THE ACQUISITION OF COORDINATION AND RECURSION OF PPS: HOW TO FARE THE DEVELOPMENT OF THESE COMPUTATIONS? [1]

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RESUMO

A recursividade, um cálculo implementado através da inserção de um constituinte dentro de outro, é amplamente reconhecido como uma capacidade cognitiva fundamental. Uma discussão interessante sobre o tema gira em torno da especificidade do domínio dessa cognição, ou seja, se ela está nas bases da capacidade de linguagem ou se é parte integral de recursos cognitivos gerais e é posta em ação na linguagem como um fator externo. Naturalmente, é primordial para essa discussão saber quando a recursividade é adquirida. Este estudo quer contribuir para esta discussão ampla, concentrando-se na aquisição de uma instância recursiva - a dos sintagmas preposicionais (PPs) em Português do Brasil. Os resultados apontam para a faixa etária de 4 anos como sendo a idade em que a recursividade começa a ser processada de forma significativa.

ABSTRACT

Recursion, a computation that is implemented by tucking a constituent into another, is widely recognized as a fundamental cognitive capacity. An interesting discussion tries to define the domain specificity of recursion, that is, if it lies in the underpinnings of language capacity, or if it is an integral part of general cognitive resources and is called into action as an external factor. Naturally, an important element in this discussion is the knowledge of when recursion is acquired. This study wants to contribute to this wide investigation by focusing on the acquisition of one recursive instance – that of Prepositional Phrases (PPs) in Brazilian Portuguese. The results point to the age bracket of 4 years of age as the one in which recursion starts being meaningfully processed.

PALAVRAS-CHAVE

recursividade, sintagmas preposicionais, especificidade de domínio, aquisição de recursividade

KEYWORDS

recursion, prepositional phrases, domain specificity, acquisition of recursion

Introduction

A standard observation in linguistics is that an expression of a given syntactic, semantic or phonological category may become part of another expression if both hold the same category. This computation, named recursion, that is implemented by tucking a constituent into another, is widely recognized as a fundamental cognitive capacity. An interesting discussion in this field tries to define the domain specificity of recursion, that is, if it lies in the underpinnings of language capacity (CHOMSKY, 2005; FITCH; HAUSER; CHOMSKY, 2005; HAUSER; CHOMSKY; FITCH, 2002) or if is an integral part of general cognitive resources and is called into action as an external factor (ARSENIJEVIC, HINZEN, 2010; ARSENIJEVIC, HINZEN, 2012). While the first option would explain the fact that recursion is supposed to be a major language principle found in all languages (cf. localized dispute in EVERETT, 2005, 2007; NEVINS, PESETSKY, RODRIGUES, 2009), the second option makes it easier to understand the multiple characteristics that involve the implementation of recursion in different aspects and phrases of different languages.

A significant factor that can shed light onto this discussion is the acquisition of recursion. How and when exactly do children start processing recursion? On one hand it does not seem to be present in children's earliest utterances (ROEPER; SNYDER, 2004, 2005; ROEPER, 2011). Contrastingly, coordination appears as an earlier acquisition in language comprehension and production (PÉREZ-LEROUX et al., 2012).

The fact that coordination appears earlier is rather intuitive and can be explained by the simple fact that coordination is a straight-forward way to bypass computation by accounting for items that are sent to storage (for instance, short-term memory) the way they appeared, without any correlation or hierarchy between them. This simplicity is likely to be successeful for at least a few items. Nevertheless, when there

is a number of items that starts challenging memory capacity, a safer cognitive decision is to resort to structure, which exponentially increases memory and processing capacities (MILLER, 1956).

If items are organized hierarchically, then embedding computation, that is recursion, is a processing resource that once deployed might bring a reduction to the cost of combinatory computation. It might be costly to start the recursive structure, for instance: *There is a banana in the box on the tray*. But after the computation is established, it might be easier to embed other PPs, for instance: *on the chair, over the carpet* (MAIA et al., 2013).

Clearly the evaluation of most economical choices can be readily attested in adult language, but how do children acquiring language implement these choices?

