REVIEW OF LITTERATURE

How to best train children and adolescents for fMRI? Meta-analysis of the training methods in developmental neuroimaging

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Abstract

Neuroeducation aims to improve pedagogical approaches by adding neuroimaging data. Practical and technical challenges emerge when children undergo magnetic resonance imaging (MRI), thereby raising several problems. We performed a meta-analysis of functional MRI datasets that were published during 1995 to 2011 according to the type of training of 4001 typically developing children and adolescents. The meta-analysis investigated whether different types of training (standard, mock, coaching trainings) improved the success rate of functional MRI inclusion rate and decreased the exclusion rate for excessive motion. We wondered if these specific trainings have differential developmental effects. Additionally, we examined if certain factors, such as age, the type of the cognitive tasks, the sex ratio, the financial compensation, the session order with structural MRI and the duration of the functional runs would influence the functional MRI success rate (more inclusion and less exclusion). The results indicated that coaching training for all of the children is the most relevant type of training to reduce motion and include more data. The type of task also took part in the success rate for fMRI. We propose guidelines to optimize the inclusion rate of functional MRI studies with typically developing children. Finally, we offer clinical and educational implications.

1. Introduction

Neuroeducation is a very promising research field. It came from developmental cognitive neuroscience and educational sciences, which aim to address educational issues at the brain level using neuroimaging and other psychophysiological techniques. The ambition of this up-and-coming research field is to add brain data to the models in order to improve pedagogy. One of the main challenges is basically to collect usable imaging data of the developing brain. This is more demanding with children and adolescents because functional Magnetic Resonance Imaging (fMRI) requires close cooperation and self-control for several minutes (Bookheimer, 2000). The applicability of fMRI has been demonstrated with a typically developing population (Casey et al., 1995) and since then, different types of training have been developed to scan young active children using fMRI. The aim of the present study is first to identify which one best improves the success rate of the fMRI inclusion rate and decreases the exclusion rate the most for excessive motion in particular. Secondly, the goal was to possibly detect additional factors that can be manipulated to maximize data quality (such as the financial compensation, the session order, the scan duration, the task type or the sex ratio) regarding experimental designs centered on the developmental stage/age.

Functional MRI technique requires all volunteers to lay still and avoid any movement (i.e. no more than a very few millimeters) during the examination (Byars et al., 2002). Although the motivation issue in this population can be reduced by being cheerful and offering financial compensation when it is legally possible, the motion artifact still presents a serious issue. Motion artifacts are the first of all concerns when scanning young children (Wilke, Holland, Myseros, Schmithorst, & Ball, 2003). Three main training types for fMRI with an awake developmental population were identified in the literature: (1) standard training as it is usually performed with adults; (2) training with an MR simulator (Berl et al., 2010; Cantlon, Pinel, Dehaene, & Pelphrey, 2011; Scherf, Luna, Avidan, & Behrmann, 2011); and (3) coaching training (Lukins, Davan, & Drummond, 1997; Quirk, Letendre, Ciottone, & Lingley, 1989).

A standard training consists of offering children a detailed explanation of the protocol and presenting tasks without focusing on the motion issue or the MRI environment, as for adults. The type of training is fast, easily automated across participants; it enables the volunteer to focus his/her attention on the cognitive task without particularly focusing on the motion issue or on the MRI environment.

Training with an MR simulator consists of using a mock scanner, which is a full-scale replica of an MRI scanner, without a magnetic field. It is generally equipped with a manually operated subject table, head coil, foam cushions, headphones, and earplugs. When possible, a sound system allows the volunteers to hear the different noises produced by the MR sequences. It has been widely experienced and described that a first exposure to an MR environment, with a mock scanner here, prior to the actual MR session dramatically decreases stress for the child and the family on one hand and critically improves the success of the scanning session on the other hand (Bookheimer, 2000). In a research context, a significant positive effect of a training session of 15-30 minutes, in which an MR simulator is employed, has been demonstrated with healthy children using heart rate measures and self-report distress scale scores compared to children who did not undergo the simulation scanning procedure (Durston et al., 2009). In a clinical context, a mock scanner reduces the rate of general anesthesia (GA) by 17 % for children aged three to eight years (Carter, Greer, Gray, & Ware, 2010) and incurs a net cost savings of approximately $117,870 per year and per full-time use of one MR scanner.

Parallel to these two types of training, coaching training produced good results. In this case, experimenters use extensive repetition of the task requirements and behavioral reinforcement methods to control anxiety and motor movements in the scanner. The coaching training methodology consists of relaxation sessions (Ciesielski, Lesnik, Savoy, Grant, & Ahlfors, 2006; Lukins, Davan, & Drummond, 1997), play therapy (Pressdee, May, Eastman, & Grier, 1997), cognitive behavioral therapy (Byars et al., 2002; Rosenberg-Lee, Barth, & Menon, 2011; Slifer, 1996; Slifer, Cataldo, Cataldo, Llorente, & Gerson,1993, Slifer, Bucholtz, & Cataldo, 1994; Slifer, Koontz, & Cataldo, 2002; Tyc, Fairclough, Fletcher, Leigh, & Mulhern, 1995) or training for the “statue game”, for example, inside a play tunnel (Houdé et al., 2011). Sometimes, supplementary tools are used, such as photos, videos, an active presentation, a CD or a website, a guided tour of the facilities, audio-visual systems (Lemaire, Moran, & Swan, 2009; Slifer, Penn-Jones, Cataldo, Conner, & Zerhouni, 1991), decoration with colorful posters and stickers to create a child-friendly environment (Byars et al., 2002; Holland et al., 2001, 2007; Houdé et al., 2011; Levesque et al., 2004; Schmithorst, Holland, & Plante, 2006; Yuan et al., 2009). Coaching training is a cheap and efficient way to familiarize children compared to the cost of a mock scanner; however, such efforts can be time consuming.

To date, developmental cognitive neuroscience groups lack quantitative comparisons between the different strategies to reduce head motion during fMRI and to optimize successful neuroimaging sessions. We faced several challenging tasks. First, we investigated whether an fMRI training (coaching or mock scan), as opposed to a standard training, led to greater gains in fMRI success rate improving the fMRI inclusion rate and decreasing the exclusion rate for excessive motion. Based on previous research (Berl et al., 2010; Cantlon, Pinel, Dehaene, & Pelphrey, 2011; Lukins, Davan, & Drummond, 1997; Quirk, Letendre, Ciottone, & Lingley, 1989; Scherf, Luna, Avidan, & Behrmann, 2011), we assumed that studies with children trained with a mock scanner or with coaching training would show significantly greater inclusion rates and smaller exclusion rates than children who underwent a standard training. Moreover, we supposed that these specific trainings have differential developmental effects; the older the children, the less specific the preparation (LeBaron & Zeltzer, 1984). Secondly, we evaluated which factors would influence the fMRI success rate. Some factors, like the sex variable, have already been identified as an obvious candidate impacting head motion (Dantendorfer et al., 1997; Katz, Kellerman, & Siegel, 1980; Yuan et al., 2009). But others remain to be investigated. We assumed that in addition to the type of training, the age, the duration of the functional runs, the sex ratio, the session order with structural MRI (sMRI), the type of task and the financial compensation might be potential modulation factors. According to the type of training published from 1995 to 2011, we performed a meta-analysis of the fMRI datasets, including 4001 awake and normally developing children and adolescents.

