. Aphasia is usually seen as simply a language disorder where cognition is mostly unaffected, but this is not always the case since aphasics have been found to exhibit problems with performance on cognitive function measures like attention, executive skills and working memory (Lee 2014, Villard 2017), therefore describing it as a mere language disorder as it often is, seems inaccurate. Baldo's studies (2005, 2010) have also suggested that aphasia due to a stroke can have an impact not only on linguistic skills but also on non-verbal cognition, for example she found aphasics performed worse than healthy controls in the WCST (see Figure 1) test and in Raven's (see Figure 3) items that required relational reasoning compared to those items that only required visual-pattern completion.

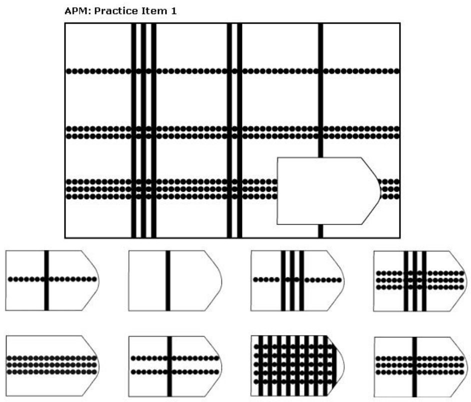

Figure 2 Example of Raven´s Progressive Matrices Test, a non-verbal reasoning test

In a study to test cognitive deficits in patients with aphasia, Lee (2014) concluded that these exist (for example in terms of working memory) and may be associated with language measures. In the comparison between left hemisphere injured patients (26 aphasics and 32 non-aphasic patients) working memory seemed to be significantly impaired in the aphasia group. The fact that there is not a more systematic evaluation of non-verbal skills in patients with aphasia prevents inferences about the direct impact of language on other cognitive functions. These findings can have an important role in recovery and rehabilitation and can influence the development of better assessment and rehabilitation materials and adjust treatment protocols to subjects needs as well as understanding the risk of dementia in aphasic patients (Fonseca et al. 2016:137).

Baldo (2005, 2015) and Fedorenko & Varley (2016) explore the connection between language and thought using aphasia as a model. These authors seem to reach very different conclusions from each other. As previously mentioned, from fMRI studies Fedorenko & Varley (2016) conclude that high-level language processing brain regions appear to be inactive during a wide range of non-linguistic tasks. This suggests for them that these regions selectively respond only to features that are present in linguistic stimuli. On the other hand, Baldo (2010, 2015) found – again through fMRI studies – that lesions involving language areas in the left hemisphere are associated with decreased performance on reasoning and problem solving-tasks. Left hemisphere stroke patients with aphasia performed worse than left hemisphere stroke patients without aphasia on the Raven´s Matrices Test. There was a significant interaction showing that participants with aphasia were disproportionately impaired on items that required relational reasoning compared to those items that only required visual-pattern completion as mentioned before (Baldo 2015:10). She does however mention that this could be due to overlapping networks that underlie language and reasoning processes or even that a third unidentified cognitive process which could potentially underlie both language and reasoning.

1.3.1 Aphasia as a model of cognition with language subtracted?

As stated before, aphasia is often characterized as a language-specific disorder. If we were to see it that way, then we could say that aphasia is a model of cognition with language subtracted. But is this really the case? This question could be addressed using the competence-performance distinction as developed by Chomsky (1965), competence refers to a person's knowledge of a language and performance would be putting that knowledge in practice when using said language. Discussing this distinction in relation to aphasia, Bates (1991) argues that language-specific knowledge (competence) is actually preserved in patients with Broca's and Wernicke's aphasia, but the problem lies within the performance aspect, meaning people with aphasia cannot access and put into use the language knowledge that they have. Evidence supporting this view comes from experiments like Linebarger (1983) and Bates' (1991) own replication of Linebarger´s experiments among others. Here patients with Broca's aphasia where presented with ungrammaticality judgement tasks (with the sentences being spoken out loud to them) and could actually perform this task very well, but not at celling[4]. The fact that they can recognize a sentence as grammatical but they cannot produce a grammatical sentence could be explained if we adopt the performance and competence model. Linebarger (1983) argues based on these experiments that the explanation that production and comprehension problems of agrammatism are due to an inability to construct syntactic representations is flawed. It seems the patients are unable to retrieve syntactic structures for the purposes of expressing propositional thought (Linerbarger 1983), but they can retrieve them for processing purposes.

1.3.2 The case of Theory of Mind in aphasia

Theory of Mind (ToM) can be defined as the ability to understand that other people have beliefs, knowledge, desires and emotions that may be different from those of one's own

[4] The study had no control group to compare the aphasic's performance against.

(DeVilliers & DeVilliers 2012:313). It is usually believed to be a non-linguistic ability, independent of grammar (Siegal & Varley 2006), although some authors like DeVilliers (2014) think otherwise due to evidence from infancy that suggests that ToM develops parallel with language. Since ToM undergoes a lot of change when children are around 4 years old, the argument could be made that ToM depends on the ability of embedding propositions (*Ana thinks that…*). Nevertheless, some researchers (Oshini & Baillargeon 2005) have found by following looking patterns during false belief tasks of very small children who are barely verbal (15-month old) that ToM is already present.

