Versatility of phonemic pitch in affective iconicity and perceptual reorganisation

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Appendices

Appendix A. Affective iconicity in Standard Chinese: Related studies overview and supplementary results

Table A1

An overview of studies on pitch iconicity.

Citation	Language	Pitch parameters	Main finding
Lester (1974)	American English	Mandarin tones (presented by visual symbols ¯ˊˇˋ)	No significant recognition of Mandarin tones presented visually (52% correct)
Marks (1974)	English	Pitch height	Higher-pitched sounds were associated with brighter lights.
Tarte (1982)	English	Pitch height	Low tones were perceived as large, heavy, slow, dull, low, and masculine, whereas high tones were perceived as small, light, fast, sharp, high, and feminine.
Walker & Smith (1985)	English	Pitch height	Participants responded more slowly when pitch was incongruent with the multimodal features of test words.

Citation	Language	Pitch parameters	Main finding
Marks (1987)	English	Pitch height	Response times were faster when auditory and visual stimuli were congruent (e.g., high-pitched beeps with fast-flashing lights).
Marks et al. (1987)	English	Pitch height	Children and adults matched high pitch with brightness and low pitch with dimness. Pitch-size associations emerged around age 11.
Melara & O'Brien (1987)	English	Pitch height	Participants classified dot location and tone height faster in congruent conditions (e.g., a high tone with a dot at a high location).
Melara (1989)	English	Pitch height	Faster and more accurate responses when pitch and colour were congruent (e.g., high-pitched tones with white dots).
Lapolla (1995)	Mandarin Chinese	Mandarin tones	High-level tones were linked to "coarse" and "wide," while falling tones were associated with "largeness."

Citation	Language	Pitch parameters	Main finding
Lapolla (1995)	Cantonese	Cantonese tones	Mandarin speakers linked high-level tones with "smallness" and falling tones with "largeness."
M. K. M. Chan (1996)	Chinese	Overall pitch or pitch register	Across Standard Cantonese, Xiamen, and Wu dialects, higher pitch (Yin register) was linked to lightness, while lower pitch (Yang register) was linked to heaviness.
Ohala (1984, 1994, 1997)	Ewe, Yoruba, Cantonese	Tones in West African languages	High tones were associated with smallness and low tones with largeness.
Mondloch & Maurer (2004)	(Canada) English	Pitch height	Children reliably matched higher-pitched sounds with smaller, lighter objects.
Gallace & Spence (2006)	English	Pitch height	Participants reacted faster when a low-frequency sound was paired with a larger disk.
Shintel et al. (2006)	American English	Pitch height	Speakers described an upward-moving dot with a higher fundamental frequency.

Citation	Language	Pitch parameters	Main finding
Parise & Spence (2008)	English	Pitch height	High-pitched sounds were associated with smaller sizes, and low-pitched sounds with larger sizes.
Crisinel & Spence (2009)	British English	Pitch height	Faster responses to congruent pitch-taste pairings (e.g., high-pitched notes with sweet tastes).
Crisinel & Spence (2010a)	English	Pitch height	Sweet and sour tastes were associated with high-pitched sounds; bitter and salty tastes lacked a clear association with low pitch.
Crisinel & Spence (2010b)	English	Pitch height	Non-synesthetes showed systematic associations between tastes and musical notes (e.g., bitterness with lower-pitched notes, sweetness with higher-pitched notes).
Evans & Treisman (2011)	English	Pitch height	Pitch spontaneously mapped onto visual position, size, and spatial frequency but not contrast.
Perniss et al. (2010)	NA	NA	Pitch functions as a form of iconicity in sound symbolism and signed