In order to verify children's processing of recursion, this study will focus on a highly recursive structure: prepositional phrases (PP) in Brazilian Portuguese. The aim here is to contrast PP recursion to PP coordination in acquisition. To do this, this research will try to assess children at the earliest moment that recursion of PPs becomes an available property of their grammar, so that coordination can be compared at this very point.

Since MAIA *et al.* (2013) attested a scale advantage in embedding multiple layers of PPs[5], this study also controlled for this possibility in children. That is, since the number of layers was a controlled factor it will be possible to verify if multiple embedding once deployed has processing advantages over coordination of several items, because it supposedly generates no extra computational cost, while coordination still requires reiteration and memory.

[5] Maia *et al.* 2013 tested adult participants using stimuli with three levels of PP embeddings. In addition to an off-line oral sentence/picture matching test, there was an on-line experiment, that evaluated neurophysiological (EEG-ERP) parameters.

1 The test

An oral sentence picture matching test was produced to be applied to sixteen 3 y-o and sixteen 4 y-o children, following a between-subject distribution. Children heard a sentence and had to match it with one of two pictures: one depicted a situation of a coordinated list and the other depicted a situation of embedded nouns hierarchically organized.

The prosodic contour of phrases was controlled, using PRAAT platform[6], such that the only cue used for interpretation was syntactic. We left no pauses and suppressed all prosodic modulation, so that there were no biases that could confound participants.

Using a preferential looking paradigm, participants listened to test sentences either in the recursive or coordination condition. For instance, in the recursive condition: *There is a banana in the box on the tray on the chair*; and in the coordinated condition: *There is banana in the box and on the tray and on the chair*. At the same time, children were presented with two images displayed side-by-side on the computer screen. One image was associated with the coordinated representation of the sentence (e.g., three bananas: one placed in the box, another on the tray, and another one on the chair) and the other with the recursive representation of the sentence (e.g., only one banana on top of the three containers) (Figure 1).

Then, when listening to the test sentence, children had to point toward the best match. All the while, there was a camera filming children's gestures from behind, so that the experimenters could have an after-test response control, besides the register taken down by the experimenter's assistant during the test.

1.1 Materials and Method

In this experiment, participants listened to test sentences either in

[6] *Using Praat for Linguistic Research* is completely free, and is available for use at http://www.fon.hum.uva.nl/praat/download_win.html

the recursive or coordination conditions For instance, in the recursive condition: *There is a banana in the box on the tray on the chair*; and in the coordinated condition: *There is banana in the box and on the tray and on the chair*. At the same time, children were presented with two images displayed side-by-side on the computer screen (Figure 1). One image (on the right) was associated with the coordinated representation of the sentence (e.g., three bananas: one was placed in the box; one, on the tray; and one, on the chair). The other image (on the left) was associated with the recursive representation of the sentence (e.g., only one banana on top of the three containers). Then, when listening to the test sentence in one of the experimental conditions (coordination vs. recursive), children had to point toward the image that best matched, in their opinion, the sentence they had just heard.

FIGURE 1: A pair of images shown in the experiment, originally in color. The participant would choose the image on the left if she had an interpretation of recursion (on the left: «There is a banana in the box, on the tray, on the chair»), or the one on the right for coordination (on the right: «There is a banana in the box, AND on the tray, AND on the chair»).

When children clearly and resolutely pointed to one of the pictures, experimenters would count the response as relating to a coordinated or a recursive interpretation. Thus, if participants in each one of the two age groups were able to process and to correctly interpret the recursion of PPs, there would be more pointing toward the images representing the recursion, when they listened to the recursive sentences and more pointing responses toward the images representing coordination, when they listened to the coordinated sentences.

The number of recursive layers and that of coordinated items were also controlled for. There were sentences with to or three recursive layers and coordinated items, as it can be seen in the examples below:

- Recursive sentence with two embeddings

  Tem gato na caixa na mesa

  (There is cat in the box on the bed)
- Recursive sentence with three embeddings

  Tem porco no balde na bandeja na cadeira

  (There is pig in the bucket on the tray on the chair)
- Coordinated sentence with two items

  Tem maça na caixa e no balde

  (There is apple in the box and in the bucket)
- Coordinated sentence with three items

  Tem cachorro na caixa e no balde e na cadeira

  (There is dog in the box and in the bucket and on the chair)

1.2 Participants

Thirty-six children, native speakers of Brazilian-Portuguese

participated in this experiment. They were divided into two age groups: the 3-year-old group (2,9 to 3,8; M =3,5; *n* = 18) and the 4-year-old group (4,0 to 4,6; M = 4,3; *n* = 18).