In this context aphasia is very interesting because it provides a test case for exploring the issue of the need of language for ToM. One could argue that since there is evidence that people with aphasia don't have a problem with these tasks (Varley 2016, Siegal & Varley 2006), this means that language is not needed to correctly perform them. An explanation for why this population succeeds in ToM tasks could be that language acquisition is needed to develop the structures necessary to understand other mental states but that once this skill has been acquired the access to it is not indispensable for ToM. It could be seen as a case where competence is necessary but not performance. The role of language in ToM might be one of scaffolding for the construction of cognitive architecture and one the system is in place the linguistic support may not be necessary anymore (Siegal & Varley 2006).

According to Varley (2016), dissociation has more weight than association, meaning that the evidence that there are individuals with aphasia who can perform certain non-linguistic cognitive tasks is enough proof that such tasks do not need to be supported by language. She claims that language may play a role in non-linguistic cognition in the development of certain skills, like ToM, and can work as an additional representation format to ease cognitive load when facing certain tasks (for example visual spatial orientation). She bases this conclusion strongly on Varley & Segal (2000), where they present a case study of an agrammatic patient S.A., who despite of scoring at chance at grammatical comprehension tests was able to correctly perform on ToM tasks. The authors claim that S.A 'was not able to make judgments as to whether a sentence is grammatical, or to match sentences to pictures, or to identify the meaning of verbs (Varley & Segal 2000:724). However, when looking carefully at the chart with his scores (see Figure 4) we can see that he was well above chance in several measurements, for example spoken word-picture matching and written word-picture matching.

Table 1

Performance of S.A. on measures of language processing.

Test	S.A. score	Chance score
Spoken word–picture matching	35/40*	8/40
Written word–picture matching	37/40*	8/40
Spoken sentence–picture matching 1	23/60	20/60
Spoken sentence–picture matching 2 (re-test)	28/60	20/60
Written sentence–picture matching	15/30	10/30
Grammaticality judgments	19/30	15/30
Auditory comprehension of verbs	14/27	13.5/27
Auditory comprehension of adjectives	10/14	7/14
Written picture naming	24/60	–

Figure 3 S.A test scores with chance scores as reference values

Baldo et al. (2005) also bring up a strong point when referring to the fact that S.A can understand the instructions needed for the tasks, meaning his language comprehension must be only mildly or moderately impaired.

1.3.3 Categorization in aphasia

As it was mentioned before, language is crucial for the acquisition of categories in infancy, but is it also necessary to access them once we have already acquired them? If we have a person with limited access to their language faculties – like a person with aphasia – would they have problems with categorization? Grouping objects into categories is a perceptual process, which intuitively would not have to be language-dependent. Regarding aphasia and this particular topic there is little research done. Lupyan & Mirman (2013) compared the performance of 12 people with relatively mild anomic aphasia to that of 12 healthy controls on a categorization task. The participants were asked to choose all the objects that fitted a certain category from sets of 20 pictured objects. The participants with aphasia performed worse than controls in cases where the objects shared one or few features (for example objects were the only feature they had in common was the material there were made out of) and this impairment correlated with naming impairment. The researchers find that these results ‘offer some support for the hypothesis that language supports cognitive functioning, particularly the ability to select task-relevant stimulus features’ (Lupyan & Mirman 2013:1187).

1.3.4 Event processing in Aphasia

Nicholas & Vaughn (2013) tested 28 aphasic participants on an event processing task and compared them to healthy controls. Their experiment consisted of 32 video segments -lasting 5 seconds each- that the participants had to watch. Afterwards they had to pick a picture from a set of three that showed the outcome of the event they had seen in the video. No language is spoken in the video and half of the actions were reversible while the other half were non-reversible.

> Using a criterion of more than two standard deviations below the mean of the controls as indicative of impairment, a surprisingly large portion of the sample with aphasia (54%) had impaired event processing. The data analysis indicated deficits in event processing were related to impairments in language and nonverbal cognition. (Nicholas & Vaughn 2013:532)

As previous evidence of aphasia and problems with processing events there is Fazio´s 2009 study, where he had 6 participants with Broca’s aphasia perform a picture arrangement task where they watched a video and then were presented with 4 snapshots of that same video that they had to place in the correct order. His findings show that the aphasics were ‘specifically impaired in sequencing pictures representing actions (transitive or intransitive) performed by a human agent but not in the sequencing of physical events’ (Fazio 2009:1986). Marshall (2005) had found similar results to Nicholas & Vaughn (2013), but only in case studies, never with a large number of participants. Marshall (2005) claimed that it could be that the thinking for speaking hypothesis[5] is the explanation behind why people with aphasia have problems with these sorts of tasks: ‘some people with aphasia may be unable to build grammatically principled, constrained schematisations of events that can be mapped onto their language’ (Marshall 2005:1011).