Citation	Language	Pitch parameters	Main finding
			languages (e.g., prosodic marking).
Walker et al. (2010)	English	Pitch height	Infants looked longer at animations where pitch changed congruently with motion (e.g., rising pitch for rising objects).
Ludwig et al. (2011)	NA	Pitch height	Chimpanzees and humans performed better in congruent pitch-colour associations (e.g., high pitch with white, low pitch with black).
Rojczyk (2011)	Polish	Pitch height	Lowered pitch did not significantly influence size ratings, except for the vowel /u/.
Spence (2011)	NA	Pitch height	High pitch corresponded with smaller objects, higher elevation, brighter colours, angular shapes, higher spatial frequency, and upward motion.
Chiou & Rich (2012)	English	Pitch height	Matching auditory pitch facilitated visual elevation judgments, suggesting

Citation	Language	Pitch parameters	Main finding
			pitch-location mapping at an attentional level.
Chang et al. (2021)	Mandarin Chinese	Mandarin tones	Tone was more often matched with rounded shapes and large size, and tone with angular shapes and small size.
Crisinel et al. (2012)	English	Pitch height	Taste perception was influenced by background music (e.g., toffee tasted more bitter with low-pitched sounds).
Parise & Spence (2012)	British English	Pitch height	High pitch was linked to smaller, sharper shapes, while low pitch was linked to larger, more rounded shapes.
Stel et al. (2012)	NA	Pitch height	Lowering one's voice pitch increased feelings of power, but only when self-produced.
Walker (2012)	English	Pitch height	High-pitched words were associated with angular shapes and low-pitched words with curved shapes.

Citation	Language	Pitch parameters	Main finding
Deroy & Spence (2013)	NA	Pitch height	Higher pitch was consistently matched to brightness, small size, high elevation, angularity, and upward movement.
Yao et al. (2013)	Mandarin Chinese	Mandarin tones	Words expressing sadness had higher tonal levels, while joy and anger had steeper tonal contours.
Perlman & Cain (2014)	English	Pitch average: fundamental frequency in Hz; Pitch range: the absolute value of the difference between the maximum and minimum *fo*; Pitch change: the ordered difference between the maximum and minimum *fo*.	Smooth textures are vocalised with higher pitch than rough ones. Downward space corresponds to falling and lower pitch, while upward space aligns with higher pitch. Sharp shapes elicit higher pitch than dull shapes. Positive appraisals have a wider pitch range and higher pitch than negative ones. Male voices are lower with less pitch decrease than female voices. Only hearing children consistently used pitch for magnitude, unexpectedly associating larger items with higher

Citation	Language	Pitch parameters	Main finding
			pitch, contrary to previous English-speaking findings.
Fernández-Prieto et al. (2015)	English	Pitch height	Crossmodal pitch-size correspondence effects emerged in 6-month-old infants but not in younger ones.
Perlman, Dale, et al. (2015)	English	Pitch height	Readers used lower pitch when narrating "big" stories compared to "small" ones.
Perlman, Dale, et al. (2015)	English	Pitch height Pitch range	Smooth textures are vocalised with higher pitch. Downward space corresponds to falling and lower pitch, while upward space aligns with higher pitch. Positive appraisals have a wider pitch range and higher pitch than negative ones.
Lowe & Haws (2017)	English	Pitch height	Lower pitch in voice or music led consumers to infer larger product sizes.
Perlman (2017)	English	Pitch height Pitch contour Pitch range	Iconic vocalisations in vocal charades followed these pitch patterns: smooth-higher, downward-

Citation	Language	Pitch parameters	Main finding
			falling/lower, sharp-higher, good appraisal-larger range/higher, male-lower/less decrease, cut action-higher.
Shang & Styles (2017)	Mandarin Chinese	Mandarin tones	Native speakers: T1-curvy, T4-pointy. English speakers: T1-pointy, T3-curvy. Bilinguals: bivalent pattern.
Svantesson (2017)	NA	High vs. low tone	Kammu, Yoruba, and Ewe onomatopoeic ideophones followed the frequency code (higher pitch = smaller size).
Getz & Kubovy (2018)	English	Pitch height	AVCs rely on both bottom-up and top-down processing. Top-down influence was strongest for size, weakest for height, while bottom-up effects were strongest for height, weakest for brightness.
Hamilton-Fletcher et al. (2018)	NA	Pitch height	Blind individuals showed reduced pitch-shape correspondence but maintained pitch-size and pitch-weight associations.

