The neural network of action language: a comparative meta-analysis

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Systematic review

Introduction

Different parts of the motor system are activated during processing of **manual action language** (AL);

Knowing whether activation patterns of AL resemble those of other motor-related processes will help clarify the **role of the motor system in AL processing**;

AIM: compare the AL activation profile to those of:

- action observation[1]
- motor imagery[2]
- motor execution[3]

through a review of the literature and a comparative meta-analysis.

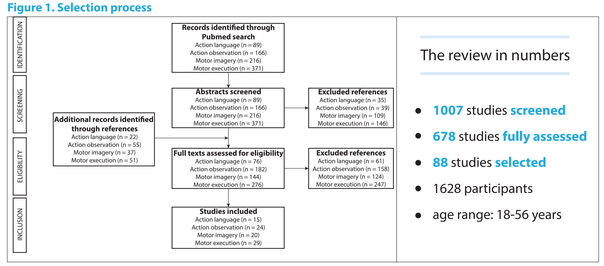
Methods

Systematic selection of articles on Pubmed (Fig 1)

Inclusion criteria verified by 2 judges:

- peer-reviewed journals in English
- at least 1 group of healthy right-handed participants
- aged 18-60 years
- manual actions (right hand)
- method: fMRI
- Talairach or MNI coordinates reported
- contrast of interest (rest or non-action)

Figure 1. Selection process



The review in numbers

- **1007** studies **screened**
- **678** studies **fully assessed**
- **88** studies **selected**
- 1628 participants
- age range: 18-56 years

Parameters typically considered in the study of other motor-related processes are rarely considered in AL studies (Table 1):

- uni- or bimanual aspects of actions
- tool- or object-related
- motor sub-category: **action vs movement**.

AL (Table 1) and action observation (Table 2) studies mainly focus on action (*i.e.* goal-oriented series of movements) while motor imagery (Table 3) and motor execution (Table 4) mainly focus on movement.

Results & Discussion

Table 1. Action language

Article	Sample	Linguistic level	Stimuli presentation	Task	Action of	Contrast	Type[a]	Tool -related[a]	Object -related[a]	Hand[a]
Tyler et al. (2003) NeuroImage	12	word	visual	semantic relatedness judgement	hand	strings of letters	1	1	0	N/A
Hauk et al. (2004) Neuron	14	word	visual	passive reading	arm	strings of hash marks	1	N/A	N/A	N/A
Noppeney et al. (2005) Cogn Brain Res	12	word	auditory	semantic judgement	hand	gender identification	1	-	-	-
Tettamanti et al. (2005) J Cogn Neurosci	17	word	visual	semantic judgement	hand	false fonts	1	-	-	-
Rüschemeyer et al. (2007) J Cogn Neurosci	20	sentence	visual	passive listening	hand	abstract sentences	1	-	-	-
				pseudoword identification	hand/arm	simple action verbs	1	-	-	-
						complex action verbs	1	-	-	-
Kemmerer et al. (2008) Brain Lang	16	word	visual	semantic judgement	hand/arm	strings of symbols	1	1	0	1
						strings of symbols	1	0	1	1
Boulenger et al. (2009) Cereb Cortex	18	sentence	visual	reading + comprehension questions	arm	strings of hash marks	1	N/A	N/A	N/A
Raposo et al. (2009) Neuropsychologia	22	word	auditory	passive listening	arm	non-action verbs	1	N/A	N/A	N/A
Desai et al (2010) Cereb Cortex	33	sentence	auditory	semantic judgement	hand	abstract sentences	1	-	1	-
						visual sentences	1	-	1	-
Willems et al. (2010) J Cogn Neurosci	20	word	visual	infrequent lexical decision	hand	non-manual actions	1	N/A	N/A	1
Desai et al. (2011) J Cogn Neurosci	22	sentence	visual	semantic judgement + recognition	hand	abstract actions	1	0	1	-
Hauk & Pulvermüller (2011) Front Hum Neurosci	20	word	visual	passive reading	hand	strings of hash marks	1	-	-	1,2
Desai et al. (2013) NeuroImage	28	sentence	visual	covert semantic judgement	hand	abstract sentences	1	-	1	1,2
de Zubicaray et al. (2013) J Cogn Neurosci	21	word	visual	grammatical judgement	hand	non-body-related nouns	1	-	-	-
Di Cesare et al (2017) Brain Cogn	22	word	auditory	passive listening	hand	silence	1	0	1	-
						abstract words	1	0	1	-

