

Neural Evidence of Cross-domain Structural Interaction between Language and Arithmetic

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1 Introduction

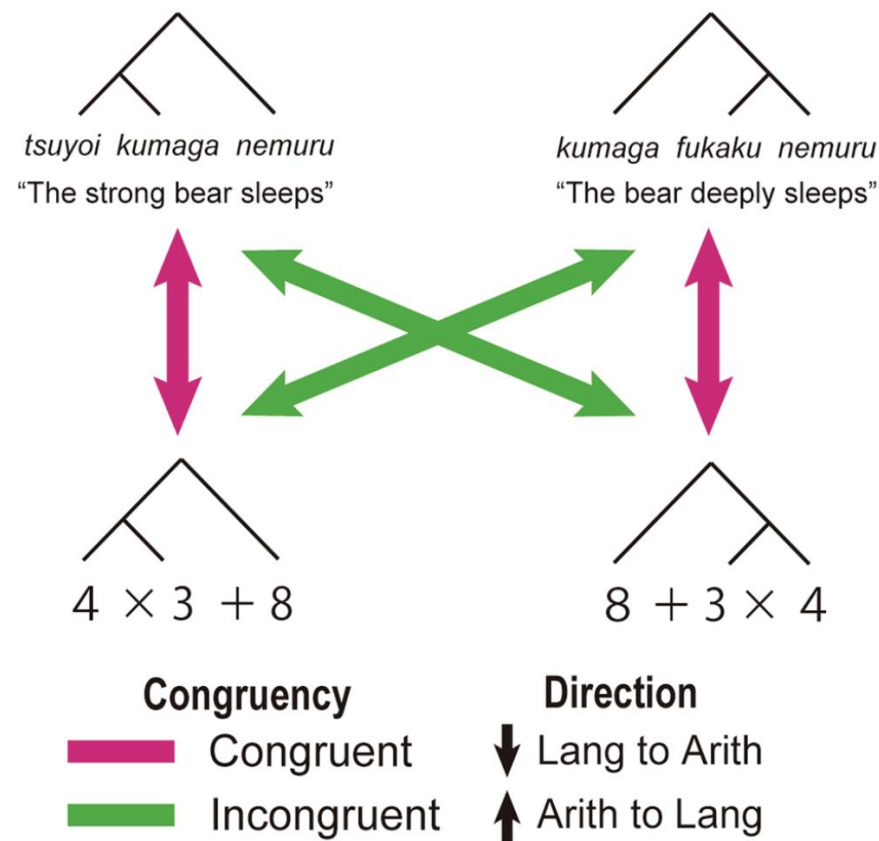


32 Language

8 LB ✓, 8 LB ×
8 RB ✓, 8 RB ×

32 Arithmetic

8 LB ✓, 8 LB ×
8 RB ✓, 8 RB ×



source: Nakai & Okanoya, 2018

Repetition Suppression

display	time
LB/RB	800ms
LB: left branches, [adv., n., vi.]	2000ms
RB: right branches, [n., adv, vi.]	200ms
The strong bear sleeps.	2000ms
ITI (inter-trial interval)	12000-15000ms

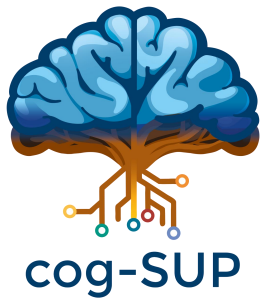
standard/ deviant (coherency)

standard: multiplies of 10

deviant: +1/-1 to standard

Functional Localizer

display	time
+	800ms
congruency	2000ms
The strong bear sleeps.	
congruent: LB → LB, RB → RB	
incongruent: LB → RB, RB → LB	
ITI (inter-trial interval)	4500-7500ms



2.1 Functions for pairing stimulus

-----derangement of repetition suppression and functional localizer-----

```
def derangements_RS(df):  
def derangements_FL(df):
```

-----Presenting functions-----

```
def present_instructions(text, key=K_SPACE):  
def timed_draw(*stims):  
def present_for(*stims, t=1000):  
def present_for_wait_key(*stims, t=1000):  
    # check keyboard while present stimuli  
def present_blank(t=200):  
def present_ITI(iti_win, text = ''):
```