Citation	Language	Pitch parameters	Main finding
Nielsen & Rendall, (2018)	NA	Pitch height	Pitch-affect connections, often labelled as synesthetic, were also observed in non-synesthetes.
Shih et al. (2019)	Japanese, English, Mandarin, Cantonese, Korean, and Russian	Mandarin tones, Cantonese tones	In Mandarin, tone was linked to male names and powerful Pokémon attributes. In Cantonese, tone was negatively correlated with height and power.
Sidhu & Pexman (2018)	NA	Pitch height	High-pitched sounds were perceived as brighter, sharper, and faster.
Sun et al. (2018)	NA	Pitch height	High pitch was associated with red and yellow, while low pitch was linked to blue and orange.
Thompson (2018)	Mandarin, Cantonese, and Taiwanese	Mandarin tones, Taiwanese tones, and Cantonese tones	Across Mandarin, Cantonese, and Taiwanese, sound symbolic strata were skewed toward specific tonal categories.

Citation	Language	Pitch parameters	Main finding
Anikin & Johansson (2019)	English	Pitch height[2]	High pitch showed weak associations with blue, light grey, high saturation, and high luminance.
Wong & Kang (2019)	Cantonese	Cantonese tones	Rising tones showed a significant preference for female names.
Matsui (2020)	Japanese Chinese	Pith height	Vowels /u/ and /o/ were responded for low frequencies, /i/ for high frequencies across speakers of different languages. There are common relationships between the pitch of pure tones and onomatopoeic expressions.
Akita (2021)	Japanese	Japanese pitch accent	Low-pitched quotatives after exclamatory quotations and ideophonic adverbs in Japanese serve as backgrounding depiction markers, suppressing description while

[2] In this article, the authors pointed out that pitch is usually considered a metathetic dimension, in the sense that higher pitch is not "larger" or "greater" than low pitch, but qualitatively different.

Citation	Language	Pitch parameters	Main finding
			highlighting depiction. Ideophone pitch contours, including HLL and HHL patterns, carry partial semantic motivation.
X. Wang (2021)	Chinese	Mandarin tones	Nature: rising tones (T35) were more common in human names than in animal or monster names, though post hoc analysis showed no significant difference. Gender: rising tones (T35) were more frequent in male names than female names. Personality traits: high-level tones (T55) were prevalent in positive character names, while negative characters often featured rising tones. Size: no significant tonal distinctions were found.
Winter et al. (2021)	Japanese, English, Catalan, Spanish, Dutch, Korean,	Pitch height	A meta-analysis of speech production experiments across multiple languages (Korean, Japanese, Chinese, Catalan, Austrian German, German, Russian) found

Citation	Language	Pitch parameters	Main finding
	German, Austrian, Russian, Chinese		that speakers lower their pitch when addressing an imagined superior compared to a friend or peer.
Ekström et al. (2022)	NA	Pitch height	Motion-prosody congruent pairings, particularly those with a declining *fo*, were more readily selected than incongruent ones, except for Turkish-speaking participants.
González-Alvarez & Sos-Peña (2022)	Spanish	Pitch height	Listeners more accurately perceived the speaker's body size when *fo* was raised.
Shang & Styles (2023)	Mandarin	Pitch height	All language groups exhibited basic pitch-height congruence (high-pointy, low-curvy) for the non-linguistic stimuli.
Vainio, Kilpeläinen, et al. (2023)	Finnish	Pitch height	The results reveal a novel sound-space symbolism phenomenon, where spatial concepts of forward/front and backwards/back are iconically linked to high-

Citation	Language	Pitch parameters	Main finding
			and low-pitched speech sounds.
Vainio, Wikström, et al. (2023)	Finnish	Pitch height	This study replicated the pitch-elevation effect, showing an increase in vocalisation pitch when responding to an up-directed stimulus.