2. Method

2.1. Article selection and datasets

We reviewed articles with brain imaging in children from September 1, 1995 until September 1, 2011, including healthy or control groups of alert and non-sedated children from 4 to 17 years of age. The articles had to include original data in transversal fMRI designs with at least one task requiring attention from the participant (rest session was not considered). The number of runs was noted to determine the “minimum number of runs” acquired during the fMRI session (Tables 2, 3, 4). The resulting 247 identified articles were then submitted to a full text review. A total of 133 articles reporting the ratio of included children were considered. Of these 133 articles, we identified 23 articles that studied the same sub-samples / samples; therefore, only the study reporting the whole sample was considered (Table 1). Among these 110 original articles, the number of independent datasets was the number of independent samples, as specified by the authors in their Method section. Indeed, some studies included several samples with different ages (e.g. on Table 2, article N° 10 was described on two rows for the two datasets: one row with a mean age of 9.3 years and another row with a mean age of 13 years because the two samples were described separately by the authors).

The final selection of 110 original articles that were included in this meta-analysis involved 154 independent datasets with 4001 children. The datasets were classified into three categories according to the method section: participants prepared for the fMRI session with a standard training inherent to an fMRI session (STANDARD, n = 61), with a full-scale mock scanner (MOCK, n = 70), or with a coaching preparation (COACH, n = 23; see Tables 2-4).

Table 1. Study selection and datasets according to the type of training.

	STANDARD	MOCK	COACH	Total
Identified articles	131	93	23	247
Included articles	61	57	15	133
With: Redundant / Original samples	9 / 52	8 / 49	6 / 9	23 / 110
Independent datasets	61	70	23	154

For each study, the inclusion rate was defined as the percentage (N, last row of Table 5) of individual fMRI datasets included in the group analysis and the exclusion rate was the 1-N percentage. Among the 154 datasets, all of them indicated the number of included children, 120 denoted the number of excluded children according to one or several reasons and only 103 pointed out the number of excluded children due to excessive motion (only or with other reasons). The reasons of exclusion were either described in the Method section of the article either informed by email by the corresponding authors. The exclusion rate was therefore subdivided (percent) according to the reasons of exclusion (excessive motion, low performances, technical problems, sleepiness, premature stop of the scan by the child and other reasons). Other reasons (abnormal neurologic examination or structural MRI, major psychiatric condition, stainless steel dental crowns, etc.) were rarely mentioned except in one study of the COACH groups (Byars et al., 2002) where this category was broader than in other studies (history of migraines, weight or height greater than the 95th percentile). Note that the main reason of exclusion was due to excessive motion and represents the focus of this meta-analysis.

The age groups were defined as follows: kindergarten children (range, mean ± Standard Deviation – SD –, 4-7 years, 6 ± 1 years); school-age children (8-9 years, 9 ± .6 years); pre-adolescents (10-12 years, 11 ± .9 years); and adolescents (13-17 years, 15 ± 1 years).

Table 2. Descriptive information of 61 STANDARD articles included in the meta-analysis revealing 61 independent datasets.

				Sample			Protocol					Inclusion /exclusion rates (%)					
# included articles	Authors	Year	# dataset	No. of part.	Sex (F/M)	Age (years)	Min. # of runs x run duration (min)	fMRI before sMRI	Allowance or price of the gift ($)	Consent	Task's domain	Inclusion rate*	Exclusion due to motion	Exclusion due to low performances	Exclusion due to techn pb	Exclusion due to sleep	Exclusion due to other reasons
1	Nelson et al.	2000	1	9	n/r	9.8[a]	1 x 5.7	yes	13	Parents+child	Executive function	64	100				
2,3	Thomas et al.	2001a, b	2	12	6/6	11.0	3 x 5	no	n/r	Parents+child	Perception	75	100				
4	Durston et al.	2002	3	10	5/5	8.7	5 x 4	n/r	n/r	Parents+child	Executive function	45	100				
5	Klingberg et al.	2002	4	13	9/4	13.4	2 x 5	n/r	n/r	n/r	Executive function	93		100			
6	Kwon et al.	2002	5	16	n/r	12[a]	n/r x 7.2	n/r	n/r	n/r	Executive function	59	100				
7	Aylward et al.	2003	6	11	6/5	11.5	2 x 5.7	n/r	n/r	Parents+child	Language	55	100				
8	Durston et al.	2003	7	7	6/1	6.7	5 x 4	n/r	n/r	Parents+child	Executive function	70	100				
9	Ansari et al.	2005	8	12	n/r	10.4	3 x 4.25	yes	26	Parents	Numerical	44	100				
10	Aylward et al.	2005	9	8	4/4	9.3	1 x 5.7	n/r	n/r	Parents+child	Perception	73	100				
	Aylward et al.	2005	10	10	6/4	13.0	1 x 5.7	n/r	n/r	Parents+child	Perception	100					
11	Menon et al.	2005	11	15	6/9	15.1	n/r x 5.5	n/r	n/r	Parents+child	Executive function	60	100				
12	Rivera et al.	2005	12	17	6/11	13.7	n/r x 3.5	n/r	n/r	Parents	Numerical	100					
13	Ansari et al.	2006	13	9	6/3	10.4	3 x 4.25	yes	26	Parents	Numerical	53	100				
14	Bitan et al.	2006	14	15	8/7	10.9	2 x 9	n/r	n/r	n/r	Language	100					
15	Brem et al.	2006	15	13	5/8	16.2	4 x 13.1	yes	65	Parents+child	Language	100					
16	Chen et al.	2006	16	16	8/8	12.0	n/r	n/r	n/r	Parents	Numerical	94	100				
17	Kaufmann et al.	2006	17	11	10/1	9.6	1 x 12.8	no	33	Parents+child	Numerical	65					100
18-20	Kucian et al.	2006, 08, 11	18	20	10/10	11.0	n/r x 4.6	n/r	n/r	Parents	Numerical	77	67	33			
21	Pliszka et al.	2006	19	15	9/6	13.2	1 x 12	n/r	n/r	Parents+child	Executive function	65	88	13			
22	Rubia et al.	2006	20	29	29/0	15.0	3 x 6	no	26	Parents+child	Executive function	71					100
23	Smith et al.	2006	21	18	18/0	14.1	n/r	n/r	33	Parents	Executive function	67	100				
24,25	Wilke et al.	2006, 11	22	23	13/10	10.2	4 x 5.5	no	16	Parents+child	Language	92					100
26	Golarai et al.	2007	23	20	10/10	9[a]	3 x 2.3	no	n/r	Parents+child	Perception	87	100				
	Golarai et al.	2007	24	10	5/5	14[a]	3 x 2.3	no	n/r	Parents+child	Perception	100					
27	Leibenluft et al.	2007	25	17	9/8	14.6	4 x 8	n/r	n/r	Parents+child	Executive function	65	100				
28,29	Marsh et al.	2006, 07	26	20	11/9	13.5	2 x 3.8	n/r	52	Parents+child	Executive function	77	100				
30	McAuley et al.	2007	27	12	8/4	15.6	2 x 4.3	n/r	n/r	n/r	Executive function	100					
31	Ofen et al.	2007	28	17	9/8	10.7	5 x 3.5	no	26	Parents+child	Executive function	74	83	17			
	Ofen et al.	2007	29	18	9/9	15.7	5 x 3.5	no	26	Parents+child	Executive function	95	100				
32	Olesen et al.	2007	30	13	10/3	13.1	3 x 7.1	yes	n/r	Parents+child	Executive function	81			100		
33	Smith et al.	2007	31	24	24/0	14.1	n/r	n/r	33	Parents	Executive function	89	100				
34	Hare et al.	2008	32	12	7/5	9.1	6 x 5.1	n/r	n/r	Parents+child	Executive function	75	100				
	Hare et al.	2008	33	24	14/10	16.0	6 x 5.1	n/r	n/r	Parents+child	Executive function	89	100				
35	Kaufmann et al.	2008	34	12	8/4	8.6	1 x 10.7	yes	33	Parents+child	Numerical	55	60	40			
36	Siok et al.	2008	35	12	10/2	11.0	n/r x 3.8	n/r	n/r	Parents+child	Language	75	100				
37	Smith et al.	2008	36	27	27/0	14.1	n/r	n/r	33	Parents	Executive function	100					
38-40	Suskauer et al., Simmonds et al.	2008a,b, 07	37	25	15/10	10.6	2 x 5	n/r	n/r	Parents+child	Executive function	100					
41,42	Braet et al.	2009, 11	38	20	20/0	12.4	1 x 12	yes	13	Parents+child	Other	100					
43	Brem et al.	2009	39	19	9/10	10.3	4 x 13.1	yes	65	Parents+child	Language	79	100				
44	Cao et al.	2009	40	13	7/6	11.2	2 x 9	n/r	n/r	n/r	Language	72	20	80			
45	Geier et al.	2009	41	13	7/6	10[a]	n/r	yes	39	Parents	Perception	100					
	Geier et al.	2009	42	13	7/6	15[a]	n/r	yes	39	Parents	Perception	87	100				
46	Kaufmann et al.	2009	43	9	4/5	9.7	1 x 10.7	yes	32.5	Parents+child	Numerical	69	50				50

Table 2 – continued, last page.

