The Link Between Action Verb Processing and Action Observation: A Developmental Study

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Abstract

In this work we aimed to assess the typical link in human development between action observation and language. For this, we studied, in 66 children aged 5-11 years of age, how action verbs can prime action representation. While children 7-8 years of age benefited from a congruent action verb prime when they had to judge an image representing an action, this effect was not present in 5-6-year-olds. Thus, the link between language and action observation changes during development at about age 7. We discussed these findings in consideration of current theories proposed to account for the action-language link.

Key words: action verb processing, action observation, typical development

Introduction

In the last decade, many studies have shown reciprocal links between action verb processing and action observation (see Bidet-Ildei, et al., 2020 for a review). To date, two main models have been proposed to explain this link: evolution theory (Rizzolatti, 2005) and associationism (Pulvermüller, 2005). Evolution theory posits that the link between language and action is based on the activation of motor mirror neurons, a cortical network involved when a person either produces an action or merely imagines or observes another individual producing an action (Rizzolatti, 2005; Rizzolatti & Craighero, 2004). From this perspective, human language is considered to have evolved from nonverbal language (as observed in monkeys), with a common neuronal pathway activated to both process action verbs and interpret action observations (Arbib, 2005; Aziz-Zadeh et al., 2006). In contrast, Associationism proposes that activation of action representations during action verb processing is related to associative learning (Pulvermüller, 1996, 2005) as described by Hebb (1949) in which simultaneous activation of separate cells can generate functional unity. Indeed, during development, action verbs are often acquired and experienced in association with observing and/or producing the corresponding action (Nomikou et al., 2017); this phenomenon could explain why action verb processing automatically coactivates perisylvian language and motor areas of the brain. Consequently, from these theoretical views, we can consider that either the link between action language processing and action observation exists as soon as the action word is learned (i.e., evolution theory) or the action-language link is built little by little from associative experiences.

Some studies have tried to probe these theories by studying the link between action and language in children. For example, by using functional magnetic resonance imaging (fMRI), James and Maouene (2009) showed that passive action verb listening specifically activated motor areas in 5-year-old children. Moreover, Antognini and Daum (2019) recently showed, in toddlers, that observing actions and listening to action verbs led to a suppression of mu rhythm (i.e., an electroencephalographic or EEG marker that reflects an activation of motor mirror neurons). These findings suggest that from an early age, children associate action verbs with body part activity, meaning that the link between language and action might appear very early and be related to evolution. Other investigators have studied the development of this link by analyzing how new action verbs are associated with cortical motor activation in both adults and children (Fargier et al., 2012; Gampe & Daum, 2014; James & Swain, 2011). From this perspective, Fargier et al. (2012) measured the desynchronization of mu rhythms in adults before and after learning new action verbs associated with hand or arm movements. These authors showed that the desynchronization of mu rhythms appeared during action verb processing only after a learning session in which action verbs were associated with action observations. Moreover, in 12-month-old children, the presentation of an action sentence interfered with performing the action perceived, but only when the verb contained in the sentence was already present in the toddler's receptive vocabulary (Gampe & Daum, 2014). This implies that action representation can change when children acquire an action's linguistic counterpart. Therefore, these two experiments suggest that motor activation related to action verb processing is dependent on word-action associations, even at very early ages, reinforcing the idea that the link between language and action may be related to associative learning based on the Hebbian theory.

Globally, it seems that the link between language and action appears in early development and can increase with associative learning. Therefore, there remains a persistent debate between evolutionary and associationist views of learning. In the present study, we examined this question by studying the natural development of the link between language and action in typically developing children. We asked three age groups of children to perform a priming task in which they had to judge the presence/absence of a human body after they heard an action verb. Following findings in the literature, we hypothesized that, if the link between language and action exists in children, then, due to the activation of common sensorimotor representations, the response time to judge whether an image contained a person should be faster when the images illustrating human actions were primed with congruent action verbs (Bidet-Ildei, et al., 2020). Moreover, if associative learning occurs, the difference in response times between incongruent and congruent conditions should evolve with age. This change should not be evident if the link between language and action is present from the learning of the word (motor mirror neuron theory).