Table A2

Summary of inferential statistics for LOOCV for arousal in the DCAWS dataset.

Sub set	GLMM F (HLM, ΔR^2) coefficients	Significance of multiple comparisons: *p-values in GLMM (HLM)*				
		FF-RL	**FF-RR**	**HF-RL**	**HL-RL**	**FH-RL**
1	36.7 (0.016)	0 (0)	0.006 (0.014)	0.006	0.007	0.014
2	31.1 (0.015)	0 (0.001)	0.008 (0.037)	0.058	0.018	*n.s.*
3	33.1 (0.015)	0 (0)	0.007 (0.031)	0.015	0.022	*n.s.*
4	29.1 (0.014)	0 (0.002)	0.012 (0.051)	0.048	0.048	*n.s.*
5	31.2 (0.015)	0 (0.003)	0.005 (0.028)	0.041	0.060	*n.s.*
6	32.4 (0.015)	0 (0)	0.005 (0.027)	0.052	0.050	0.046
7	33.9 (0.016)	0 (0)	0.004 (0.018)	0.016	0.026	0.038
8	34.0 (0.017)	0 (0)	0.003 (0.014)	0.042	0.013	*n.s.*
9	34.4 (0.016)	0 (0)	0.004 (0.019)	0.016	0.015	0.038
10	31.5 (0.016)	0 (0)	0.004 (0.014)	0.031	*n.s.*	*n.s.*

The HLM indicated that the ratings of emotional valence were not significantly influenced by the lexical tonal sequence. Additionally, the impact of the lexical tonal sequence on emotional valence seems comparatively minor when contrasted with its influence on emotional arousal. Table A3 indicates the detailed R-squared coefficients.

Table A3

ΔR^2 of lexical tonal sequences in explaining emotional arousal and valence across all corpora.

Corpus	Emotional arousal	Emotional valence
CAWS	2.22%***	0.88%
NORM	0.44%***	0.22%
DCAWS	1.60%**	0.84%

Note. The differential R-squared coefficients *(ΔR^2)* were obtained by subtracting the R^2 of the two-block HLM models in each corpus analysis.

Appendix B. Pseudowords formulation and their wordlikeness ratings in Dutch and Japanese

A set of pseudowords was created based on the shared phonotactic rules of Dutch and Japanese. First, phonemes that exist in both languages were identified. These phonemes were then composed into pseudowords with vowel (V) or consonant-vowel (CV) syllabic structures. The pseudowords were subsequently manipulated and recorded by a bilingual speaker fluent in both Japanese and Dutch. Finally, native speakers of Japanese and Dutch evaluated the pseudowords for their wordlikeness in each language. More details are shown as follows.

Phonemes

Six co-existing phonemes, i.e., /p/, /t/, /k/, /s/, /i/, and /a/, were selected (Gussenhoven, 1992 for Dutch; Okada, 1991 for Japanese). Specifically, /p/ is a voiceless bilabial plosive consonant, /t/ a voiceless alveolar plosive, /k/ a voiceless velar plosive, and /s/ a voiceless alveolar fricative. Furthermore, the vowel /i/ is a close (or, high), front, and unrounded vowel, while /a/ open (or, low), front and unrounded vowel.

Words composition

All pseudowords were created according to the phonotactic rules of both languages, based on previous studies of acceptability judgments for pseudowords (Bailey & Hahn, 2001; Needle et al., 2022). The chosen phonotactic framework followed a (C)VCV disyllabic structure. Six distinct syllabic constituents (i.e., /i/, /pi/, /pa/, /ta/, /ka/, and /sa/) were concatenated to make ten disyllabic pseudowords, including

/ipa/, /kapi/, /pasa/, /pika/, /pipa/, /pisa/, /pita/, /sapa/, /sapi/, and /tapi/.