# included articles	Authors	Year	# dataset	Sample: No. of part.	Sample: Sex (F/M)	Sample: Age (years)	Protocol: Min. # of runs x run duration (min)	Protocol: fMRI before sMRI	Protocol: Allowance or price of the gift ($)	Protocol: Consent	Protocol: Task's domain	Inclusion /exclusion rates (%): Inclusion rate*	Exclusion due to motion	Exclusion due to low performances	Exclusion due to techn pb	Exclusion due to sleep	Exclusion due to other reasons
47	Lu et al.	2009	44	24	11/13	10.5	1 x 8	no	n/r	Parents+child	Language	86	100				
	Lu et al.	2009	45	20	n/r	11[a]	n/r x 6.1	n/r	n/r	Parents+child	Language	80	40				60
48	Morton et al.	2009	46	14	5/9	12.2	1 x 3.9	yes	33	Parents	Executive function	82	100				
49	Schulz et al.	2009	47	30	n/r	10.2	n/r x 14.2	n/r	65	Parents+child	Language	79					100
50	Cohen et al.	2010	48	18	9/9	10.8	2 x 6.1	yes	13	Parents+child	Other	64	50	30	20		
	Cohen et al.	2010	49	16	10/6	15.8	2 x 6.1	yes	13	Parents+child	Other	76	20	20	60		
51	Dumontheil et al.	2010a, b	50	12	0/12	12.9	2 x 7	yes	13	Parents	Reasoning	92		100			
	Dumontheil et al.	2010a, b	51	12	0/12	16.1	2 x 7	yes	13	Parents	Reasoning	100					
52	Geier et al.	2010	52	18	10/8	15.3	4 x 5	yes	39	Parents	Other	82	100				
53	Holloway et al.	2010	53	19	7/12	8.2	4 x 3	yes	n/r	n/r	Numerical	59	100				
54	Ebner et al.	2011	54	43	24/19	12.0	2 x 5.5	no	39	Parents+child	Language	91	75	25			
55	Grande et al.	2011	55	25	12/13	9.5	2 x 4	yes	39	Parents+child	Language	100					
56	Krinzinger et al.	2011	56	10	6/4	9.9	4 x 4	yes	13	Parents	Numerical	71	75		25		
57	Lee et al.	2011	57	46	35/11	12.8	2 x 4.7	yes	n/r	Parents+child	Language	100					
58	Pitskel et al.	2011	58	15	9/6	13.0	1 x 13.6	no	n/r	Parents+child	Perception	63	78	22			
59	Sebastian et al.	2011	59	19	0/19	15.4	1 x 4.8	no	13	Parents+child	Other	100					
60	Tahmasebi et al.	2011	60	1110	518/592	14.4	1 x 6	n/r	91	Parents+child	Perception	91	100				
61	You et al.	2011	61	16	13/3	10[a]	2 x 6.1	n/r	n/r	Parents+child	Language	94	100				

No. of part., number of participants; F/M, female/male; n/r, not reported

[a] middle value of age range

* Percentage of participants included compared to the total number of participants scanned

Note that some articles (e.g. articles #10, #26, #31, #34, #45, etc.) involved several independent datasets so they were described on multiple rows.

Table 3. Descriptive information of 57 MOCK articles included in the meta-analysis revealing 70 independent datasets.

				Sample			Protocol					Inclusion /exclusion rates (%)					
# included articles	Authors	Year	# dataset	No. of part.	Sex (F/M)	Age (years)	Min. # of runs x run duration (min)	fMRI before sMRI	Allowance or price of the gift ($)	Consent	Task's domain	Inclusion rate*	Exclusion due to motion	Exclusion due to low performances	Exclusion due to techn pb	Exclusion due to sleep	Exclusion due to other reasons
1	Casey et al.	1997	1	10	n/r	9.9	2 x 6	n/r	46	n/r	Executive function	91	100				
2	Luna et al.	2001	2	11	3/8	10.9	1 x 9	n/r	n/r	Parents+child	Perception	69	100				
	Luna et al.	2001	3	15	9/6	15.7	1 x 9	n/r	n/r	Parents+child	Perception	94	100				
3	Schlaggar et al.	2002	4	19	9/10	9.3	3 x 3.4	no	33	Parents+child	Language	86	100				
4	Shaywitz et al.	2002	5	74	43/31	10.9	1 x 3.3	no	n/r	Parents+child	Language	94	100				
5	Kang et al.	2003	6	16	8/8	8.1	5 x 3.7	no	39	Parents+child	Executive function	70	100				
6, 7	Turkeltaub et al.	2003, 08	7	41	20/21	14.1	2 x 5.4	no	13	Parents+child	Language	72	100				
8	Wenger et al.	2004	8	10	3/7	8.5	6 x 4.5	no	39	Parents+child	Perception	77	100				
9	Wood et al.	2004	9	48	20/28	11	2 x 7.8	yes	n/r	Parents+child	Language	94					100
10,11	Ernst et al., Eshel et al.	2005, 07	10	16	7/9	13.3	3 x 7.2	yes	39	Parents+child	Reasoning	89	100				
12,13	Blumenfeld et al., Booth et al.	2006, 04	11	15	8/7	10.7	2 x 9	yes	n/r	n/r	Language	94		100			
14	Cantlon et al.	2006	12	8	3/5	4.7	2 x 11.9	no	52	Parents	Numerical	47	100				
15	Crone et al.	2006a	13	17	8/9	10.1	4 x 8	yes	n/r	Parents+child	Executive function	71	100				
16	Crone et al.	2006b	14	17	6/11	15	4 x 8	yes	n/r	Parents+child	Executive function	94	100				
17	Dibbets et al.	2006	15	7	7/0	6.8	1 x 10.8	no	10	Parents	Executive function	100					
18	Noble et al.	2006	16	31	15/16	7.9	2 x 4	n/r	n/r	Parents+child	Language	42	84	9			7
19	Scherf et al.	2006	17	9	3/6	11.2	1 x 5.3	yes	65	Parents+child	Perception	41	62		15	15	8
	Scherf et al.	2006	18	13	11/2	15.7	1 x 5.3	yes	65	Parents+child	Perception	81	67				33
20,21	Brauer et al., Friederici et al.	2007, 11	19	12	4/8	6.2	4 x 6	yes	n/r	Parents+child	Language	67	100				
22	Kobayashi et al.	2007a	20	24	12/12	9	1 x 8.7	no	n/r	Parents+child	Other	92	100				
23	Kobayashi et al.	2007b	21	12	6/6	9.8	2 x 9.7	no	n/r	Parents+child	Other	86	100				
24	Meyler et al.	2007	22	67	21/46	9.8	n/r x 4.7	n/r	39	Parents+child	Language	55	26	9			65
25	Price et al.	2007	23	8	n/r	12.1	3 x 2.5	no	n/r	n/r	Numerical	57	83	17			
26	Scherf et al.	2007	24	10	6/4	7.2	1 x 9	yes	65	Parents	Perception	48	64			9	27
	Scherf et al.	2007	25	10	6/4	12.5	1 x 9	yes	65	Parents	Perception	56	50				50
27	Burman et al.	2008	26	62	31/31	12[a]	8 x 8	no	n/r	Parents+child	Language	90	86	14			
28,29	Crone et al., Koolschijn et al.	2008, 11	27	17	9/8	9.5	3 x 8.2	yes	n/r	Parents+child	Executive function	85	100				
	Crone et al., Koolschijn et al.	2008, 11	28	20	11/9	14.5	3 x 8.2	yes	n/r	Parents+child	Executive function	100					
30	O'Hare et al.	2008	29	12	6/6	9	1 x 7.5	yes	n/r	Parents+child	Executive function	86	50	50			
	O'Hare et al.	2008	30	10	4/6	13.6	1 x 7.5	yes	n/r	Parents+child	Executive function	100					
31	Paz-Alonzo et al.	2008	31	16	8/8	8.5	2 x 6.3	no	22	Parents+child	Executive function	89	100				
	Paz-Alonzo et al.	2008	32	16	8/8	12.4	2 x 6.3	no	22	Parents+child	Executive function	94	100				
32	Raizada et al.	2008	33	14	7/7	5.4	1 x 5.8	yes	91	Parents+child	Language	93	100				
33	Van Duijvenvoorde et al.	2008	34	16	8/8	8.6	4 x 8.5	yes	39	Parents	Executive function	89	100				
	Van Duijvenvoorde et al.	2008	35	16	10/6	11.7	4 x 8.5	yes	39	Parents	Executive function	84	33	67			
34	Wright et al.	2008	36	16	7/9	9.9	4 x 4.5	yes	20	Parents+child	Language	70	100				
35	Cantlon et al.	2009	37	14	7/7	7.2	4 x 6	no	n/r	n/r	Numerical	70	67		33		
36	Crone et al.	2009	38	23	11/12	9.7	5 x 8	yes	n/r	Parents+child	Reasoning	74	50		50		
37,38	Davis et al.	2009a, b	39	27	13/14	8.1	4 x 5	no	n/r	Parents+child	Numerical	77	100				
39	Van den Bos et al.	2009	40	18	9/9	10	2 x 8.5	yes	30	Parents+child	Other	100					
	Van den Bos et al.	2009	41	27	14/13	14.3	2 x 8.5	yes	30	Parents+child	Other	100					
40-42	Velanova et al., Hwang et al.	2008, 09, 10	42	26	11/15	10.5	4 x 6.3	no	65	Parents+child	Perception	74	56	22			22
	Velanova et al., Hwang et al.	2008, 09, 10	43	25	10/15	15.3	4 x 6.3	no	65	Parents+child	Perception	71	60		40		