Method

Participants

We used G*Power software (Faul et al., 2007) to perform an *a priori* calculation of our necessary sample size. Our calculation was based on a mixed-measures ANOVA design and the results of a previous study (Bidet-Ildei et al, 2011) in which Cohen's d was 0.20 and the correlation between repeated measures was 0.96. We set statistical significance at $p < 0.05$, and power at 0.80. The calculation showed that 15 participants per group would be sufficient. However, because the design differed slightly from the previous study and our participants were children, we decided to include 22 participants per group.

Initially, our participants were 68 French-speaking right-handed children between 5-11 years of age. Nine were excluded from analysis because they either did not follow the assignments (3 participants) or they had atypical performances in relation to their group (i.e., values more than 2.5 standard deviations (*SD*s) from the mean (*M*)). Thus, we entered the results of 59 children into statistical analyses. We divided these children into three groups according to their level in school: (a) 5-6 year-old kindergarteners (n = 18; 9 females, 9 males; *M* age = 5.06, *SD* = 0.2 years); (b) 7-8 year-old third graders (n =19; 13 females, 6 males; *M* age= 7.9, *SD*=0.3 years); and (c) 9-11-year-old fifth graders (n = 22 children; 11 females; 11

males; *M* age = 9.95, *SD* = 0.4 years). All children had normal or corrected-to-normal vision and no declared history of motor, perceptual or neurological disorders. Before the experiment, the children provided verbal assent to participate in the study, and tutors with legal capacity to act on their behalf signed written informed consent forms. The experiment was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and was approved by a local ethics committee.

Apparatus

The participants sat on a chair in front of a table in a dimly lit room. A laptop (Dell, 15’, 1768*724) and a felt tip marker were placed on the table. A keyboard was accessible to allow the participant to readily provide responses by pressing buttons associated with the answers “yes” and “no”.

Primes and Stimuli

For the language-action priming task, primes comprising 15 action verbs were selected from the Manulex database (Lété et al., 2004) for their high standard frequency index (SFI) (at least 36.25% SFI for children who were 5 years of age, see Appendix 1). All verbs were presented in French in infinitive form. The stimuli comprised 30 images: 15 representing concrete objects and 15 representing human actions. All images were selected from the French database, Clic images 2.0, which provides royalty-free illustrations (see Clic-Image2-0–Réseau Canopé http://www.cndp.fr/crdp-dijon/clic-images/ and Appendix 2). All images were presented on a computer with dimensions of 960*720 pixels and vertical and horizontal resolutions of 96 dpi.

Procedure

The procedure was the same as that used in a previous study with adults (Bidet-Ildei, et al., 2020). The experiment entailed two phases, with a total duration of approximately 20 minutes. First, the participants performed the language-action priming task conducted with E-prime 2 software and comprised of 49 trials (4 training and 45 experimental). In each trial, the child first heard an action verb prime and then attempted to determine as quickly as possible whether the image contained or did not contain a human body. Among the 45 experimental trials, 15 presented a congruent relationship between the prime and the stimulus (e.g., the participant heard the action verb prime “run” and then saw an image representing a running movement), 15 others presented an incongruent relationship between the prime and the stimulus (e.g., the participant heard the action verb prime “run” and then saw an image representing a drawing movement), and 15 others presented no relationship (i.e., the participant heard an action verb prime and then saw an image that did not contain a human body). The data from the no-relationship trials were not analyzed; these trials were included only to propose a task for the children. To report their determination, the children pressed on the A key (with the left hand) or the P key (with the right hand) on an AZERTY keyboard. The response buttons were marked with stickers of different colors. The “yes” response was consistently entered with the right (dominant) hand of the participant to limit the variability of the responses. Response accuracy and time were recorded for each trial. Each participant had been directed to repeat the verb prime after responding to ensure that the verb had been processed correctly during priming. No time limit was given for this task, but the experimenter encouraged the children to be spontaneous.

At the end of the language-action priming task, the children performed an action-image naming task. The experimenter presented each action image used in the language-action priming task (15 images) and asked the child to name the represented action; there was no time constraint imposed. For each image, the response was considered correct only when it was the expected action verb. This procedure was used to ensure that the child spontaneously associated the verb and the image in the priming task. The associations between image and name were proposed in the open-source image database (see Clic-Image2-0–Réseau Canopé http://www.cndp.fr/crdp-dijon/clic-images/) and were tested in a prior study with adults (Bidet-Ildei, et al., 2020) and in a preliminary study of 30 children, aged between 5-10 years.

The procedure is presented in Figure 1.