Words recording

Two pitch patterns, High-Low (HL) and Low-High (LH), were used for all pseudowords during recording. All stimuli were recorded in isolation with a Sennheiser MKH416T microphone (sample size 44.1 kHz, 16 bit) at Leiden University's Phonetics Lab by a female native speaker of Japanese (from the Tokyo area) who is proficient in Dutch. The speech signals were digitised at a 44.1 kHz sampling rate with 16-bit resolution. She was asked to produce the stimuli as a statement without any emphasis. The stimuli were recorded three times, with the stimulus list randomised for each recording. Tokens judged to be most clearly articulated by the first author were selected for further manipulations.

Words manipulation

To optimise the stimuli for use in both languages, the pseudowords were further resynthesised. All steps were performed using Praat (Boersma & Weenink, 2024).

Segmentation

Since all target words contained a second syllable starting with an obstruent onset, segmentation was relatively straightforward. The acoustic waveforms, accompanied by corresponding spectrograms and auditory verification, provided clear cues of spectral shifts in a zoomed-in display to identify reliable syllable boundary locations.

The first syllables had either a stop onset (/p/, /k/, /t/), a fricative onset (/s/), or a vowel onset (/i/), which is often preceded by a phonetic

glottal closure. We marked the onset of the first syllable at the first positive-going zero crossing in the waveform for the vowel /i/, right before the noise burst for the release of a stop closure (/p/, /k/, /t/ and /ʔ/), or at the start of the medium amplitude noise for /s/.

The end of the first syllable was marked at the last negative-going zero crossing for both the vowel and the nasal coda before the closure for the following stop onset.

We took the end of the first syllable as the start of the following syllable, while the offset of the second syllable was marked as the last negative-going zero crossing for both the vowel and nasal coda.

Annotation

After segmenting the sounds, we cut them into monosyllables using TextGrid files and moved the start and end of each monosyllable to the nearest zero crossings. According to phoneticians and phonologists' consultations, some of the syllables were manipulated in length or replaced with better-recorded ones.

Duration modification

To enhance the experimental parameters, we further manipulated the duration lengths of the concatenated words, given that duration proved the most reliable correlate of stress in Dutch and can be exploited for recognising spoken words (Cutler & van Donselaar, 2001; Sluijter & van Heuven, 1996). Based on studies of vowel discrimination, the durations of V syllables were calibrated to 220 ms, the CV syllables to 250 ms, and the pause interval between syllables, if any, was adjusted to 100 ms (De Klerk et al., 2019; Shafer et al., 2012; Swoboda et al., 1976). Note that /s/ was adjusted to 150 ms to avoid harsh sound

effects. All pseudowords were evaluated as natural as real words in two languages by phoneticians and phonologists.

Ratings on the pseudowords

After manipulating the lexical items, we conducted an online rating task using Qualtrics (Provo, UT, USA. Copyright © 2020 Qualtrics. https://www.qualtrics.com) to evaluate their perceived qualities. Native speakers of Japanese and Dutch assessed all pseudowords to determine the extent to which they resonated with the auditory characteristics of actual Dutch or Japanese vocabulary. Participants rated each word on a 5-point scale, where 5 indicated that a word sounded very much like a possible Dutch/Japanese word, and 1 indicated that a word did not sound like a possible Dutch/Japanese word at all.