Table 2. Action observation

Article	Sample	Stimuli	Observation of	Contrast	Concomitant task	Type[a]	Tool -related[a]	Object -related[a]
Buccino et al. (2001) Eur J Neurosci	12	movie	hand	static hand	0	0	0	0
Wheaton et al. (2004) NeuroImage	12	movie	hand	static hand	0	1	0	1
Costantini et al. (2005) Cereb Cortex	13	movie	finger	static hand	0	0	0	0
Molnar-Szakacs et al. (2005) Cereb Cortex	58	images	hand	rest	unclear	0	0	0
Grosbras & Paus (2006) Cereb Cortex	20	movie	hand	non-biological motion	0	1	-	-
Hamilton et al. (2006) NeuroImage	19	movie	hand	bouncing ball	0	1	0	1
Pierno et al. (2006) J Cogn Neurosci	14	movie	hand	movie of non-moving person	0	1	0	1
Fillmon et al. (2007) NeuroImage	15	movie	hand	static object	0	1	0	1
Jonas et al. (2007) NeuroImage	19	picture	hand	static hand	0	1	0	1
Meister & Iacoboni (2007) PlosOne	14	movie	hand	rest	1	1	0	1
Adamovich et al. (2009) Restor Neurol Neurosci	13	movie	finger	static hand	1	0	0	0
Pierno et al. (2009) Cereb Cortex	15	picture	hand	static hand (with object)	0	1	0	1
Turella et al. (2009) NeuroImage	17	movie	hand	static hand (with object)	0	1	0	1
Biagi et al. (2010) Brain Res Bull	12	movie	hand	static hand (with object)	0	1	0	1
Tremblay & Small (2011) Cereb Cortex	21	movie	hand	rest	0	1	1	1
Tubaldi et al. (2011) Hum Brain Mapp	15	movie	hand	static hand (with object)	0	1	0	1
Heitger et al. (2012) J Neurophysiol	19	movie	hand	static hand (with object)	0	1	0	1
				fixation cross	0	1	0	1
Turella et al. (2012) Cereb Cortex	19	movie	hand	static hand (with object)	1	1	0	1
Vingerhoets et al. (2012) Neuropsychol Rehabil	17	movie	hand	static object	1	1	0	1
Di Dio et al. (2013) NeuroImage	14	movie	hand	static arm	1	1	0	1
	16	movie	hand	static arm	1	1	0	1
Liew et al. (2013) Front Hum Neurosci	16	movie	hand	static hand	1	1	0	1
Plata Bello et al. (2014) PlosOne	19	movie	finger	static hand	0	0	0	0
Plata Bello et al. (2015) Neuroscience	31	movie	finger	static hand	0	0	0	0
Simos et al. (2017) NeuroImage	21	movie	hand	static hand (with dot)	0	0	0	0

Table 3. Motor imagery

Article	Sample	Imagery type[a]	Motor imagery of	Contrast	Concomitant task[a]	Type[a]	Tool -related[a]	Object -related[a]
Gérardin et al. (2000) Cereb Cortex	8	0	finger	rest	0	0	0	0
Vingerhoets et al. (2002) NeuroImage	12	1	hand	non-rotated hand	0	0	0	0
Dechent et al. (2004) Cogn Brain Res	6	0	finger	imagery of static scenery	0	0	0	0
Seurinck et al. (2004) NeuroImage	22	1	hand	non-rotated hand	0	0	0	0
Fillmon et al. (2007) Eur J Neurosci	15	0	hand	object viewing	0	1	0	1
Szameitat et al. (2007) Eur J Neurosci	17	0	hand	rest	0	1	-	-
de Vries et al. (2008) Clin Neurol Neurosurg	9	0	hand	rest	0	0	0	0
Guillot et al. (2008) NeuroImage	13	0	finger	rest (with sounds)	0	0	0	0
	15	0	finger	rest (with sounds)	0	0	0	0
Guillot et al. (2009) Hum Brain Mapp	13	0	finger	rest (with sounds)	0	0	0	0
Sauvage et al. (2011) Brain Imaging Behav	8	0	finger	rest	0	0	0	0
Szameitat et al. (2012) Plos One	17	0	hand	rest	0	1	1	1
Mizuguchi et al. (2013) Neurosci Res	18	0	hand	rest	0	1	0	1
Mizuguchi et al. (2013) Front Hum Mapp	16	0	hand	rest	0	0	0	0
Bartolo et al. (2014) Eur J Neurosci	14	1	hand	scrambled images	0	1	0	1
Mizuguchi et al. (2014) Front Hum Neurosci	17	0	hand	rest	0	0	0	0
Zappasodi et al. (2014) Exp Brain Res	2	1	hand	rest	1	0	0	0
Gardini et al. (2016) Brain Topogr	15	0	finger	rest	0	0	0	0
Lu et al. (2016) Neural Regen Res	10	0	finger	rest	0	0	0	0
Zanardi et al. (2016) Brain Cogn	14	1	hand	visual mental rotation	0	0	0	0
Simos et al. (2017) NeuroImage	21	0	finger	rest	0	1	0	0