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[5] Thinking for speaking is a theory developed by Slobin (1987). He suggests that, “during utterance formulation, speakers direct their attention to the properties of events and situations that are most readily expressed in their language. (Marshall 2005:1009)”

As an explanation for their findings Nicholas &Vaughan (2013) propose that a language deficit can affect the processing of non-verbal observed events because the person is not able to engage their internal language, especially when it comes to a task that will require a response from them (even if is not a verbalized response). Without access to inner speech faculties, certain tasks may not be performable. He gives the example of how after watching a video of a man buying a camera for a woman, our inner speech might automatically generate something like 'I saw a man pay cash to a woman for a camera' (Nicholas &Vaughan 2013:541). This is in line with Baldo's (2005) findings that people with aphasia performed much poorer than healthy controls at the picture arrangement task but not at the picture completion task of the WAIS test[6]. She also cites inner speech as a requirement to be able to correctly perform the task, saying that not being able to engage in inner speech would cause a problem with working memory. Since picture completion doesn´t have a narrative element but picture arrangement does this makes a strong argument. Lupyan & Clark (2015) on their paper regarding the language-perception-cognition interface, make very similar claims regarding self-directed speech, saying it´s a powerful tool for manipulating thought and reasoning.

Nicholas &Vaughan (2013) also mention that when checking which variables predicted scores on the Role Video, the CLQT non-verbal cognitive score emerged as a predictor for 65% of the variance in the Role Video score within the aphasia group and a similar result was found in the control group as well. From the subtests of the CLTQ the one that emerged as a significant predictor was the Symbol Cancellation subtest[7]. This could mean that maybe the task requires a combination of both language and non-verbal cognition and having only one available makes the performance on the task harder but not impossible.

A deficit in understanding observed actions can be extremely important for communication, interacting with other and basically daily functioning, a person with such deficits would not be able to correctly identify the thematic roles of the participants of an event. This itself is key to therapeutic endeavours with aphasic patients since both linguistic and non-linguistic treatment protocols rely on this process (Nicholas &Vaughan 2013:533).

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[6] In the picture arrangement task the participant is shown pictures that tell a story and is told to put them in the correct order. In the picture completion task the participant is shown a picture and has to identify the element that is missing.

[7] This is a non-linguistic task of visual attention and perception. The participants need to search for target items and either cancel or circle them.

2 Research question and hypotheses

The present study builds on the above findings and explores further event categorization under conditions of language impairment in aphasia, focussing on visually presented reversible transitive events. Our primary research question was whether people with aphasia would succeed in the task of generalizing across events that exhibit visual differences, while still falling under the same general event concept, e.g. *dog pushes car*.

Based on the findings mentioned above by Baldo (2005) and De Villiers (2014) with healthy adults under a verbal shadowing condition, as well as Nicholas & Vaughan's (2013) findings on people with aphasia and their problems regarding event processing, we predicted that people with aphasia would perform worse than the control group on this task.

3 Methods and materials

The study consisted of two experiments and involved three different groups of participants tested on the same eye-tracking paradigm. First, we conducted a replication of the Boston study mentioned in the background section of this paper (Shukla & De Villiers (2014), see 1.2) with UPF students. Afterwards we tested a group of people with aphasia paired with an aged and education-matched control group.

3.1 Participants

For the initial replication, 19 students of both genders aged 20-30 were recruited from the Brain and Cognition Lab of the University Pompeu Fabra in collaboration of Professor Luca Bonatti. We only did the eye tracking task that is described below (3.2) with this group and not the other tests (mentioned in section 3.2 and performed with the aphasia and control group) because this were not done in the original study we were replicating. The replication experiment was important to see if we had the same findings as the researchers who developed the stimuli did, using a different tobii eye tracker, before moving on to the aphasics group.

The participants of the aphasia group were 5 patients recruited according to the following inclusion and exclusion criteria: the patients had to have any kind of aphasia without dementia, caused by a single stroke affecting the left hemisphere and could be in any phase of the rehabilitation process. They were aged 48-90. They were all patients from the Hospital

General de L'Hospitalet and were recruited by Dr. Maria Isabel Gomez Ruiz. Clinical data are summarised in Table 1. Initially she had recruited 12 patients, but 7 patients had to be ruled out for the following reasons:

- 2 patients never showed up to their appointment.
- 2 patients agreed when visiting the hospital to participate in our study, but then we were not able to reach them on the phone for scheduling their appointment.
- 1 had dementia.
- 1 had to cancel his appointment because was hospitalized for an infection.
- 1 was on a wheel chair and had transportation issues to come to the hospital without an ambulance being available.

A control group for the aphasia group was also recruited, matched on age and educational level. This group was recruited by me with the help of the Center of Brain and Cognition.

Table 1: Clinical Data							
Participant	**Group**	**Aphasia**	**Sex**	**Age**	**Education**	**Lession**	**Speech Therapy**
1	AP	Crossed Aphasia	F	72	Elementary	Right Temporal Lobe Hemorrage	July-December 2014
2	AP	Transcortical sensory	F	55	High School	Left temporal lobe hematoma	March-July 2016
3	AP	Motor	F	77	Elementary	Middle cerebral artery stroke	18.08.17-07.02.17
4	AP	Motor	F	48	Elementary	Left pariotemporal stroke	April-Nov 2017
5	AP	Mixed	F	90	Elementary	Left parietal stroke	July-August2017
6	CO		M	67	High School		
7	CO		F	53	High School		
8	CO		M	50	High School		
9	CO		M	50	High School		
10	CO		F	53	High School		
AP=APHASIC							
CO=CONTROL							

Table 1 Control's and Aphasic's Data

3.2 Procedure

All participants underwent the same eye-tracking protocol, described below. Younger and aged matched controls were tested at the Brain and Cognition Lab at UPF. Patients with aphasia were tested in the hospital Hospital General de L'Hospitalet.