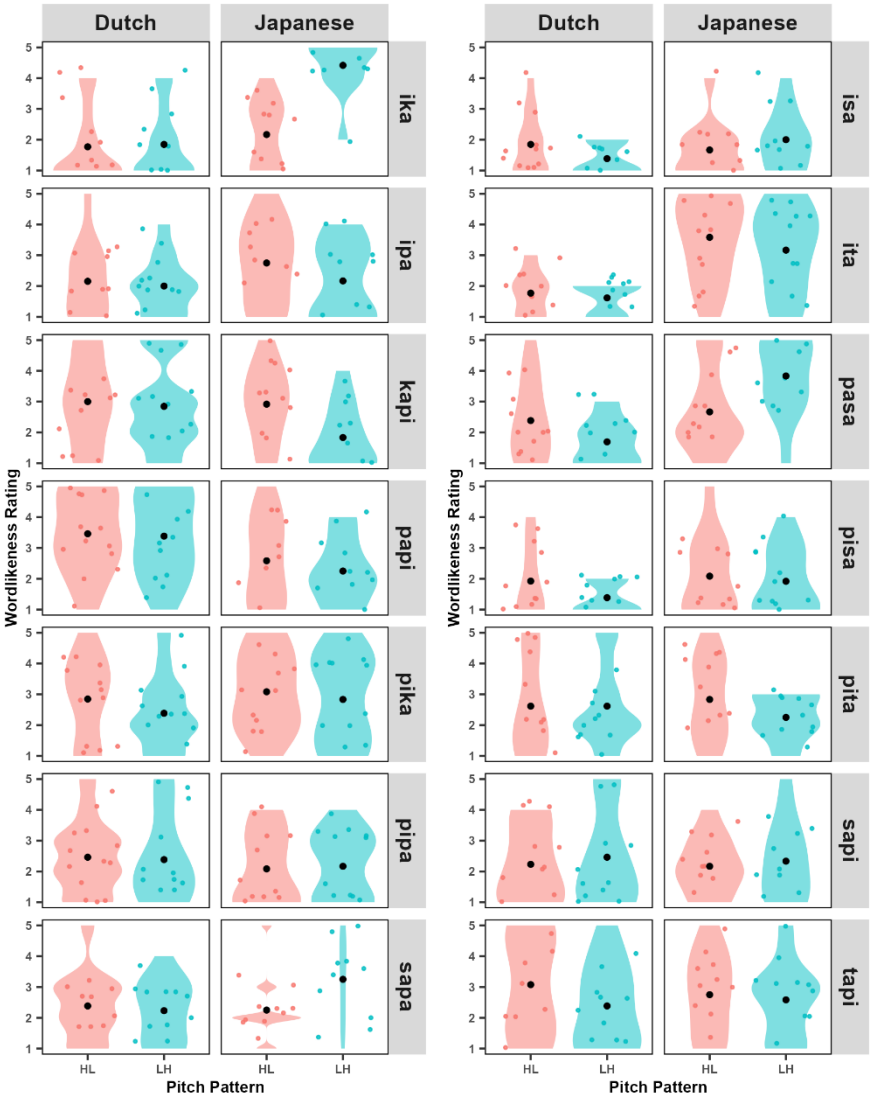
Table B1

The demographics information of Dutch and Japanese raters.

Rater	Male	Female	Age range	Mean age
Dutch	3	10	20–73	55.70
Japanese	5	7	19–48	35.50

Figure B1

The likeness rating on all words by native language speakers in Japanese and Dutch.



Appendix C. Outcomes from all fNIRS data preprocessing pipelines in Experiments 2 and 3 of Chapter 5

This table summarises the outcomes of all preprocessing pipelines and datasets, including dataset inclusion counts and hemispheric response patterns for pitch processing from 4 months (4m) to 10 months (10m).

- Pipeline-Dataset: Represents the pipeline and dataset numbers (e.g., 1-2 indicates Pipeline 1 applied to Dataset 2).
- Inclusions (4m/10m): Indicates the number of datasets included in statistical analyses (e.g., 21/27 means 21 datasets for 4m and 27 for 10m).
- Hemispheric Response (4m–10m): Shows dominant hemisphere patterns for PT and Word conditions. For example, RH-BH under "Word" indicates a shift from right-hemispheric (RH) dominance at 4m to bilateral (BH) response at 10m. "n.s." (non-significant): Indicates that the interaction effect of Condition × Hemisphere × Age was not statistically significant, meaning no clear hemispheric dominance was observed.