Children were tested in two public preschools in Rio de Janeiro, and their parents signed an informed consent form. An additional eight children participated in the study, but were not included in the final analysis because they were not concentrated on the task during the experiment (4), there were experimental problems (2), or there was some kind of fussiness during the experiment session in the school (2).

1.3 Stimuli

Eight pairs of experimental sentences were created from eight target words likely to be known by children, for example: *banana*, *cat*, *apple*, *pig*, *cake*, *dog*, *sandwich*, *rabbit*. For each target word, we recorded a pair of sentences: one was the coordinated version and the other was the recursive version. The coordinated version was recorded with the conjunction AND before each PP, for example: *There is banana in the box and on the tray and on the chair*. The recursive version was recorded without a pause between the PPs, for instance: *There is banana in the box on the tray on the chair* (c.f., Appendix 1, for stimuli's list). Although the sentences were carefully recorded, so that no additional cues, such as pauses, could be extracted from prosody, the sentences were uttered as if they were being spoken naturally to a child, in a child-direct speech way. The recording was done by a male Brazilian Portuguese speaker (the second author) who recorded the stimuli after a few sessions of practice in order to control for other extraneous factors (e.g., pauses, noises, pitch variations, etc.). In total, we created sixteen test sentences: eight in the recursive condition and eight in the coordination condition. Thus, we created two lists of stimuli, so that each version of a given sentence pair appeared in a different list. This means that a given child would listen to a given sentence only in a recursive or a coordination condition, but not in both,

following a Latin square distribution. Each list contained four sentences recorded in the recursive version and four in the coordinated one, plus eight filler sentences. Each participant listened to only one list. Half of the participants were assigned to each list and the order of sentences presentation within each list was pseudo-randomized.

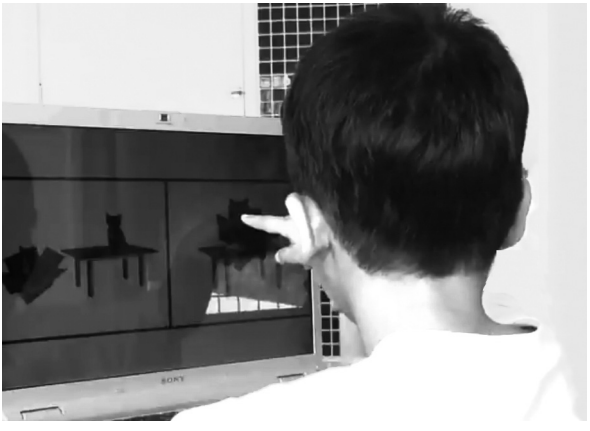
1.4 Procedure

Children were tested individually in their own preschool. During the experiment, participants were seated in front of a computer screen displaying the visual stimuli.

They were told that they were going to play a game in which they would have to find the image that corresponded to the sentences they would listen to.

The experiment started by a practice session consisting in a presentation of a filler sentence that corresponded to one of the two pictures simultaneously presented to them (Figure 2).