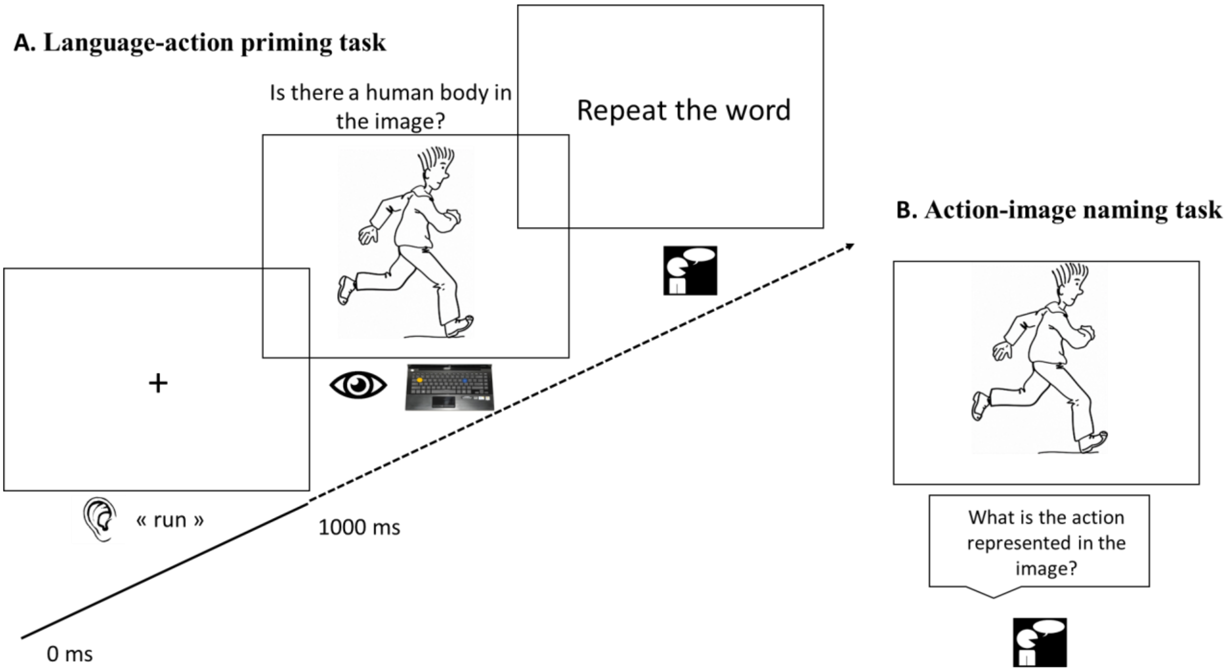

Figure 1: Procedures Used in the Experiment. A. Language-Action Priming task. This figure was adapted from Bidet-Ildei, Beauprez & Boucard, 2020, https://doi.org/10.1016/j.archger.2020.104099

Note: In each trial, the child listened to an action verb prime and then determined as quickly as possible whether a static image contained a human body. After responding, the child repeated the action verb prime; no time constraint was imposed.

B. Action-Image Naming Task.

Note: In each trial, the child named the action represented in an action image; no time constraint was imposed.

***Data Analysis*[1]**

For the language-action priming task, response accuracy, repetition accuracy and response time (for correct answers and correct repetitions only) were analyzed with a mixed model using version 0.14.1 of JASP software (https://jasp-stats.org/). For response and repetition accuracy, we constructed a logistic general mixed model with participant and verb as random-effects factors. Two fixed-effect factors, Age (5-6 years old, 7-8 years old, 9-11 years old) and Congruency (congruent, incongruent), and their interaction were considered. For response time, the analysis was performed on filtered response times (with response times greater than 2 *SD*s above or below the *M* [2.7% of the data] excluded). We performed a linear mixed model with participant and verb as random-effects factors and age (5-6 years old, 7-8 years old, 9-11 years old) and congruency (congruent, incongruent) as fixed-effect. For all analyses, we calculated *p* values for the reported F values (type III analysis of variance, ANOVA) with the error degrees of freedom calculated according to the Satterthwaite approximation, as the number of observations varied across conditions. The significance level was set at $p = 0.05$. Where significant interactions were identified, contrasts were applied, and *p* values were adjusted using Tukey's adjustment; Cohen's d indicated the effect size. For the action-image naming task, we analyzed response accuracy with a logistic general mixed model, with participant and verb as random-effects factors and age (5-6 years old, 7-8 years old, 9-11 years old) as a fixed factor.