2.2 def derangements_RS

split groups

```
sent_df = df[df.type=='language'].copy()
arith_df = df[df.type=='arithmetic'].copy()
```

```
def split_groups(df):
```

```
    return {
```

```
        'Lcoh': df[(df.branch=='LB') & (df.coherency=='coherent')].copy(),
```

```
        'Lincoh': df[(df.branch=='LB') & (df.coherency=='incoherent')].copy(),
```

```
        'Rcoh': df[(df.branch=='RB') & (df.coherency=='coherent')].copy(),
```

```
        'Rincoh': df[(df.branch=='RB') & (df.coherency=='incoherent')].copy(),
```

```
    }
```

```
sent_groups = split_groups(sent_df)
```

```
arith_groups = split_groups(arith_df)
```

type	text	branch	coherency
language	The strong bear sleeps.	LB	coherent

language to arithmetic

```
pairs_LangArith = []
```

```
a_available = {k: list(v.to_dict('records')) for k,v in arith_groups.items()}
```

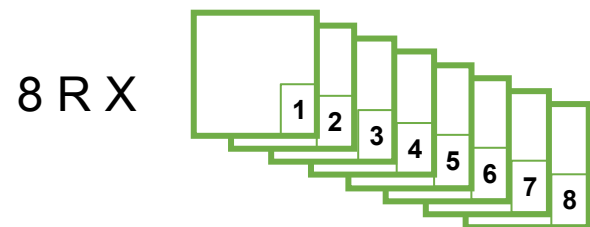
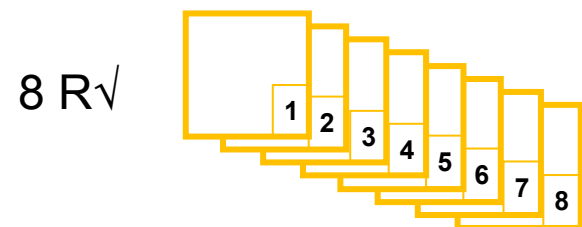
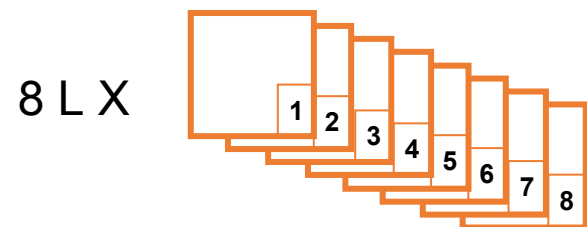
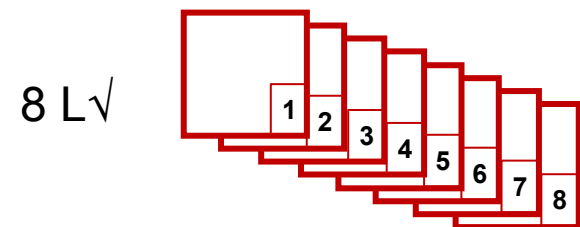
```
for s_group_name, s_group in sent_groups.items():
```

```
    s_list = s_group.to_dict('records')
```

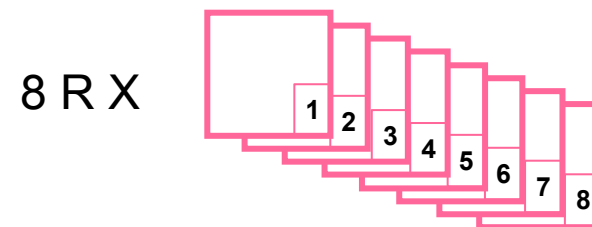
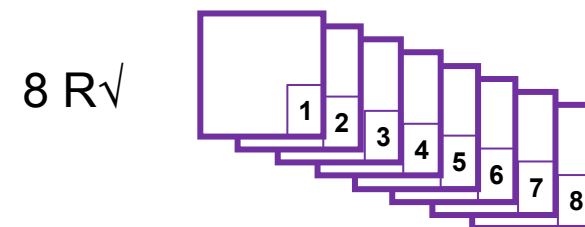
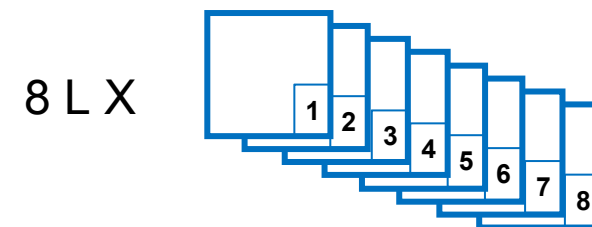
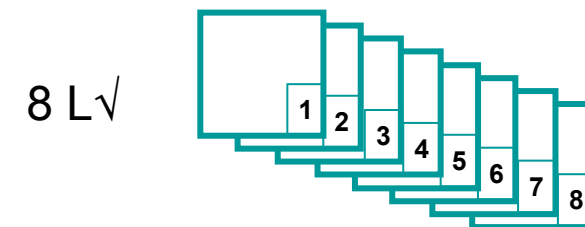
```
    for i, s in enumerate(s_list):
```

```
        a_group_name = a_group_order[(i // 2) % len(a_group_order)]
```