FIGURE **2**: Participant during the test, pointing to the image on the right

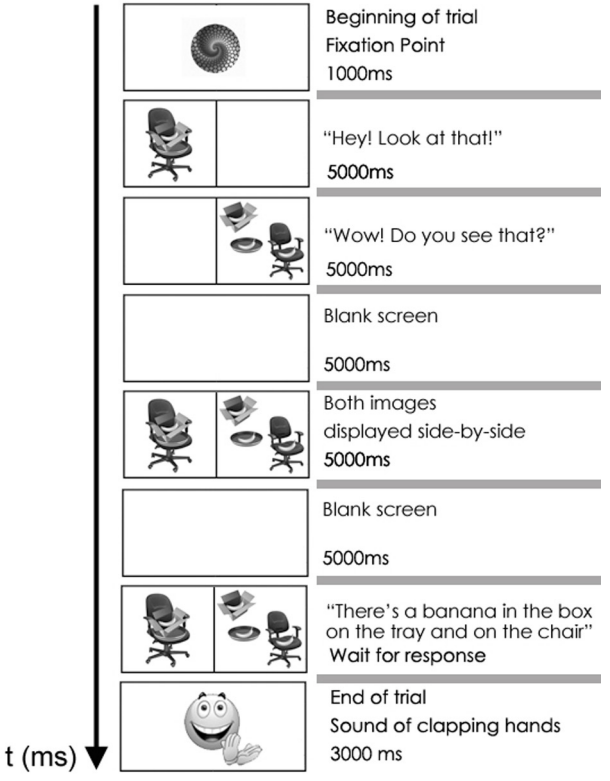


As soon as the participant gave two correct pointing responses in this practice session, the experimenter would start the test session.

Before the test session began, the experimenter would adjust headphones to the children's ears. The test session was composed of sixteen trials: eight test sentences and eight filler sentences, half of the test sentences with a recursive structure and half with a coordinated structure counterbalanced between participants.

Each test trial started by an inspection period to provide the child enough time to look at the pair of images displayed on the screen. Each image was first presented separately for 5 seconds on the left or the right side of the screen, and a neutral audio prompt was played at the same time, for instance: *Hey, look! Do you see that?* Both images were then silently presented on the screen, for 5 seconds. Then, these images would disappear, and the screen was blank for 500ms. Finally, the two images appeared again together on the screen, simultaneously to the auditory test sentence. Participants' task was to point toward the image that, in their opinion, matched the sentence they had heard. Each trial ended with the sound and illustration of clapping hands to stimulate the child's participation, regardless of whether the response was correct or not. The time course of each trial is described in Figure 3.

FIGURE 3: The complete time course of each trial.



Results

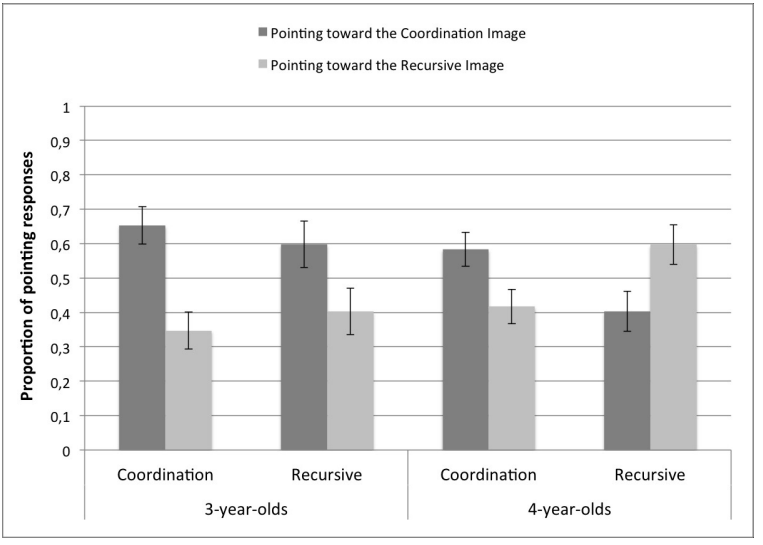
Responses that correctly matched the target interpretation of the sentences (recursive in recursive condition, coordination in coordination condition) were scored as 1, and incorrect responses were scored as 0 (See Appendix 2). Thus, for each child and for each condition, we calculated the average scores of their responses and used them as the dependent measure in our analysis.

Because recursive and coordination responses in this task are complementary, we chose the proportion of pointing toward the recursive image as our dependent measure in the statistical analysis.

Figure 4 presents the average proportion of pointing responses toward the recursive and the coordination images for each condition (Recursive or Coordination) for both groups of children (3-year-old Vs. 4-year-old).

A one-way analysis of variance (ANOVA) was conducted with participants as random factor. This analysis included a within-subject factor Condition (Recursive, Coordination), and two between-subjects factor, List (List1, List2) and Group (3 year old, 4 year old).