Table 3 – continued, last page.

				Sample			Protocol					Inclusion /exclusion rates (%)					
# included articles	Authors	Year	# dataset	No. of part.	Sex (F/M)	Age (years)	Min. # of runs x run duration (min)	fMRI before sMRI	Allowance or price of the gift ($)	Consent	Task's domain	Inclusion rate*	Exclusion due to motion	Exclusion due to low performances	Exclusion due to techn pb	Exclusion due to sleep	Exclusion due to other reasons
43	Berl et al.	2010	44	59	31/28	8.7	1 x 5	no	n/r	Parents+child	Language	80	73		20	7	
	Berl et al.	2010	45	44	24/20	10	1 x 5	no	n/r	Parents+child	Language	88	100				
44	Ghetti et al.	2010	46	60	30/30	11[a]	4 x 5	yes	39	n/r	Other (Memory)	92	60	40			
45	Gunther Moor et al.	2010	47	12	5/7	9.7	2 x 8.1	yes	39	Parents+child	Other (Social judgment)	86	100				
	Gunther Moor et al.	2010	48	14	6/8	13.3	2 x 8.1	yes	39	Parents+child	Other (Social judgment)	93	100				
	Gunther Moor et al.	2010	49	15	8/7	17.1	2 x 8.1	yes	39	Parents+child	Other (Social judgment)	100					
46	Meintjes et al.	2010	50	16	6/10	10.5	2 x 5.1	no	26	Parents+child	Numerical	89	100				
47	Van Leijenhorst et al.	2010a	51	13	5/8	9.7	2 x 2	yes	7	Parents+child	Reasoning	87	100				
48	Van Leijenhorst et al.	2010b	52	17	9/8	11.6	2 x 7	yes	39	Parents+child	Reasoning	94	100				
	Van Leijenhorst et al.	2010a	53	15	10/5	13.4	2 x 2	yes	7	Parents+child	Reasoning	100					
	Van Leijenhorst et al.	2010b	54	18	8/10	15	2 x 7	yes	39	Parents+child	Reasoning	90	100				
	Van Leijenhorst et al.	2010a	55	15	8/7	17.1	2 x 2	yes	7	Parents+child	Reasoning	100					
49	Cantlon et al.	2011	56	15	8/7	4.9	2 x 9.7	no	n/r	n/r	Perception	58	64				36
50	de Smedt et al.	2011	57	10	6/4	11.7	2 x 5	yes	20	Parents+child	Numerical	56	75	13	13		
51	Gunther Moor et al.	2011	58	19	8/11	11.6	2 x 5.7	yes	39	Parents+child	Perception	95	100				
	Gunther Moor et al.	2011	59	16	8/8	15.7	2 x 5.7	yes	39	Parents+child	Perception	100					
52	Guroglu et al.	2011	60	17	11/6	10.4	3 x 7.3	yes	7	Parents+child	Other	100					
	Guroglu et al.	2011	61	15	7/8	13.4	3 x 7.3	yes	7	Parents+child	Other	100					
	Guroglu et al.	2011	62	13	8/5	15.4	3 x 7.3	yes	7	Parents+child	Other	100					
53	Jolles et al.	2011	63	15	5/10	12.5	2 x 8.8	yes	26	Parents+child	Executive function	100					
54	Keulers et al.	2011	64	18	n/r	12.9	3 x 7.3	yes	46	Parents+child	Reasoning	67	100				
	Keulers et al.	2011	65	21	n/r	17	3 x 7.3	yes	46	Parents+child	Reasoning	95	100				
55	Scherf et al.	2011	66	13	9/4	7	2 x 2.8	yes	65	Parents	Perception	68	100				
	Scherf et al.	2011	67	13	8/5	13	2 x 2.8	yes	65	Parents	Perception	87	100				
56	Van den Bos et al.	2011	68	21	10/11	13.2	4 x 8.5	yes	30	Parents+child	Other (Social judgment)	100					
	Van den Bos et al.	2011	69	15	8/7	16.4	4 x 8.5	yes	30	Parents+child	Other (Social judgment)	100					
57	Wendelken et al.	2011	70	15	6/9	11.5	3 x 7.8	yes	20	Parents+child	Perception	68	86	14			

No. of part., number of participants; F/M, female/male; n/r, not reported

[a] middle value of age range

* Percentage of participants included compared to the total number of participants scanned

Note that some articles (e.g. articles #2, #19, #26, #30, #31, etc.) involved several independent datasets so they were described on multiple rows.

Table 4. Descriptive information of 15 COACH articles included in the meta-analysis revealing 23 independent datasets.