We also calculated Spearman's rho correlation coefficients (ρ) to assess the strength of the relationship (link) between action and language (calculated for each child as the difference in mean response times between the incongruent and congruent trials) and the percentage of

[1] The verb "boire" (drink) was excluded from the analysis because the response times were inversed (longer in congruent than in incongruent trials) in all age groups. Consequently, the results reported here are for 14 verbs.

correct responses in the action-image naming task. The data supporting our findings are openly available in OSF at https://osf.io/87y2c/?view_only=1f516d52f70b46c9846e6355a2581caf [2].

Results

Language-Action Priming Task

Concerning response accuracy, the analyses showed no effect of Age (Chi² (2) =2.88; *p* = 0.24), Congruency (chi² (1) = 0.22; *p* = 0.64) or their interaction (Chi² (2) = 0.23; *p* = 0.89). For both the congruent and incongruent conditions, all age groups had a percentage of correct responses between 86% and 100% (*M* = 99%, *SD*=2.7%).

Concerning repetition accuracy, the analyses showed a significant effect of Age (Chi² (2) =10.45; *p* =0.005), with a higher score found for 9- to 11-year-old children (*M* = 100%, *SD* = 1%) than for 7- to 8-year-old (*M* = 99%, *SD* =2%) or 5- to 6-year-old children (*M* = 97%, *SD* = 5.6%). The analysis also revealed an effect of Congruency (Chi² (1) = 8.68; *p* =0.003), with a higher score obtained for the congruent (*M* = 99.1%, *SD* = 3%) than incongruent (*M* = 97.5%, *SD* = 5.3%) conditions. No interaction was observed between the factors (Chi² (2) = 2.06; *p* = 0.36).

Concerning response times (see Figure 2), the analyses showed significant effects for Age (F (2, 55.77) = 23.81; *p* < 0.001), Congruency (F (1, 1552.36) = 26.47; *p* < 0.001) and their interaction (F (2, 1548.77) = 3.14; *p* = 0.04). The contrast analysis revealed no difference between the congruent (*M* = 2062.11 ms, *SD* = 397.55 ms) and incongruent (*M* = 2096.18, *SD* = 397.9 ms) conditions in 5-6-year-old children (Z = 0.84; *p* = 0.78; Cohen's d = 0.08). In contrast, the response times for congruent trials (*M* = 1354.3 ms, *SD* = 396.8 ms for 7-8-year-olds and *M* = 1202.4 ms, *SD* = 397.7 ms for 9-11-year-olds) were shorter than those for incongruent trials (*M* = 1494.7 ms, *SD* = 396.2 ms for 7-8-year-olds and *M* = 1364.6 ms, *SD* =

[2] The files will be public when the manuscript is published.

397.3 ms for 9-11-year-olds) in 7-8-year-old (Z = 3.73; p <0.001, Cohen's d = 0.35) and 9-11-year-old (Z = 4.66; p <0.001, Cohen's d = 0.41) children.