In addition to the eye-tracking, patients with aphasia tests:

- Boston Naming Test for word retrieval. (Kaplan et al. 1983)
- PCA (Protocolo corto para la evaluacion de la afasia del Hospital General de Hospitalet): this test measures different aspects of language (spontaneous language, automatic language, comprehension, naming, syllable/vowel/word/sentence repetition and writing.)
- Raven's Progressive Matrices for non-verbal intelligence. (Raven 1964)
- Bilingual Aphasia Test: a syntactic comprehension test. We will be using either the Spanish or the Catalan version depending on the participant. (Gomez-Ruiz 2008)
- Trail Making Test A: a test for attention and speed. (Reitan 1985)

Matched older controls were only administered the Trail Making Test and the Raven's Progressive Matrices Test, since we assumed normal performance on syntactic comprehension and language measurements.

For the visual perception experiment we used a portable eye-tracker, TobiiX120. Ocular movement patterns are a great instrument to study cognitive processes in people with little access to language. Following a subject's eye gaze can be done without he/she giving an explicit verbal response. The participants sit in front of a screen with the eye tracker placed underneath and watch a 11-minute-long video. While they watch the screen, they eye tracker takes the coordinates of their eye-gaze movement.

To construct the videos that make our stimuli, we started with a set of 16 instances of dog and car exemplars that were manipulated to have a variety of hues and saturations, we then created a set of animations, each of which had pairs of videos (see Figure 5). Each pair of videos consisted of a dog-pushing-car event loop and a car-pushing-dog event loop. Each trial began with the left video animating to show two grayscale loops, followed by the right video animating to show two grayscale loops. The offset of the second right video loop was followed by a '+' flashed briefly between the two video frames, which marked the onset of the anticipatory period. During the 2.5sec anticipatory period, there were no animations. Following the anticipatory period, the target video (e.g., the car-push-dog video) animated with the figures in color, and accompanied by a happy jingle. Participants were shown a total of up to 32 trials. There were two scripts, one had trials where following the anticipatory period, the dog-push-car event became "interesting" (they were in color and accompanied with the happy jingle), while the other two lists had the car-push-dog become interesting. For a given participant, only one of the two events, car-push-dog or dog-push-car was the target.

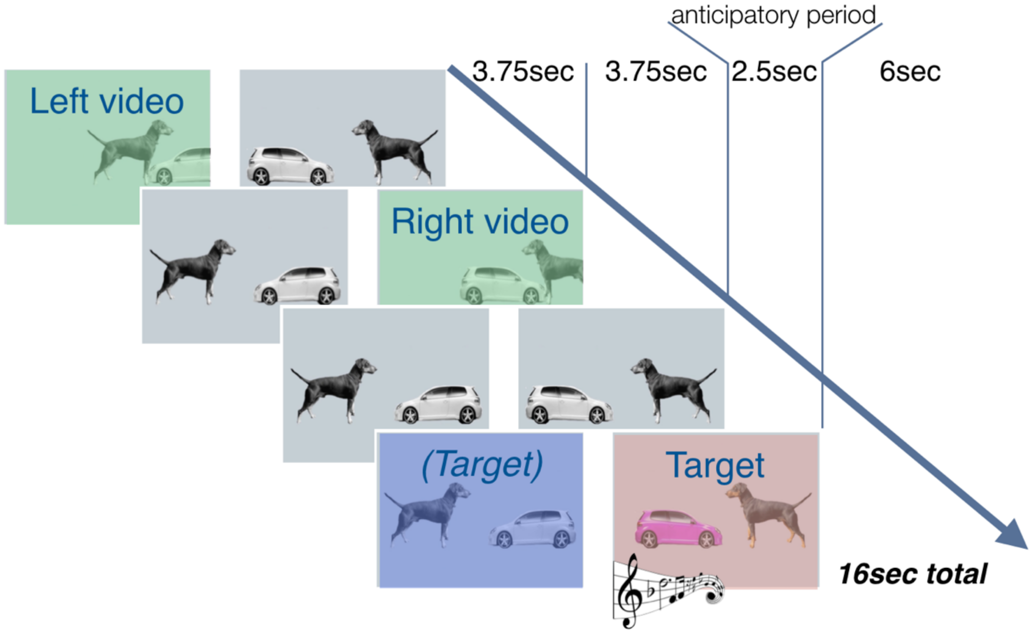

Figure 4 Example of our stimuli. The time-line of an individual trial. The four pairs of images are screenshots at different moments during a single trial. Briefly, in all trials, the left gray-scaled video animates, followed by the right gray-scaled video. After an anticipatory period, the video depicting the target predicate for that participant animates in color, accompanied by a happy jingle; in some trials, the target is on the left, and in others it is on the right.

It is important to note that participants were given no instructions before the video played other than to watch the screen and sit still. After the visualization of the video was over we asked participants of all groups if they had found a pattern that would allow them to predict which video would reanimate, we did this in order to see if the eye tracking data would match their responses.