				Sample			Protocol					Inclusion /exclusion rates (%)					
# included articles	Authors	Year	# dataset	No. of part.	Sex (F/M)	Age (years)	Min. # of runs x run duration (min)	fMRI before sMRI	Allowance or price of the gift ($)	Consent	Task's domain	Inclusion rate*	Exclusion due to motion	Exclusion due to low performances	Exclusion due to techn pb	Exclusion due to sleep	Exclusion due to other reasons
1 - 7	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		1	21	17/4	5.0	1 x 5.5	yes	91	Parents+child	Language	43					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		2	15	5/10	6.0	1 x 5.5	yes	91	Parents+child	Language	53					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		3	28	12/16	7.0	1 x 5.5	yes	91	Parents+child	Language	68					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		4	23	11/12	8.0	1 x 5.5	yes	91	Parents+child	Language	87					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		5	17	7/10	9.0	1 x 5.5	yes	91	Parents+child	Language	76					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		6	22	12/10	10.0	1 x 5.5	yes	91	Parents+child	Language	100					
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		7	16	9/7	11.0	1 x 5.5	yes	91	Parents+child	Language	100					
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		8	14	10/4	12.0	1 x 5.5	yes	91	Parents+child	Language	86					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		9	15	7/8	13.0	1 x 5.5	yes	91	Parents+child	Language	93					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		10	10	6/4	14.0	1 x 5.5	yes	91	Parents+child	Language	90					100
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		11	10	3/7	15.0	1 x 5.5	yes	91	Parents+child	Language	100					
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		12	5	1/4	16.0	1 x 5.5	yes	91	Parents+child	Language	100					
	Byars et al. 2002, Holland et al. 01, 07, Schmithorst et al. 06, 07, Wilke et al. 03, Yuan et al. 09		13	8	6/2	17.0	1 x 5.5	yes	91	Parents+child	Language	100					
8	Levesque et al.	2004	14	14	0/14	9.9	2 x 10	yes	26	n/r	Perception	93	100				
9	Balsamo et al.	2006	15	22	10/12	8.5[a]	1 x 10.7	yes	39	Parents+child	Language	85	100				
10	Ciesielski et al.	2006	16	17	9/8	8.1	1 x 2.3	yes	39	n/r	Executive function	85	100				
11	Church et al.	2009	17	27	18/9	12.5	8 x 5	no	72	Parents+child	Language	73	30			10	60
12	Everts et al.	2009	18	20	11/9	12.9[a]	4 x 10	yes	22	Parents+child	Language	71	100				
13	Houdé et al.	2011	19	23	7/16	6.0	1 x 7	no	26	Parents+child	Numerical	61	93	7			
	Houdé et al.	2011	20	16	8/8	10.2	1 x 7	no	26	Parents+child	Numerical	73	17	17	67		
14	Rosenberg-Lee et al.	2011	21	45	30/15	7.7	4 x 6.5	yes	91	Parents+child	Numerical	70	11	89			
	Rosenberg-Lee et al.	2011	22	45	21/24	8.7	4 x 6.5	yes	91	Parents+child	Numerical	76	21	79			
15	Leroux et al.	Sub.	23	13	13/0	11.2	3 x 5	yes	86	Parents+child	Executive function	65	71		29		

No. of part., number of participants; F/M, female/male; n/r, not reported, sub, submitted

[a] middle value of age range

* Percentage of participants included compared to the total number of participants scanned

Note that some articles (articles #1 to #7, #13 and #14) involved several independent datasets so they were described on multiple rows (e.g., the articles numbered one to seven involved the same number of datasets from one to thirteen).

2.2. Statistical analysis

We performed the statistical analysis using Statistica software v.10 (Statsoft Inc., Tulsa, OK, USA). We first conducted analysis of variance (ANOVAs) to test the type of training (STANDARD, MOCK, COACH) and age on the inclusion rate (n = 154) and exclusion rate. For each analysis, we report the effect size either in the ANOVA (partial eta squared noted η_p^2) or in terms of the difference of the means (Cohen's d). Then, when we compared two means, we computed one-tailed t-tests in accordance with our hypothesis; all the α levels for the t-tests were adjusted with a Tukey's correction. Secondly, we ran 2 separate multiple regression analysis to predict gains in the fMRI success rates, the first based on the inclusion rate and the second based on the exclusion rate attributed to excessive motion. Finally, we tested the specific effect of the mean age and the task's domain (executive function, perception, language, mathematics, reasoning, other) on the inclusion rate using Pearson correlations and ANOVA analysis.

3. Results

The characteristics of the datasets depending on the type of training were detailed in Table 5. The children aged four to seven years old were almost always prepared with a mock scan or coaching training (Figure 1). Also, 46% of the participants included in the COACH group provided from a large study (204 children of the 446 children came from Byars et al. 2002, Table 4).

Table 5. Characteristics of the datasets according to the type of training.

	STANDARD	MOCK	COACH	Total
Number of included children	2126	1429	446	4001
Mean age in years (SD) Range	12 (2) 7- 16	11 (3) 5 - 17	10 (3) 5 - 17	11 (3) 5 – 17
Percentage of boys (SD) Range	53 (26) 0 - 100	47 (16) 0 - 100	51 (21) 0 - 100	50 (22) 0 – 100
Financial compensation in $ (SD) Range	25 (15) 10 - 70	28 (15) 5 - 70	57 (21) 17 - 70	34 (21) 5 – 70
Number of independent datasets	61	70	23	154
Number of datasets of session order with sMRI [1]	12/21/28	21/44/5	3/20/0	36/85/33
Total scan duration in min. (SD) Range	15 (10) 4 - 52	17 (11) 3 - 64	11 (12) 2 - 40	15 (11) 2 – 64
Number of datasets of each type of task [2]	10/9/21/14/2/5	6/15/14/13/9/13	4/1/2/16/0/0	20/25/37/43/11/18
Inclusion rate N (SD) Range	80 (16) 44 - 100	83 (16) 41 - 100	80 (16) 43 - 100	82 (16) 41 – 100

[1] Session order with sMRI: sMRI before fMRI / fMRI before sMRI / not reported.
[2] Type of task: numerical / perception / executive functions / language / reasoning / others

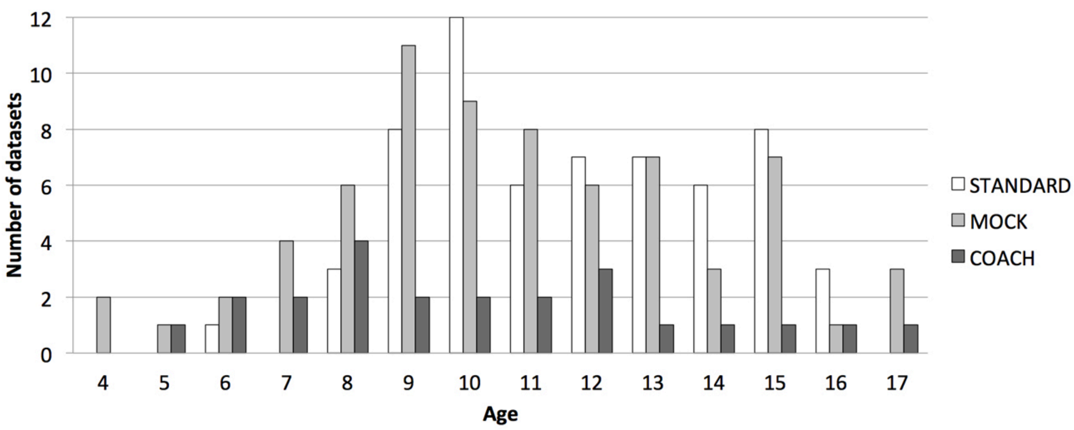

Figure 1. Distribution of the datasets according to the type of training and age of the children.

3.1. First question: Do coaching or mock scan fMRI trainings lead to greater gains in fMRI success rate than standard training? Do these specific trainings have different effects across development?