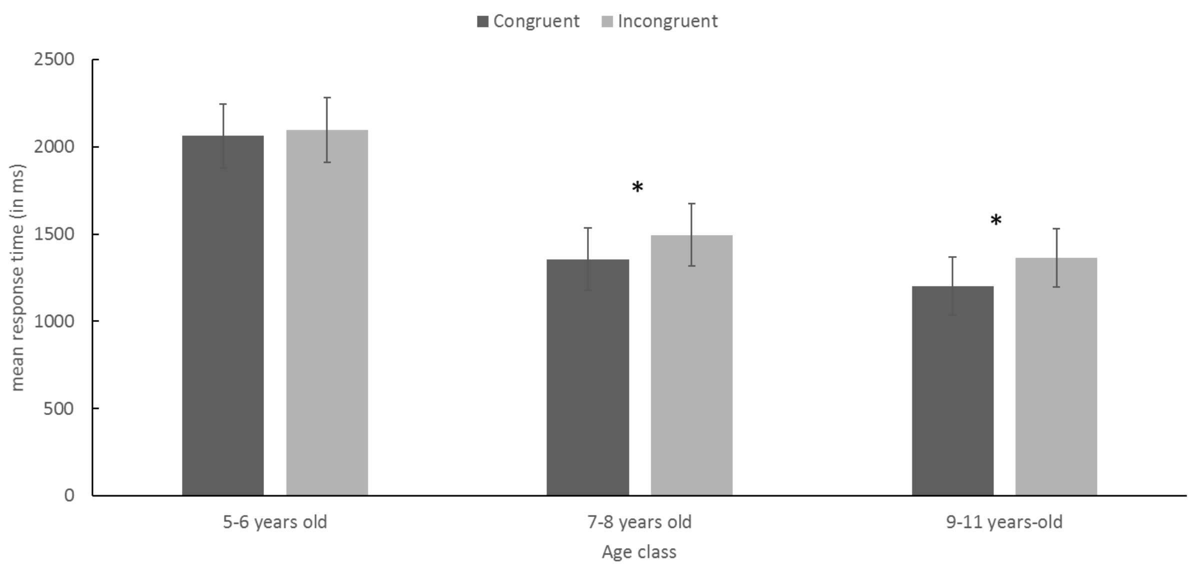

Figure 2: Mean Response Times by Age (5-6 years old, 7-8 years old, and 9-11 years old) for the Congruent and Incongruent Conditions.

Note: Error bars represent 95% confidence intervals. * indicates a significant difference at $p < 0.001$.

Interestingly, when we examined the individual data distribution of children whose results suggested the presence of a link between action and language (i.e., faster response times for congruent than for incongruent trials), we found that the percentage of participants with such results clearly increased with age, with 56% of participants 5-6 years old, 84% of participants 7-8 years old and 100% of participants 9-11 years old exhibiting faster response times for congruent trials (see Figure 3).

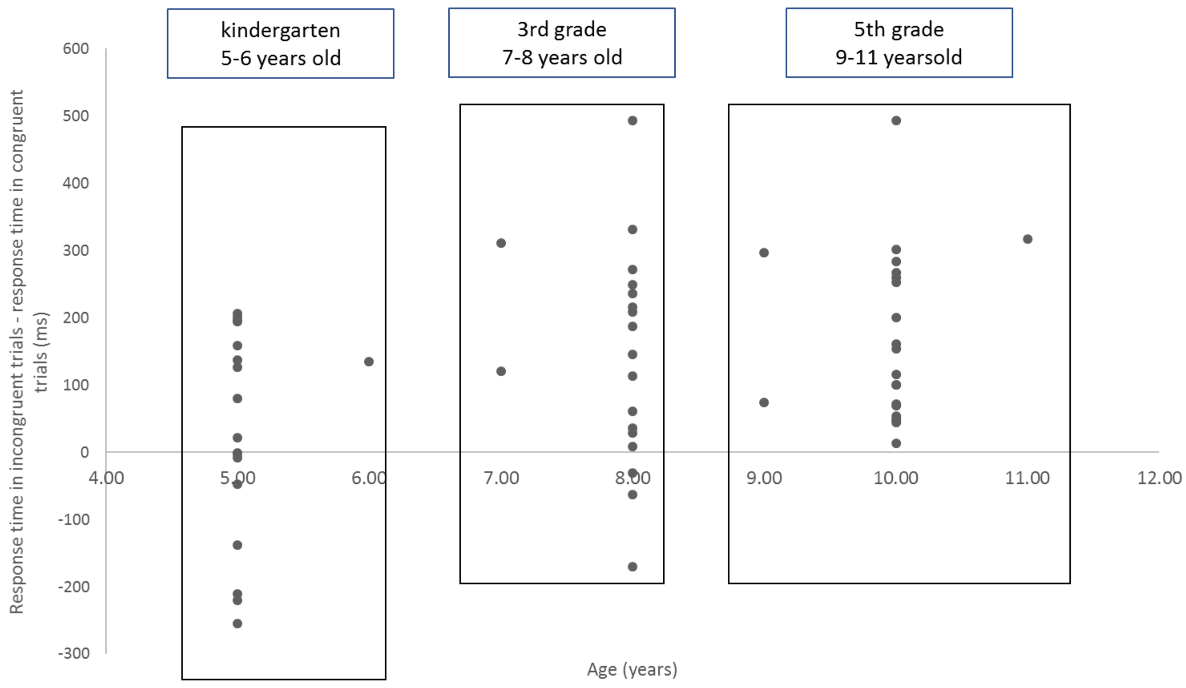

Figure 3: Individual Differences Between the Incongruent and Congruent Conditions.