Table 4. Motor execution

Article	Sample	Execution of	Contrast	Concomitant task	Type[a]	Tool-related[a]	Object-related[a]
Rao et al. (1997) J Neurosci	13	finger	rest	0	0	0	1
van Oostende et al. (1997) NeuroImage	7	finger	rest	0	1	0	0
Binkofski et al. (1999) Eur J Neurosci	12	hand	rest	0	1	0	1
Sakai et al. (1999) J Neurosci	6	finger	control tone sequence	0	0	0	1
Jäncke et al. (1999) Cereb Cortex	12	hand	rest	0	1	0	1
Cunnington et al. (2002) NeuroImage	12	finger	rest	0	0	0	1
Rowe et al. (2002) NeuroImage	15	finger	rest	0	0	0	1
Kuhtz-Buschbeck et al. (2003) Eur J Neurosci	12	hand	visual imagery (static landscape)	0	1	0	1
Maguire et al. (2003) NeuroImage	6	finger	rest (with fixation)	0	1	0	1
Dechent et al. (2004) Cogn Brain Res	6	finger	rest (with fixation)	0	0	0	0
Kudo et al. (2004) NeuroImage	12	finger	rest (with fixation)	0	0	0	1
Wenderoth et al. (2005) Eur J Neurosci	10	hand	rest	0	1	1	0
Dicstein et al. (2007) NeuroImage	9	finger	rest	0	0	0	0
Fillmon et al. (2007) NeuroImage	16	hand	rest (with fixation)	0	1	0	1
Suminski et al. (2007) J Neurophysiol	10	wrist	rest (with fixation)	0	0	0	1
de Vries et al. (2008) Clin Neurol Neurosurg	9	wrist	rest	0	0	0	0
		hand	rest	0	0	0	0
Guillot et al. (2008) NeuroImage	13	finger	rest (with sounds)	0	0	0	0
	15	finger	rest (with sounds)	0	0	0	0
Hanakawa et al. (2008) Cereb Cortex	13	finger	rest	0	0	0	0
Turella et al. (2009) NeuroImage	17	hand	rest (with fixation)	0	1	0	1
Kim et al. (2010) Neurol Res	20	elbow	rest	0	0	0	0
Sauvage et al. (2011) Brain Imaging Behav	8	finger	rest	0	0	0	0
Akhlaghi et al. (2012) Brain Res	13	finger	rest (with fixation)	0	0	0	0
Specogna et al. (2012) Radiol Med	15	finger	rest	0	0	0	0
Moody-Triantis et al. (2014) Front Hum Neurosci	18	finger	rest	0	1	0	1
Plata Bello et al. (2014) Neuroscience	31	finger	rest (with fixation)	0	0	0	0
Plata Bello et al. (2015) Bain Imaging Behav	20	finger	rest (with fixation)	0	0	0	0
Gardini et al. (2016) Brain Topogr	20	finger	rest	0	0	0	0
Rousseau et al. (2016) Neuroscience	19	wrist	rest	0	0	0	0
Adhikari et al. (2018) Brain Connect	9	finger	rest (with fixation)	0	0	0	1

[a]Legend

Type: 0 = Movement; 1 = Action; - = mixed action and movement
Tool-related: 0 = not tool-related; 1 = tool-related; - = mixed tool-related and -unrelated
Objects-related: 0 = not object-related; 1 = object-related; - = mixed object-related and -unrelated
Hand: 1 = unimanual; 2 = bimanual; - = mixed uni- and bi-manual;
Imagery type: 0 = explicit motor imagery; 1 = implicit motor imagery