On the inclusion rate, the Age x Type of training interaction was not significant ($F(2,151) = .41$, $p = .66$, $\eta_p^2 = .04$). No effect of the Type of training was evidenced for the entire datasets [$F(2,151) = 2.0$, $p = .13$, $\eta_p^2 = .006$] but the main effect of age group was significant [$F(1,151) = 39.9$, $p < .0001$, $\eta_p^2 = .16$], as expected with an increasing inclusion rate with age. The post-hoc revealed that inclusion rate was significantly lower for the kindergarten group (64 ± 17 %) compared to the older school-age children (78 ± 12 %), the pre-adolescents (81 ± 16 %) and the adolescents (90 ± 12 %), ($p < .01$ for all comparisons). The post-hoc was not significant between the school-age children and the pre-adolescents ($p = .73$).

We carried out planned comparisons for each age group to answer to the a priori hypothesis about the different effects of the specific trainings across development. The type of training was significant for school-age children [$F(2, 33) = 4.6$, $p < .05$, $\eta_p^2 = .23$] and adolescents [$F(2, 49) = 3.6$, $p < .05$, $\eta_p^2 = .14$] only. For school-age children, inclusion rate was significantly lower when participants were trained with a STANDARD training (69 ± 15 %) compared to the MOCK training (81 ± 10 %, $t(27) = 2.14$, $p < .05$, $d = 3.89$) or a COACH training (84 ± 7 %, $t(16) = 1.99$, $p < .05$, $d = 3.46$). For the adolescent group, the inclusion rate was significantly lower when participants were trained with a STANDARD training (85 ± 14 %) compared to a MOCK training (94 ± 9 %, $t(44) = 1.96$, $p < .05$, $d = .76$, Figure 2).

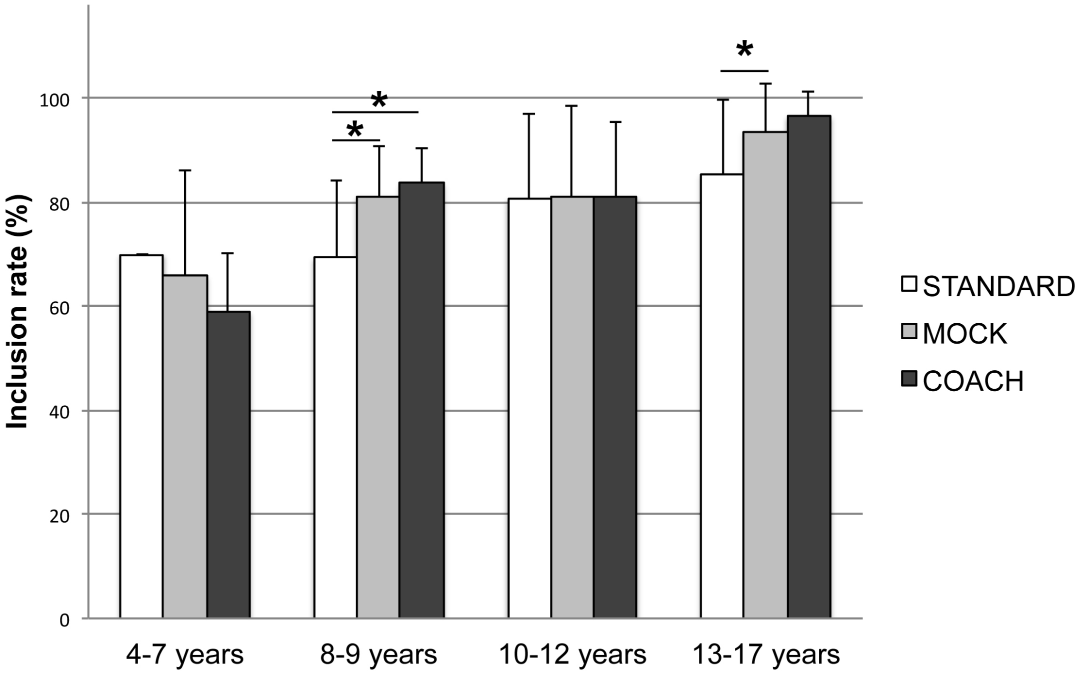

Figure 2. Percentage of inclusion rate according to the type of training in all age groups. Vertical bars represent standard deviation.

For the exclusion rate, the Age x Type of training interaction was not significant ($F(2,117) = .04$, $p = .95$, $\eta_p^2 = .05$) and neither the main effect of age ($F(1,117) = .006$, $p = .94$, $\eta_p^2 = .02$). In contrast, the main effect of type of training was significant ($F(2,117) = 10.5$, $p < .0001$, $\eta_p^2 = .22$). The post-hoc test revealed that the exclusion rate for excessive motion was significantly lower for the COACH training (36 ± 44 %) compared to the STANDARD training (75 ± 38 %, $p < .001$) and the MOCK training (84 ± 26 %, $p < .0001$) (Figure 3).

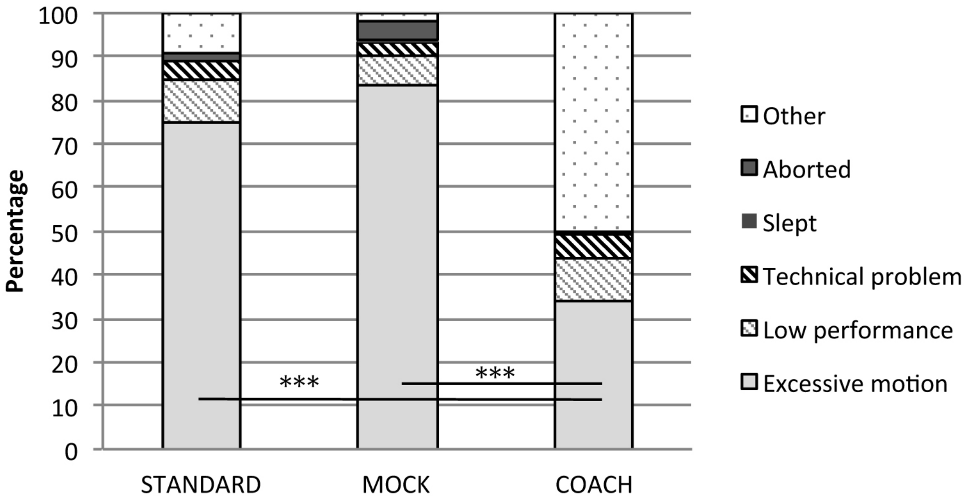

Figure 3. Percentage of the reasons of exclusion of the fMRI datasets according to the type of training.

We carried out planned comparisons for each age group to evaluate the impact of the type of training according to the children's age. The type of training was significant for kindergarten children only ($F(2, 13) = 8.8$, $p < .01$, $\eta_p^2 = .61$). Exclusion rate for excessive motion was significantly lower when kindergarten children were trained with a COACH training (21 ± 41 %) compared to a MOCK training (85 ± 18 %), $t(12) = 3.29$, $p < .01$, $d = 2.03$) and STANDARD training (100 ± 0 %, $t(5) = 2.12$, $p < .05$, $d = 2.74$), (Figure 4).