FIGURE 4: Proportion of pointing responses toward the Recursive image and the Coordination image after listening to the test sentences, with a recursive or a coordinated syntactic structure, for each group of participants. Error bars represent the standard error of the mean.



A main effect of Condition ($F(1,34) = 6.38$, $p < .02$) was observed. Taking all together, children pointed more toward the coordination image than to the recursive image when they heard the coordinated sentences. There was also a marginally significant effect of Group ($F(1,34) = 3.92$, $p = .055$) indicating that while 4-year-old children pointed more toward the recursive image than toward the coordination image when they heard the test sentences with the recursive structure (and vice-versa for the test sentences with the coordinated structure), 3-year-olds always pointed more toward the coordination image for both conditions (recursive, coordination). Thus, the proportion of pointing responses toward the recursive image in the recursive condition was above chance for 4-year-olds (60%), but for 3-year-old children the average was below chance (40%), ($t(34) = -3.164$, $p < .01$). No other effect or interaction reached significance.

Discussion

The main effect of the test points to the fact that the children tested at 3 and at 4 years of age appear to have the coordination interpretation available to them. One might argue that this test cannot properly disentangle coordination from a simple lexical effect: children might stock semantic contents of the items presented to them without really coordinating them. Nevertheless, even the simple adding of one layer of PP already entails a syntactic merge between a DP and a PP (a pencil in the box), or even a simplified merge (pencil in box).

The fact that they recognize the coordinated condition in which there is a distribution of items, for instance: *There is [a] banana in the box and on the tray and on the chair*, shows that the structure entailed in the PP coordination is being at least partially realized.

As a contrast, the recursive condition is more complex and cannot be confounded with mere memory storage, because such sentences necessarily entail hierarchical structures that yield meaning on their own, independently from the lexical properties. When the recursive figure was

correctly matched to its corresponding sentence, that meant that the child knew that a single object was nested in two or three containers. That is, the distributive reading was blocked.

The recursive structure appeared to be meaningful to the children tested as of 4 years of age (Check the two last columns in Figure 4). Four year olds pointed more to the recursive pictures than to coordinated ones when they listened to recursive sentences. Thus, this test successfully identified the transition period when PP recursion became a meaningful computation to children.

The number of recursive layers – two or three – was not a significant factor, statistically speaking. Nevertheless, since 3 year-olds do not appear to use PP recursion meaningfully, and they were tested for layers together with 4 year-olds, another test focusing on 4 year-olds and multiple layers as a factor should be applied, in order to verify if their acquired computation seems to be similar to that of adults in this respect.

Currently, we are developing a semantic investigation of manner PPs, conveying different thematic roles, and we expect to get the very same results as those of the place PPs already tested here, since recursion is a syntactic computation and should not be hindered or facilitated by the semantic content of the phrase. We also intend to test acquisition of other recursive phrases in a similar fashion.

Most importantly, since 4 years of age is the moment that PP recursion seems to become available, several types of recursive computations must be tested involving other cognitive domains, so that it is possible to fare if recursion of PPs and of other linguistic structures, arising from interface effects, derive from more primitive properties than those verified in linguistic computations.

In terms of more sophisticated perspectives, a desirable advancement, as much as it is hard to accomplish with children, is the use of online testing, that can discriminate between automatic and reasoned upon processes.

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Appendix 1: Experimental Sentences

List	Trial	Target	Condition	Sentence
List1	Test1	Cat - *Gato*	Recursive	Tem gato na caixa na mesa.
List1	Filler1	Dog - *cachorro*	F1	O cachorro está no barco
List1	Test2	Apple - *Maça*	Coordination	Tem maçã na caixa e no balde
List1	Filler2	Little cat - *gatinho*	Filler	O gatinho subiu no telhado
List1	Test3	Pig - *Porco*	Recursive	Tem porco no balde na bandeja na cadeira .
List1	Filler3	Rabbit - *coelho*	Filler	Hoje é o aniversário do coelho
List1	Test4	Banana - *Banana*	Coordination	Tem banana na caixa e na bandeja e na cadeira
List1	Filler4	Apple - *maça*	Filler	Quem botou a maçã no livro?
List1	Test5	Cake - *Bolo*	Recursive	Tem bolo na bandeja na mesa