N/A: information not available

Meta-analysis

Aims

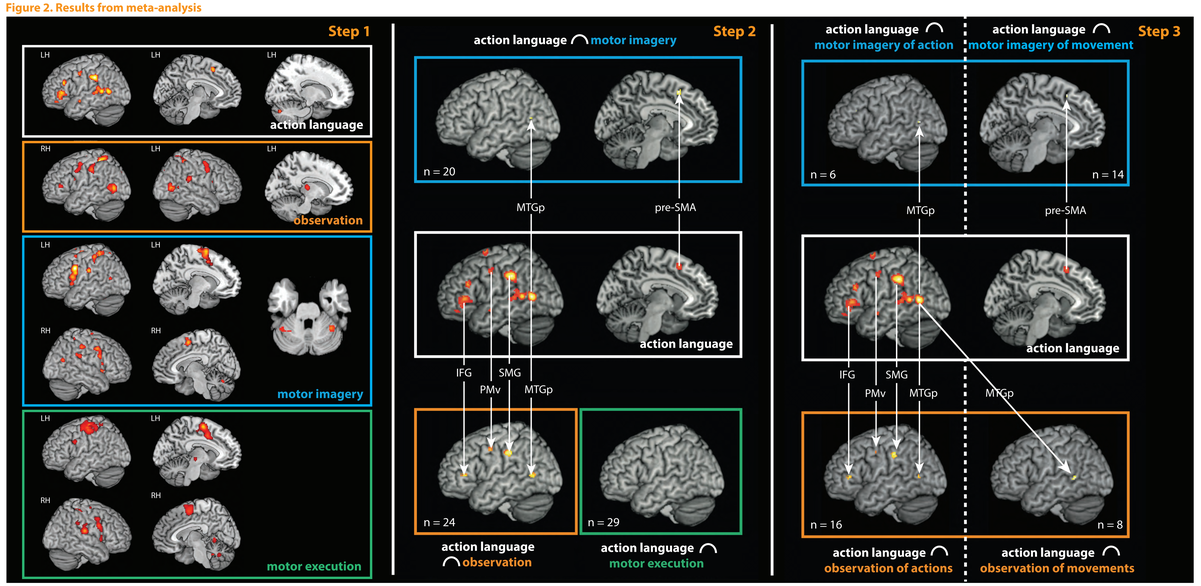
1. **Extract activation maps** for each motor-related process;
2. **Highlight overlaps** between AL maps and maps of other motor-related processes;
3. Determine whether AL maps are related to **action or movement** sub-categories of motor-related processes.

Methods

- Activation likelihood estimation (ALE) meta-analysis, using GingerAle;
- **Manual selection of coordinates**, Talairach coordinates converted into MNI;
- Uncorrected *p*-value threshold of .001, 120 mm^3 cluster [4];
  - **Step 1**: single map for each of the four motor-related processes;
  - **Step 2**: compare AL map to each of the other maps;
  - **Step 3**: compare AL map with maps of the **motor sub-categories** of observation and motor imagery (*i.e.* action vs movement).

Results & Discussion

Figure 2. Results from meta-analysis



AL activation map: no M1 and few other areas of the motor system (Fig 2, step 1)

Degree of similarity of AL map with maps of other motor-related processes (Fig 2, step 2): **observation > imagery > execution**

The AL map was (Fig 2, step 3):

- more similar to observation of **action** than movement
- related to motor imagery of both **action** and **movement**

- Activation profile of AL seems to result from an interaction between **motor-related process** and their **motor sub-categories** (*i.e.* action vs movement).
- The AL map is more similar to those of motor-related **cognitive processes** than that of motor execution itself.
- Underlying common processes of AL and other motor-related cognitive processes remains unclear; it could be related to language, motricity, semantics, other cognitive processes.

- Future studies on AL should consider the **action/movement distinction**.
- Other parameters such as the **object/tool** distinction or the **implicit/explicit nature of motor imagery** could also be considered.

References: 1.Tremblay & Small (2010) Cerebral Cortex. 2.Yang & Shu (2014) Experimental Brain Research. 3.Courson et al. (2017) Cortex. 4. Hétu et al. (2013) Neuroscience and Biobehavioral Reviews