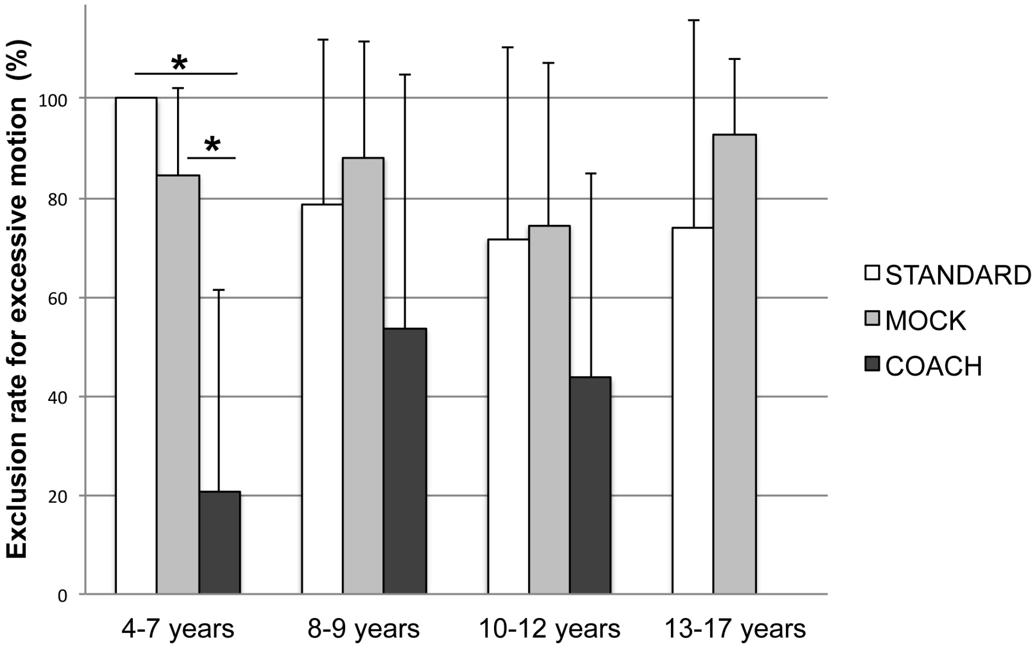

Figure 4. Percentage of exclusion rate for excessive motion according to the type of training in all age groups. Vertical bars represent standard deviation.

3.2. Second question: Do factors other than the type of training predict fMRI success rate?

3.2.1 Effects of other variables of interests on the inclusion and exclusion rates

Other factors than the significant age effect were likely to explain the children inclusion and exclusion rates of fMRI. We performed a multiple regression analysis to determine the specific contributions of several factors of interests on the child inclusion and exclusion rates for excessive motion during an fMRI scan. A total of 118 and 91 datasets had sufficient values for subsequent analysis for inclusion and exclusion, respectively, (i.e., some datasets on session order with sMRI or financial compensation are not reported, see Tables 2-4). The two multiple regressions were conducted on the residuals of the inclusion rate when removing the age effect and on the residuals of the exclusion rate for excessive motion when removing the type of training effect.

Together, the type of training, sex, the financial compensation, the session order with sMRI, the duration of the functional runs and the type of task accounted for 24 % of the variance in children inclusion rate [$F(12,117) = 2.70$, $p < .01$]. The regression weights revealed that, in addition to age, the type of task accounted for a unique variance in children inclusion rate of fMRI. The results from the multiple regression analysis are displayed in Table 6.

Table 6. Multiple regression results predicting children inclusion rate of fMRI from type of training, age, sex, financial compensation, session order with sMRI, duration of the functional runs and type of task (N = 118).

	R^2	F	β	T
	.24	2.70***		
Type of training [a]		.09	.03	.41
Sex [b]		2.60	.09	1.06
Financial compensation [c]		.25	.06	.70
Session order with sMRI [d]		.02	.01	.14
Duration of the functional runs [e]		.23	.04	.50
Type of task [f]		4.93	.54	6.37***

Dependent variables: [a] Type of training: 1 = standard, 2 = coach, 3 = mock. [b] Sex: 1 = more than 50 % of males, 2 = more than 50 % of females, 3 = equivalence of males and females.
[c] Financial compensation: 1 = yes, 2 = no. [d] Session order with sMRI: 1 = sMRI before fMRI, 2 = fMRI before sMRI. [e] Duration of the functional runs: 1 = more than 13 min, 2 = less than 13 min. [f] Type of task: 1 = numerical, 2 = perception, 3 = executive functions, 4 = language, 5 = reasoning, 6 = others.
*** $p < .0001$

Age, sex, financial compensation, session order with sMRI, duration of the functional runs and type of task accounted for 11 % of the variance in children exclusion rate for excessive motion [$F(12,90) = .82$, $p = .63$]. The regression weights underscored that, in addition to the type of training, no supplementary factor accounted for a significant proportion of unique variance in the child exclusion rate of fMRI due to excessive motion.

3.2.2. Specific effect of children's age on the inclusion rate

Concerning the main effect of Age on the inclusion rate, we wondered if this strong association was similar depending on the three Types of training. A moderate positive correlation between age and inclusion rate was significant ($r = .45$, $p < .0001$). The age and inclusion rates were positively correlated for each type of training with an increasing correlation from the STANDARD training ($r = .39$, $p < .01$), subsequently the MOCK training ($r = .46$, $p < .0001$) to the COACH training ($r = .70$, $p < .001$).

3.2.3. Specific effect of the type of task on the inclusion rate

Similarly, we tested the Type of task (numerical, perception, executive functions, language, reasoning or other) and the Age factors on the inclusion rate using an ANOVA. The interaction was not significant ($F = .9$,

$p = .46$) but the main effects were (Age: $F = 18.0$, $p < .0001$ and Type of task: $F = 2.9$, $p < .05$). The post-hoc tests revealed that the numerical tasks (68 ± 4 %) and the perceptive tasks (78 ± 3 %) were significantly associated with a lower inclusion rate compared to miscellaneous tasks (93 ± 4 %, $p < .05$ for both).

4. Discussion

The emergence of functional and structural MRI has opened a window into the human brain development. However, compared to studies on adults, there are very few MRI studies in children. Various technological, experimental and practical difficulties are amplified when imaging children and adolescents. A literature review illustrates a number of issues in contemporary MRI, which could affect a child's ability to cope. These include claustrophobia (Absar, 1993; Francis & Pennell, 2000; McIsaac, Thordarson, Shafran, Rachman, & Poole, 1998), the noise of the MRI unit, the lack of knowledge of the procedure together with emotional distress and anxiety present in adults but possibly a little bit amplified in children. The scarcity of data on the normative developmental population indicates that a training protocol for MRI should be applied with regard to children, but few studies provide a neuroimaging guideline targeting these particular participants (Raschle et al., 2009). As Carter et al. (2010) have suggested, a comparative study examining the benefits of different MRI trainings might be warranted. According to our results, training prior the fMRI session noticeably increases the success rate and decreases the exclusion of datasets due to excessive motion. In addition, this meta-analysis also evidenced that the type of training, children's age and type of tasks, are crucial in order to successfully perform a pediatric neuroimaging session.

4.1. Coaching training for all of the children to reduce motion and include more school-aged children

Challenges of developmental neuroimaging are numerous, but researchers agree that the main obstacles to overcome include: 1) the level of anxiety or distress and 2) children's movements (Bookheimer, 2000; Davidson, Thomas, & Casey, 2003; Kotsoni, Byrd, & Casey, 2006; Poldrack, Paré-Blagoev, & Grant, 2002). We assumed that a training for the fMRI environment has benefits on the motion level in the scanner. Children often lack the ability to monitor their own small movements. Consequently, the training must instruct the child how to lie still. The present results tend to confirm that the coaching training offered the best outcomes for reducing the exclusion rate because of excessive motion for all of the children, particularly for kindergarteners; the coaching training prepared them to remain immobile with cognitive behavioral / coaching training to control anxiety and motor movements in the scanner. This training is particularly adapted to kindergarten children because they may have difficulties understanding the instructions and requirements to perform functional imaging tasks. Because fMRI is highly sensitive to head motion artifacts, coaching training is essential to enable the children to stand still and simultaneously perform a cognitive task, specifically with the youngest children (Byars et al., 2002). Even with the oldest children, coaching training is recommended with a step-by-step procedure, which could pacify stressed and restless adolescents. A coaching training seems to be the best way to instruct children about immobility with play therapy, desensitization and cognitive behavioral therapy (Carter et al., 2010). This type of training consists of employing a behavior management program that uses feedback and success approximation techniques to desensitize the child to the MRI environment and train the child to stay still. Play therapy, simulation and behavioral approaches (e.g., cognitive behavioral therapy, behavioral reinforcement) are successful methods for reducing anxiety and overall movement and allowing MRI without sedation in children as young as 3 years of age (Hallowell, Stewart, de Amorim E Silva, & Ditchfield, 2008; Slifer et al., 1993, 1994). The desensitization procedure involved setting up a play tunnel, hearing scanner noises, and specific training for cognitive tasks with a pad during several sessions (Houdé et al. 2011). Moreover, the coaching training increases the inclusion rate for school-age children. Because fMRI is stressful, a cognitive behavioral training to control anxiety and motor movements in the scanner is beneficial for children.