3.3 Data analysis

Data analysis was carried out in cooperation with Dr. Mohinish Shukla (Boston), using the same analysis as was applied to parallel data sets of groups based in Boston and Smith College, Northampton. First, (1) the entire data was cleaned up by replacing all data points beyond the screen limits with NaN. (2) The entire data was centered by replacing the median x,y of the gaze data with the x,y of the screen center. This allows correcting for deviances due to improper calibrations and variations in gaze direction (3) Since the two videos in each trial were centered on the screen, we set all gaze points outside the 95th percentile along the x and y axes to NaN. (4) Gaze data was divided into a series of epochs corresponding to the individual trials. (5) Given that the centered, percentile data was constrained to the video pairs, we ignored the y-axis and looked exclusively at the (left-right) x-axis.

Data gaze were examined in the x-direction separately for those trials where the target animation was on the left and those where it was on the right (see Figure 6 below). Our initial analyses were focused on the 2.5sec anticipatory window. We examined whether the average x-values in the anticipatory period were significantly different for the trials where the target animation was to the left or to the right. Each participant contributed two values: the mean x-location of eye gaze in the anticipatory periods for all target-on-left trials, and for all target-on-right trials; paired t-tests compared these values.

Since there is sufficient information to determine the target side after watching the first animation alone, it is possible that participants anticipate the correct side on each trial well before the anticipatory period. Therefore, we examined whether the x-locations differed significantly at specific time-points across the entire trial. To do so, we first conducted t-tests for each time point across the entire trial, comparing mean eye positions for participant averages of target-on-left vs target-on-right trials, and marked the time points that were significant at $\alpha=0.05$.

Then two distinct measures were used to account for the large number of multiple comparisons. First, we used the analytic result by Benjamini & Hochberg (1995). This is a general method that, for a given series of P-values, computes a cutoff such that all P-values below the cutoff are significant in the sense that false discovery rates are below a pre-determined value; in our case this value was set to 0.05. Second, we employed a variant of the method described, e.g., in Oakes (2013). We extracted all "runs" of consecutive data points that showed significant differences at an alpha of 0.05. Then, we shuffled the labels (target-on-left or target-on-right) for gaze x-values from individual participants' means, re-computed t-tests, and re-extracted all runs of consecutive, significant points. We repeated this procedure 10000 times, and computed the probability of getting runs of various lengths. We then marked any of the original runs that were outside the upper 95% bound of the confidence interval of the bootstrapped empirical distribution as being significant.

4. Results

Top Figure 6 shows the looking pattern for the young controls (N=19). The x-axis is time in seconds, while the y-axis represents gaze position at that point in time (in pixels), with negatives values representing looks to the left of center, positive values representing looks to the right of center, and 0 representing the center of the screen. The mean gaze position across a trial is shown by the solid curves (color-coded for target-on-left vs target-on-right trials), and the ribbons surrounding these represent the 95% confidence intervals along the means. The width of the yellow rectangle represents the extent of the anticipatory period. Since all trials begin with the left video animating, followed by the right video animating, followed by the anticipatory period, the gaze position before the anticipatory period goes negative, and then positive. Magenta dots below the curve mark time slices with a significantly more positive value in target-on-right compared to target-on-left trials (one-tailed t-tests, P set to 0.05). Green halos around the magenta dots indicate time points that survive the Benjamini-Hochberg correction, while the black dots underneath indicate stretches that are significant using the shuffle method. Figure 6 shows that, already during the anticipatory period, the mean gaze position on target-on-left trials was significantly below (i.e., to the left of) mean gaze position on target-on-right trials.

Similar analyses for participants with aphasia and their age-matched controls are shown on bottom left and right in Figure 6. Both groups show some evidence for a difference between target-on-left and target-on-right trials in the anticipatory period, but more so in controls than patients. However, it is only in the aphasic group that we find a time period around 3sec with a significant difference between target-on-left and target-on-right trials with both analytic and bootstrapping methods.