Table C1

Summary of outcomes across pipelines and datasets.

Pipeline -Dataset	NL			JP		
	Inclusions 4m/ 10m	Hemispheric response 4m-10m		Inclusions 4m/ 10m	Hemispheric response 4m-10m	
		PT	Word		PT	Word
1-1	21/27	RH-RH	RH-BH	16/14	BH-RH	LH-LH
1-2	21/27	RH-RH	RH-BH	16/14	BH-RH	LH-LH

Pipeline -Dataset	NL			JP		
	Inclusions 4m/ 10m	Hemispheric response 4m-10m		Inclusions 4m/ 10m	Hemispheric response 4m-10m	
		PT	Word		PT	Word
1-3	20/26	RH-RH	RH-BH	16/14	BH-RH	LH-LH
1-4	18/26	RH-RH	RH-BH	16/14	RH-n.s.	LH-n.s.
2-1	21/27	RH-RH	RH-BH	16/14	BH-RH	LH-LH
2-2	21/27	RH-RH	RH-BH	16/14	BH-RH	LH-LH
2-3	20/26	RH-RH	RH-BH	16/14	BH-RH	LH-LH
2-4	17/24	RH-RH	RH-LH	16/14	n.s.-RH	n.s.-LH
3-1	21/27	RH-BH	LH-LH	8/2	LH-LH	LH-BH
3-2	21/27	RH-BH	LH-LH	7/2	LH-LH	LH-BH
3-3	21/27	RH-RH	LH-RH	7/2	LH-LH	LH-RH
3-4	17/26	RH-RH	LH-RH	7/2	LH-LH	LH-RH
4-1	21/27	RH-BH	LH-LH	7/2	LH-LH	LH-BH
4-2	21/27	RH-BH	LH-LH	7/2	LH-LH	LH-BH
4-3	21/27	RH-RH	LH-RH	7/2	LH-LH	LH-RH
4-4	16/26	RH-RH	LH-BH	7/2	BH-LH	RH-RH
5-1	20/26	RH-RH	RH-LH	16/9	BH-RH	LH-BH
5-2	20/26	RH-RH	RH-LH	16/9	BH-RH	LH-BH
5-3	20/26	RH-RH	RH-LH	16/9	RH-RH	LH-BH
5-4	16/24	RH-RH	RH-LH	16/9	RH-RH	LH-RH
6-1	20/26	RH-RH	RH-LH	16/9	BH-RH	LH-BH
6-2	20/26	RH-RH	RH-LH	16/9	BH-RH	LH-BH
6-3	19/24	RH-RH	RH-LH	16/9	BH-RH	LH-BH
6-4	16/24	RH-RH	RH-LH	16/9	BH-RH	LH-LH
7-1	21/27	RH-BH	BH-LH	8/2	LH-LH	BH-RH
7-2	21/27	RH-BH	BH-LH	8/2	LH-LH	BH-RH
7-3	21/26	RH-BH	BH-LH	8/2	LH-LH	BH-RH
7-4	17/24	RH-RH	BH-BH	8/2	LH-BH	BH-RH

Pipeline -Dataset	NL			JP		
	Inclu-sions 4m/ 10m	Hemispheric response 4m-10m		Inclu-sions 4m/ 10m	Hemispheric response 4m-10m	
		PT	Word		PT	Word
8-1	21/27	RH-BH	BH-LH	8/2	LH-LH	BH-RH
8-2	21/27	RH-BH	BH-LH	8/2	LH-LH	BH-RH
8-3	21/26	RH-BH	BH-RH	8/2	BH-LH	BH-RH
8-4	16/24	RH-RH	BH-LH	6/2	BH-RH	BH-RH