4.2. Mock training to include more school-age children and adolescents

With mock training, children and adolescents are familiarized with the MRI equipment (head coil, foam cushions, headphones, and earplugs) and the sounds of various scan sequences. Mock MRI reduced the need for GA in children with the greatest effect exhibited in children aged 3 to 8 years (Carter et al., 2010); this training allowed us to perform fMRI studies in children as young as 4 years (Cantlon, Brannon, Carter, & Pelphrey, 2006; Cantlon et al., 2011). It increased the school-age children's and adolescent's inclusion rate probably by reducing the stress induced by the MRI (de Bie et al., 2010; Durston et al., 2009). There was a consensus that desensitization in a mock scanner greatly improved the likelihood of a successful scan (Bookheimer, 2000) and reduced anxiety and distress. Approximately 4 % to 20 % of the patients refused to undergo the MRI session or finish an imaging session before completion (Garcia-Palacios, Botella, Hoffman, & Fabregat, 2007). MRI sessions in children have reportedly imposed higher levels of anxiety and distress (Byars et al., 2002; Davidson et al., 2003). However, Rosenberg et al. (1997) demonstrated that distress in children aged 6 to 17 could be significantly reduced by careful subject training, including the use of mock scanners. The intense scanner noise was one potential cause for anxiety and discomfort (Cho et al., 1997).

4.3. Guidelines and procedures to optimize inclusion rate of fMRI studies with typically developing children

We should recommend for a study sampling a large age-range to recruit 20 % additional young children to improve the possibility of properly correlating the data with variables (BOLD signal, behavioral measures or biographical data).

For children, we recommend a coaching training for fMRI, supported by developmental psychologists, to decrease the exclusion rate because of excessive motion. Pressdee et al. (1997) used play therapy techniques (a doll-sized model of an MRI unit) to prepare children for MRI. Smart (1997) used relaxation techniques during imaging procedures. Houdé et al. (2011) organized a complete educational program to train children in schools. The latter included informational meetings at school with parents, teachers, headmasters and a research team, a visit to the imaging center with children and their families, researchers and medical staff one month before the day of scanning, training at school the day before the day of scanning and training at the imaging center on the day of scanning. Because this MRI procedure is important, it is critical that children benefit from a structured, individually targeted approach to procedural training. This method is an efficient, fun and inexpensive means to train children for MRI sessions, transportable at schools without the need of a dedicated room at the laboratory and easy to transpose in any pediatric service. Children from 4 to 17 years old, and particularly the youngest children, require coach training supported by human interactions and emotional scaffolding to lie motionless in the scanner. Surprisingly, adolescents seem to also benefit from a mock training. During the breaks between the runs, the experimenter must be cheerful and interact as long as possible with the child in the scanner with positive reinforcement and feedback, even if the means of communication is restricted to audio or video contact (Davidson et al., 2003; Slifer et al., 1993). The training should be provided in advance, i.e., one or two days before the scan (Hallowell et al., 2008; Houdé et al., 2011), to enable the children to receive, process and remember all of the instructions. Moreover, we suggest that adding some of these approaches to the mock scanning training might improve its efficiency.

Even though we did not find a significant impact of the total scan duration on the success rate, we should consider several recommendations that were also suggested by Hallowell et al. (2008): a) instruction should be provided in short sequences because children tend to lose their focus faster than adults; b) cognitive tasks involving a motor response should last no more than four to five minutes; and c) the session order between fMRI and sMRI is flexible because session order did not have any impact on the success rate.

4.4. Limitations of the meta-analysis

To the best of our knowledge, this meta-analysis is the first to compare several types of training using fMRI research protocols with the pediatric population. However, this study has limitations, of which several were unavoidable. There was a selection bias in the group construction according to the type of training. In our datasets, the children aged four to seven years were almost always prepared for fMRI. It was not possible to obtain repetition data for each child. We did not find many studies conducted in kindergarten children because the fMRI research protocols with children aged 4 to 7 remained relatively infrequent. We encountered a large number of missing data about the inclusion and exclusion rates and reasons for exclusion. Finally, it is likely that there were false negatives (in mock or coaching trainings) if the authors did not mention whether they used a training tactic in the methods section or did not reply to our inquiry.

4.5. Clinical and educational implications

Future studies should address several issues. Overall, our results should be useful to describe a neuroimaging research project to the ethics committee, to set up a developmental laboratory with MRI data collection or to set up a new experiment with the available equipment. Our results can justify a methodological choice (according to the patient's age, type of training, etc.).

According to the clinical implications, our results should be relevant for clinicians and the medical staff working with clinical pediatric populations to reduce the use of pharmacological sedation or GA and help children and their families to resolve distress issues before an MRI scan. The potential for avoiding sedation or GA as a means of managing children's compliance during MRI sessions represents one of the main advances of such preparations for the clinical practice (de Amorim e Silva, Mackenzie, Hallowell, Stewart, & Ditchfield, 2006; Rosenberg et al., 1997). Although serious adverse effects of GA are rare (Cravero et al., 2006), less serious effects occur in approximately 0.4-1.5 % of the patients who receive GA (Cravero et al., 2006; Sandborn et al., 2005). In addition to potential adverse patient outcomes, the use of GA has significant resource implications in terms of costs, staffing requirements and possible hospital admission needs (Carter et al., 2010).

Concerning educational implications, children benefit from participating in neuroimaging research studies, particularly when researchers use the experience as a teaching and educational tool. In fMRI research studies, children have the rare opportunity to watch their brain and interact with cutting-edge technology. They gain exposure to potential career choices, they contribute to critically needed research and they help create better connections between education and research. Several research studies offer educational fMRI training programs in schools, including implementing a research protocol in a pedagogical project, creating brain educational modules adapted from preschool to adolescence, conducting trainings for teachers on developmental cognitive neuroscience, and promoting opportunities for teaching neuroscience in early elementary settings (Houdé et al. 2011; Lubin, Lanoë, Pineau, & Rossi, 2012; Marshall & Comalli, 2012; Rossi, Lubin, Lanoë, & Pineau, 2012).

5. Conclusion

Learning about the brain should highlight the brain mechanisms underlying school learning and teaching in order to improve teaching practices. It should also help children and adolescents to better understand the brain links to all bodily functions (Marshall & Comalli, 2012), their own metacognitive strategies and change their attitudes towards disabled children who are affected by neurological disorders (Cameron & Chudler, 2003). However, there are many challenges that developmental researchers face when they conduct functional neuroimaging studies. One challenge is to offer children a relevant training that helps them successfully complete a clinical or a research scan without sedation or GA. This fMRI training supports the needs of children and adolescents to understand the procedure they are preparing to undergo, it helps to manage their anxiety, and it enables and improves their ability to lay motionless. We believe that the field of developmental neuroimaging will benefit from this updated review and meta-analysis and will have direct applications for research, clinical and educational research protocols.

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