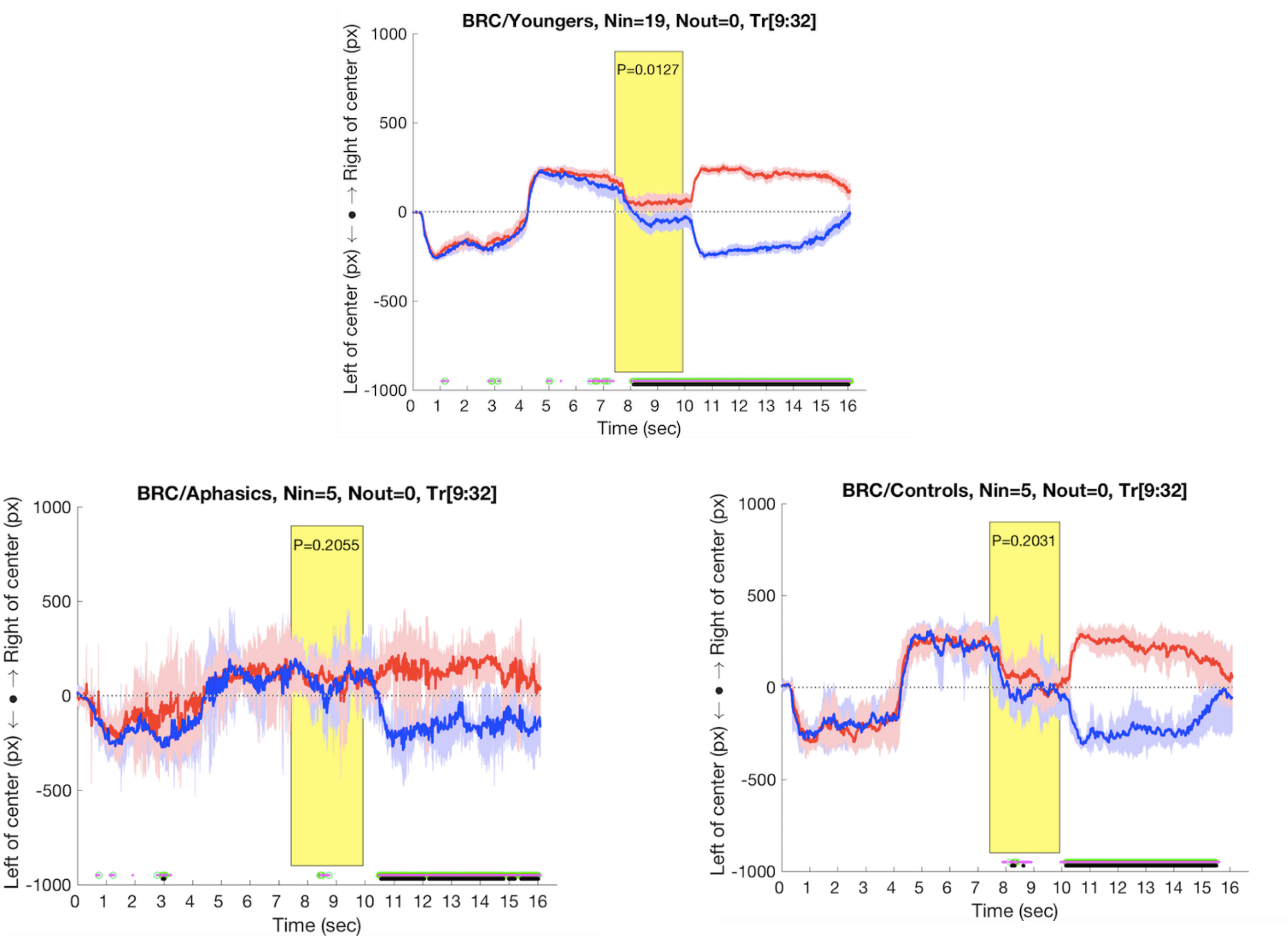

Figure 6 From top to bottom right: looking patterns for young controls, aphasics and aged matched controls. The section marked in yellow is the anticipatory period (2.5 seconds before the video reanimates), the blue line indicates target-on-left trials and the red line target-on-right trials. A gap between both lines (red towards the right of center and blue towards the left of center) means the anticipation was done correctly. In the youngers-group there is a clear anticipation of the pattern in the 3secs anticipatory period. The aphasic group overall does worse than the controls in the 2.5 second anticipatory period, but it seems to get the pattern before the controls, while then 'losing it' (see black dot around the 3secs mark). The p-values inside the yellow rectangle show there is no significant difference for both the aphasic group and the control group between gazing to the left and gazing to the right ($p>.05$) during the anticipatory period as a whole (meaning they gaze arbitrarily) but the colored dots underneath show that there are stretches of significance, in controls more than aphasics. The case is different for the Youngers ($p<.05$) where there is significance during almost the whole anticipatory period.

4.1 Correlations

Using SPSS we checked for correlations between the scores in the syntactic comprehension test and an eye tracking numerical measurement as well as the Raven´s test results and the eye tracking numerical measurement (see Table 2), using Pearson's correlation. The eye tracking numerical measurement is the number of frames that survive the shuffle algorithm mentioned on our data analysis section, from the beginning of the trial till the end of the anticipatory period. We found no correlation between the score in the syntactic comprehension test and the eye tracking test as there was no statistical significance $p>.05$ ($p=0.86$).

PARTICIPANT	GROUP	TMT	RAVEN´S	SYNTACTIC	EYE-TRACKING
1	AP	n/a	30	20	26
2	AP	n/a	45	32	37
3	AP	120sec	34	17	0
4	AP	n/a	44	29	28
5	AP	267sec	19	25	18
6	CO	32sec	44	n/a	0
7	CO	34sec	54	n/a	254
8	CO	22sec	51	n/a	7
9	CO	26sec	52	n/a	11
10	CO	35sec	48	n/a	0
AP=APHASIC			Max score 60	Max score 37	
CO=CONTROL					

Table 2 Results from Trail Making Test, Raven´s Progressive Matrices Test and Syntactic Comprehension tests for both groups of participants

In the case of the Raven's Progressive Matrices test and the Eye-Tracking measurement, the assumptions to run the Pearsons correlation were checked but not satisfied. There were outliers, it failed the assumption of normality and linear relationship.[8]

[8] Spearman's correlation was also not possible to run since the scatter plot was non-monotonic.