List1	Filler5	Pig - *porco*	Filler	O porco vai comer os morangos.
List1	Test6	Dog - *Cachorro*	Coordination	Tem cachorro na caixa e no balde e na cadeira
List1	Filler6	Strawberries - *morangos*	Filler	A caixa de morango está cheia.
List1	Test7	Sandwich - *Sanduiche*	Recursive	Tem sanduiche na caixa no balde na mesa
List1	Filler7	House - *casa*	Filler	Será que o porco vai entrar na casa?
List1	Test8	Rabbit - *Coelho*	Coordination	Tem coelho no balde e na cadeira
List1	Filler8	Dog and Cat - *Cão_e_gato*	Filler	O cachorro e o gato subiram na mesa.
List2	Test1	Cat - *Gato*	Coordination	Tem gato na caixa e na mesa
List2	Filler1	Dog - *cachorro*	F1	O cachorro está no barco
List2	Test2	Apple - *Maça*	Recursive	Tem maça na caixa no balde
List2	Filler2	Little cat - *gatinho*	Filler	O gatinho subiu no telhado
List2	Test3	Pig - *Porco*	Coordination	Tem porco no balde e na bandeja e na cadeira
List2	Filler3	Rabbit - *coelho*	Filler	Hoje é o aniversário do coelho
List2	Test4	Banana - *Banana*	Recursive	Tem banana na caixa na bandeja na cadeira
List2	Filler4	Apple - *maça*	Filler	Quem botou a maçã no livro?
List2	Test5	Cake - *Bolo*	Coordination	Tem bolo na bandeja e na mesa
List2	Filler5	Pig - *porco*	Filler	O porco vai comer os morangos.
List2	Test6	Dog - *Cachorro*	Recursive	Tem cachorro na caixa no balde na cadeira
List2	Filler6	Strawberries - *morangos*	Filler	A caixa de morango está cheia.
List2	Test7	Sandwich - *Sanduiche*	Coordination	Tem sanduiche na caixa e no balde e na mesa
List2	Filler7	House - *casa*	Filler	Será que o porco vai entrar na casa?
List2	Test8	Rabbit - *Coelho*	Recursive	Tem coelho no balde na cadeira
List2	Filler8	Dog and Cat - *Cão_e_gato*	Filler	O cachorro e o gato subiram na mesa.

Appendix 2: Example of stimulus control flow used with Participant M

Sujeito	Sexo	Data_nasc	Data_teste	Idade	Grupo	trial	Item	condicao	Animacidade	Lado correto	resposta	correto?
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Practice1	Pato	Practice1	Animado		Practice1	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Practice2	Sorvete	Practice2	Inanimado		Practice2	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste1	Gato	Recursividade	Animado	direita	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler1	F1_cachorro	F1	Animado_F	direita	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste2	Maça	Coordenação	Inanimado	esquerda	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler2	F2_gatinho	Filler	Animado_F	esquerda	esquerdo	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste3	Porco	Recursividade	Animado	direita	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler3	F3_coelho	Filler	Animado_F	esquerda	esquerdo	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste4	Banana	Coordenação	Inanimado	direita	esquerdo	0
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler4	F4_maça	Filler	Inanimado_F	esquerda	esquerdo	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste5	Bolo	Recursividade	Inanimado	direita	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler5	F5_porco	Filler	Animado_F	direita	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste6	Cachorro	Coordenação	Animado	esquerda	direito	0
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler6	F6_morangos	Filler	Inanimado_F	direita	direito	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste7	Sanduiche	Recursividade	Inanimado	esquerda	esquerdo	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler7	F7_casa	Filler	Animado_F	esquerda	esquerdo	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Teste8	Coelho	Coordenação	Animado	esquerda	esquerdo	1
M	Feminino	25/06/2010	18/07/2014	4 anos e 23 dia	G1A	Filler8	F8_cao_e_gato	Filler	Animado_F	direita	direito	1