32 sentences



32 A-expressions



3 trial: def run_trial_RS

present process

```
present_for(FIXATION, t=FIXATION_DURATION)
key_1, rt_1 = present_for_wait_key(stim1, t=STIMULUS_DURATION)
present_blank(t=BLANK_DURATION)
key_2, rt_2 = present_for_wait_key(stim2, t=STIMULUS_DURATION)
```

present_for_wait_key:
record the pressed key and
reaction time of participants

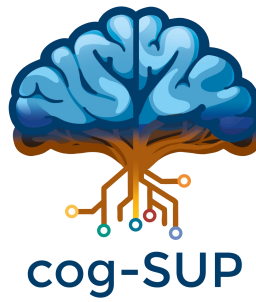
record the keys

```
if direction == 'Lang->Arith':
    lang_RT = rt_1
    arith_RT = rt_2
    lang_key = 'none'
    arith_key = 'none'
    if key_1:
        lang_key = key_map[key_1]
    if key_2:
        arith_key = key_map[key_2]
else:
    .....
```

record data

```
exp.data.add([session, trial, direction, congruency, 'language',
language_text, language_branch, language_coherency, lang_RT,
lang_key, 'arithmetic', arithmetic_text, arithmetic_branch,
arithmetic_coherency, arith_RT, arith_key])
```

4 Main Experiment: result



subject_id	session	trial	direction	congruency	lang_type	language_text	language_branch	lang_coherent	lang_RT	lang_key	arith_type	arithmetic_text	arithmetic_branch	arith_coherent	arith_RT	arith_key
793	RS1	1	Arith->Lang	True	language	Soldiers bravely	RB	coherent	1482	YES	arithmetic	$8 + 3 \times 4$	RB	coherent	1314	NO
793	RS1	2	Arith->Lang	False	language	The gentle rabbit	LB	incoherent	None	none	arithmetic	$3 + 4 \times 2$	RB	incoherent	1092	NO
793	RS1	3	Lang->Arith	True	language	The strong rabbit	LB	coherent	660	YES	arithmetic	$2 \times 3 + 4$	LB	coherent	278	NO
793	RS1	4	Arith->Lang	False	language	Dogs quickly	RB	coherent	None	none	arithmetic	$3 \times 4 + 8$	LB	coherent	576	NO
793	RS1	5	Lang->Arith	False	language	The brave soldiers	LB	coherent	1567	YES	arithmetic	$1 + 3 \times 3$	RB	coherent	980	YES
793	RS1	6	Arith->Lang	False	language	Bears deeply	RB	coherent	806	YES	arithmetic	$3 \times 6 + 3$	LB	incoherent	701	NO
793	RS1	7	Lang->Arith	False	language	Bears deeply	RB	coherent	589	YES	arithmetic	$3 \times 4 + 8$	LB	coherent	992	NO
793	RS1	8	Lang->Arith	False	language	The shy student	LB	incoherent	None	none	arithmetic	$2 + 4 \times 2$	RB	coherent	None	none
793	RS1	9	Lang->Arith	False	language	Birds loudly	RB	incoherent	846	YES	arithmetic	$3 \times 9 + 3$	LB	coherent	682	NO
793	RS1	10	Arith->Lang	True	language	Children slowly	RB	coherent	1537	YES	arithmetic	$1 + 5 \times 6$	RB	incoherent	1713	NO
793	RS1	11	Arith->Lang	False	language	The gentle rabbit	LB	coherent	1549	YES	arithmetic	$5 + 2 \times 3$	RB	incoherent	1113	NO
793	RS1	12	Lang->Arith	True	language	The blue bird	LB	incoherent	None	none	arithmetic	$3 \times 6 + 2$	LB	coherent	753	NO
793	RS1	13	Arith->Lang	True	language	The clever child	LB	coherent	975	YES	arithmetic	$2 \times 3 + 4$	LB	coherent	799	YES
793	RS1	14	Lang->Arith	False	language	The brave soldiers	LB	incoherent	851	YES	arithmetic	$2 + 6 \times 3$	RB	coherent	1127	NO
793	RS1	15	Arith->Lang	True	language	The strong rabbit	LB	incoherent	953	YES	arithmetic	$4 \times 2 + 3$	LB	incoherent	1022	NO
793	RS1	16	Arith->Lang	False	language	The shy student	LB	incoherent	1213	YES	arithmetic	$2 + 4 \times 2$	RB	coherent	1699	YES