5. Discussion

The aim of this study was to investigate if people with aphasia would succeed in the task of generalizing across events that exhibit visual differences, while still falling under the same general event concept. We started off, as previously stated, with a replication of the Boston study, where we found that the results replicate fairly well the non-verbal shadowing 2 place-predicate adults in their group (Figure 7). A difference we found in the data is that their subjects show insight into the pattern earlier, meaning their group overall managed to do the generalization earlier. It must be noted that both groups were not of the same size, we had 19 participants and the Boston lab 10. In any case, the Boston results replicated sufficiently in order to move on to the aphasia part of the study.

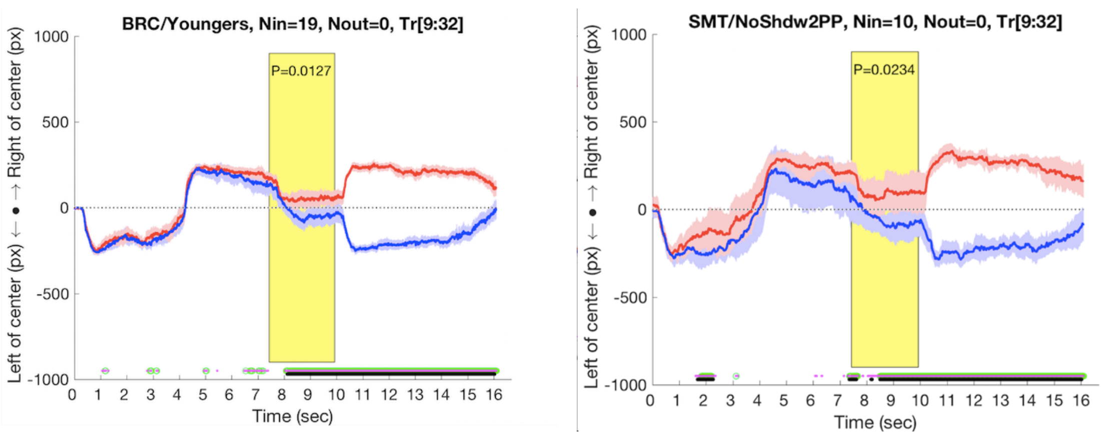

Figure 7 Comparison of results for the Barcelona younger control group (left) and the Smith College non-verbal shadowing young adult groups (right).

We expected the aphasics to perform worse at the task than healthy controls because of their language impairment. It was surprising to us that the aphasics are actually able to understand the event generalization and they do so even before the anticipatory period, in this sense performing better than the control group (see Figure 6). On the other hand, they are not able to properly 'hold on' to the generalization and loose the pattern across the trials, in this way performing worse than the control group, where we see that the participants understand the pattern later (within the anticipatory period), consistently anticipating which video will reanimate. As an explanation, we speculate that the participants with aphasia 'get' the generalization before because they rely mainly on visual perception during the task performance. Since their language faculty is not fully accessible to them, the perceptual information is not coded linguistically as automatically as it might be when language is fully functional. Therefor the brain relies on other, more perceptual forms of coding this information. Our evidence comparing the controls to the aphasics suggests that the linguistic format of the internal code is necessary to maintain the insight.

A deficit in language is known to relate to working memory deficits, this could explain why the aphasic patients are unable to keep the pattern in mind. According to Baddeley (2002:204) working memory is a temporary storage system that supports our capacity for thinking, therefor it would have implications for language processing which is why disorders in working memory may impact on language processes.

Individuals with aphasia are known to have working memory problems, as shown for example in their usual poor performance on forward and backward digit span tests and other working memory tests (Laures-Gore 2011, Fonseca 2016, Lee 2014, Christensen 2010). This has been linked to a deficit in language understanding and even though this remains controversial, evidence shows that generally a deficit or limitation in working memory leads to a deficit in language comprehension when the sentences are complex in some respect (Friedman & Gvion 2003:24). This finding is relevant to our study because we were using for our visual stimuli actions that if verbalized (for example in a form of inner speech) would be reversible two place predicate sentences, where the two arguments occupy different thematic positions. These kinds of sentences are complex to process especially for patients with aphasia who are known to have problems with sentence processing and argument structure (Nicholas &Vaughan 2013, Whitworth 2015) and comprehension of reversible passive sentences (Luzzatti 2001).

We could be more specific and relate the problem aphasics have with retaining the generalization present in our experiment with an issue connected to a subsystem of working memory. Baddeley & Hitch (1974) in their working memory theory divide it into three subsystems: the phonological loop, the visuospatial sketchpad and the central executive, which would work as a control system. The first is concerned with verbal and acoustic information and the visuospatial sketchpad "serves the function of integrating spatial, visual, and possibly kinaesthetic information into a unified representation which may be temporarily stored and manipulated." (Baddeley 2002:200). Since our stimuli are exclusively visual and require the participants to pay attention to movement and position (where and what reanimates), perhaps a problem with this specific subsystem could explain why the participants with aphasia cannot keep the generalization in mind, even though they are capable of detecting it perceptually. Another possible explanation is that the aphasic´s inability to engage on inner speech (Baldo 2005, 2015) prevents them from keeping the generalization in mind. This is similar to Nicholas &Vaughn's (2013) hypothesis for the findings in their study (see Section 1.3.3). As mentioned before a language deficit can affect the processing of non-verbal observed events because the person is not able to engage their internal language and without access to inner speech faculties, certain tasks may not be performable.