Note: Positive values indicate the presence of a link between action and language.

Action-Image Naming Task

The analysis of responses showed a significant effect for Age (Chi² (2) = 13.84; $p < 0.001$), with a higher proportion of correct responses for 9- to 11-year-old children (*M* = 98.6%, *SD* = 3.6%) than for 7- to 8-year-old children (*M* = 97.9%, *SD* = 5.23%) or 5- to 6-year-old children (*M* = 93.6%, *S*D = 13.2%).

Correlation Analysis

No significant correlations appeared between the language-action link (measured as the difference in response time between the incongruent and congruent conditions) and the percentage of correct responses in the action-image naming task in any group ($p > 0.26$ for the three groups, see Figure 4).

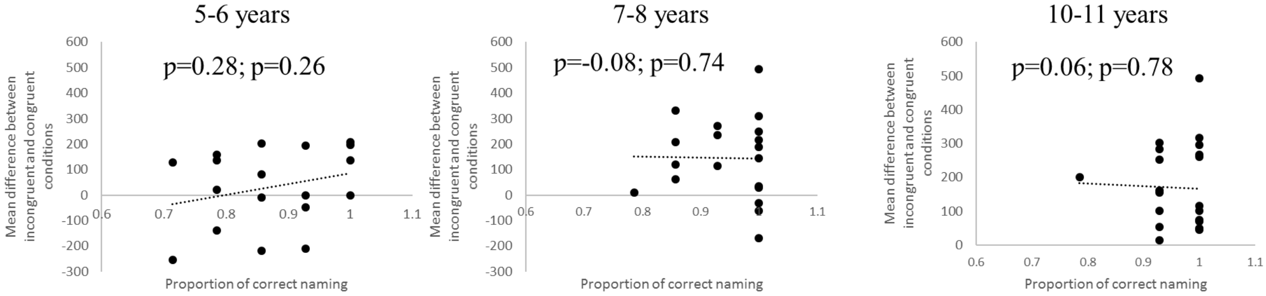

Figure 4: Spearman's Rho Correlation Coefficients (ρ) and *p* Values for the Relationship between Action-Language Performance (mean difference in response time between the incongruent and congruent conditions) and the Percentage of Correct Responses in the Action-Image Naming Task.

Discussion

The objective of this paper was to assess whether a link between language and action observation could be found in children and, if so, how this link evolves with age. We asked children in three age classes (5-6-, 7-8- and 9–11-year-olds) to perform a priming task, consisting of judging whether a human body was present in an image after listening to an action verb. The results showed a difference in response times between the congruent and incongruent trials among the 7- to 8-year-olds, suggesting that a link exists between action verb processing and action observation, as observed in adults (Bidet-Ildei, et al., 2020; Bidet-Ildei et al., 2011). We found, for the first time, that action verb processing can modify the subsequent visual judgment of static images representing actions in children. However, we detected no difference in response times between the congruent and incongruent trials in 5- to 6-year-old children, suggesting that the link between language and action had not yet matured in these children. Interestingly, this absence of a difference in response time between incongruent and congruent conditions in 5-6 years old cannot be explained by poor knowledge of actions or by incomprehension of the task. Indeed, the 5- to 6-year-old children had a very high percentage of correct responses, which did not differ from the percentages of correct responses in the two groups of older children. Moreover, although the 5- to 6-year-old children exhibited poorer performance than the older children in the action-image naming task, their performance was nonetheless strong (with more than 93.6% correct responses), and we observed no correlation between this performance and the strength of the link between action and language. This suggests that the results obtained in the priming task were not related to the capacity to name an action depicted in an image, suggesting an implicit (rather than explicit) intervention of the motor system in the link between language and action in the older children, as is the case in adults (Beauprez & Bidet-Ildei, 2018; Willems et al., 2010).

These results confirm the existence of a link between language and action observation in children, although its appearance in this study was later than previously observed for language and action production (Antognini & Daum, 2019; Gampe & Daum, 2014; James & Maouene, 2009). This later appearance suggests that younger children were not able to spontaneously activate the sensorimotor representation of action when they heard action verbs in a language-action priming task and, thus, did not exhibit a link between action verb processing and action observation. An alternative explanation of this difference in timing could be that our task not only measured the link between action verb processing and action observation but also necessitated other cognitive functions, such as response inhibition. Many investigators have shown that executive functions and, in particular, inhibition, emerge during the first years of life but continue to strengthen significantly throughout childhood and adolescence (see, for example, Best & Miller [2010] for a review). Therefore, it is possible that the effect did not appear with younger children because they have less inhibitory capacity than older children. The difference between congruent and incongruent conditions in the priming task could be related to differences in the capacity to inhibit the incongruent items.

Consequently, an inhibition defect could cause a decrease of the difference between congruent and incongruent conditions. However, research on the link between language and action observation with a priming procedure has shown that the effect is related to facilitation in congruent conditions and not inhibition in incongruent conditions (e.g.,Beauprez & Bidet-Ildei, 2017). Moreover, inhibition continues to develop until 10-11 years of age (e.g., Igazság et al., 2019), whereas the link between language and action observation was present in our study from 7-8 years of age.

Another possible explanation for the absence of a response time difference in the 5-to 6-year-olds is the methodological difference of our experiment, relative to previous experiments. Indeed, previous studies have used direct measures of the language-action link through fMRI (James & Maouene, 2009), EEG (Antognini & Daum, 2019) or eye movements (Gampe & Daum, 2014), whereas in the present study, the measure was indirect, with the language-action link being evaluated by a priming paradigm. Therefore, it is possible that our behavioral paradigm necessitates a supplementary step, perhaps a semantic resonance (see Bidet-Ildei et al., 2020), which may implicate a stronger link between language and action. As no study has yet evaluated the development of the link between language and action, it is unclear whether the implication of motor areas during action verb processing increases with age; this topic is a promising one for future studies.

Limitations and Directions for Further Research

Our study presents some limitations. First, we cannot affirm with our paradigm that our effect is specific to verbs. It is possible that children aged 5-6 years were not significantly different in their performances under congruent and incongruent conditions when the task associated a noun and a picture of object which could suggest that the problem would be more related to general competencies than to the evolution of the link between action observation and action verb processing. Second, even if some difficulties in inhibition do not seem able to explain the effects observed, it is possible that other psychophysiological capacities such as motor or reasoning competencies could intervene in the link between action observation and action verb processing. Third, it is possible that our task was too easy to put in evidence an age effect in response accuracy. We obtained very good scores for all classes of age suggesting that a ceiling effect could affect our results. Finally, our samples were relatively small and our effect sizes were weak. Future investigators should cross-validate these results with larger samples and study specifically the potential intervention of others' cognitive (e.g., reasoning) and motor competencies on the effect. Future investigators should also study the specificity of the evolution of the link between action observation and action verb processing.

Conclusion

We demonstrated in this study that the link between action verb processing and action observation has evolved with age and therefore results (at least in part) from the associations between motor and/or visual experience and action verb processing. This finding supports associationist theory. Possibly, the link between action verb processing and action observation is based on the activation of the motor mirror neuron system and the level of activation depends on the number of associations encountered with experience. This hypothesis is particularly interesting because it could account for a finding in previous studies that action verb processing recruits the motor system very early and for our finding that action verbs process prime action images only in children 7-8 years old. This possibility warrants further research.

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Appendix 1: Verbs used in the experiments and the standard frequency index (SFI) values for children at 5 years of age and between 6 and 11 years of age.

Verb	**SFI at 5 years of age (Manulex)**	**SFI at between 6 and 11 years of age (Manulex)**
Boire (Drink)	64.97%	64.20%
Chanter (Sing)	66.94%	64.76%
Courir (Run)	67.37%	67.06%
Cueillir (Pick)	61.22%	60.63%
Danser (Dance)	63.40%	62.11%
Dessiner (Draw)	64.64%	64.52%
Frapper (Knock)	61.02%	62.05%
Lire (Read)	72.45%	70.70%
Manger (Eat)	71.67%	69.31%
Marcher (Walk)	66.51%	65.89%
Monter (Climb)	66.91%/	65.93%
Nager (Swim)	62.11%	60.95%
Patiner (Skate)	36.25%	49.03%
Saluer (Salute)	57.67%	58.27%
Sauter (Jump)	66.88%	65%

Appendix 2: The actions and concrete images that were used in the experiments. All images were selected from the French database Clic images 2.0 (see Clic-Image2-0–Réseau Canopé http://www.cndp.fr/crdp-dijon/clic-images/).