Other insights emerge when comparing our aphasic subjects and the verbal shadowing students of the Smith College. In Figure 8 we can see how verbal shadowing does not prevent the participants to do the generalization during the anticipatory period, but aphasia does, however here we see again how the aphasics group shows significance around the 3 second mark while the verbal shadowing group does not (same as our control group, see Figure 7). This suggests that verbal shadowing does not induce an 'artificial aphasia' condition, since it has different effects on the participant's performance.

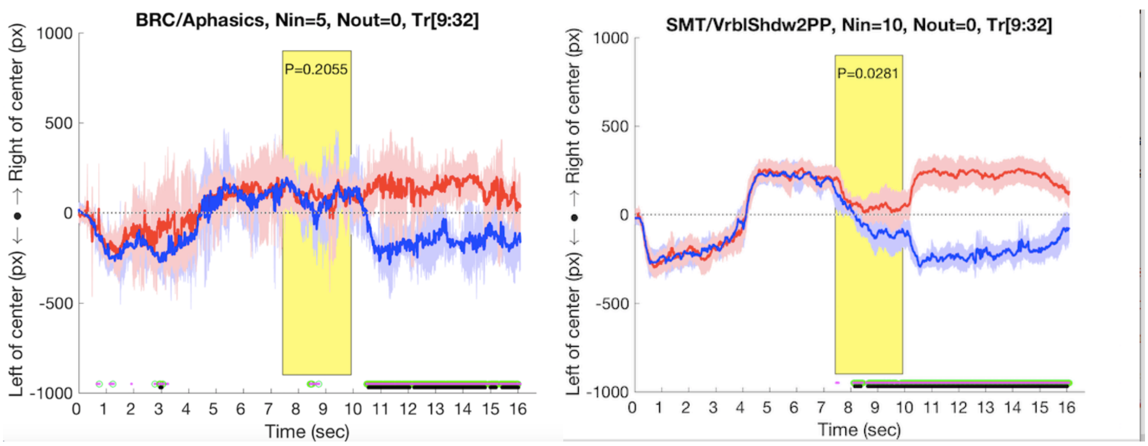

Figure 8 On the left side are the results of the aphasics (5) and on the right side the results of the non-verbal shadowing adults (10) of the Boston Lab.

Post-hoc qualitative data on participant insight also inform our data. We asked the participants if they had found some sort of pattern in the video they had just seen. In many cases there were discrepancies between what the participants answered and what the eye-tracking data showed. When looking at individual data, in the control group there are three participants who performed the generalization at some point during or before the anticipatory period, but only one of them replied to the post-test question by saying they had found the pattern, thus demonstrating an ability to verbalize the generalization.

In the case of the aphasia group we were in many cases unsure if they were even understanding our question as their answers were always very unspecific (of the sort of: ‘there are dogs and cars and they push each other’) and it did not seem to us as if they had understood the generalization by the way they replied our question. However, when looking at the eye tracking results, 4 out of 5 patients performed the generalization early on, and one remained marginal. These discrepancies show that despite the brains of these patients detecting the pattern perceptually, several participants cannot verbalize it, i.e. put it in a linguistic code, in line with the above speculation.

It would be interesting to see if the answers would differ if before the video started, the subjects would be instructed to try to find the pattern that predicts which video would reanimate. Perhaps in this case they would engage inner speech and afterwards would be able to verbalize what they are apparently perceptually detecting.

It is also important to remind ourselves that people with aphasia are not non-verbal, unlike a subset of people with autism spectrum disorders (Norrelgen et al., 2015). In the case of aphasia, they retain access to language, although restricted, and have had a normal language acquisition process and normal language skills at a previous point in their lives. It would be interesting to see if a non-verbal population with autism would behave similarly when facing the same stimuli. This could help show exactly what the role of language in these kind of tasks is and provide evidence to see if it is essential or not for performing these apparently non-linguistic perceptual tasks.

In conclusion, the data tentatively suggest that language is not necessary for detecting a reversible transitive event generalization across perceptually different trials. But it does appear to play an important role in keeping the generalization in mind, possibly because of the role of language in working memory, or because it represents a different code serving to stabilise insights obtained perceptually. Since this was a pilot study with only 5 participants and 5 controls it would be important to see if with a larger sample the findings would be the same.

5.1 Limitations

A limitation of our study could be the fact that we are not controlling for attention in all aphasics. Only some of the patients could perform the attention test because of motor problems. This is important because it could be not only problems with working memory that explain the inability of the aphasics to hold on to the generalization but it could be perhaps also explained by attention deficits or individual variations in attention (if there were to be found a correlation between this variable and a poor performance on the eye tracking task). Lee (2004:763) mentions how recent studies that have focused on attention deficits found these present in most aphasic patients and there is a connection between attention and memory failures that has been found even in healthy individuals (Unsworth et al. 2012:14). It would also be interesting to see if low working memory scores the predict a poor performance in the eye tracking task, unfortunately we don´t have working memory scores for our aphasic participants.

Another limitation of our study is the size of our sample, it is a pilot study with 5 aphasics and 5 controls but at the beginning of the recruitment process we had planned to test 12 patients and 12 controls, as explained in the participant's section of this paper (3.1).

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