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## Examining the cognitive demands of analogy instructions compared to explicit instructions

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### Abstract

**Purpose:** In many learning domains, instructions are presented explicitly despite high cognitive demands associated with their processing. This study examined cognitive demands imposed on working memory by different types of instruction to speak with maximum pitch variation: visual analogy, verbal analogy and explicit verbal instruction.

**Method:** Forty participants were asked to memorise a set of 16 visual and verbal stimuli while reading aloud a Cantonese paragraph with maximum pitch variation. Instructions about how to achieve maximum pitch variation were presented via visual analogy, verbal analogy, explicit rules or no instruction. Pitch variation was assessed off-line, using standard deviation of fundamental frequency. Immediately after reading, participants recalled as many stimuli as possible.

**Result:** Analogy instructions resulted in significantly increased pitch variation compared to explicit instructions or no instructions. Explicit instructions resulted in poorest recall of stimuli. Visual analogy instructions resulted in significantly poorer recall of visual stimuli than verbal stimuli.

**Conclusion:** The findings suggest that non-propositional instructions presented via analogy may be less cognitively demanding than instructions that are presented explicitly. Processing analogy instructions that are presented as a visual representation is likely to load primarily visuospatial components of working memory rather than phonological components. The findings are discussed with reference to speech therapy and human cognition.

**Keywords:** *Analogy instruction, speech motor task, visuospatial sketchpad, phonological loop*

### Introduction

Often information that can facilitate learning is presented by the coach, therapist or clinician as explicit, verbal instructions. The ability of a learner to follow the instructions is a function of their ability to memorise the information and use it during attempts to learn. The neuropsychological framework for this ability is often conceptualised as working memory (e.g. Miller, Galanter, & Pribram, 1960; Baddeley, 1995; Baddeley & Hitch, 1974). Working memory is considered to be a process of the brain that provides temporary storage and manipulation of the information necessary for complex cognitive tasks, such as language, comprehension, learning and reasoning. Three sub-components of working memory are proposed, including a visuospatial sketchpad that handles visual and spatial information; a phonological loop that handles speech-based and

auditory information and a central executive that coordinates attention to the information in the different components (Baddeley, 1995; 2003; 2012). A significant limitation of working memory is that it has a limited capacity to hold information (Cowan, Fristoe, Elliot, Brunner, & Sauls, 2006; Engle & Kane, 2004). The central executive, therefore, regulates distribution of attentional resources to different levels of a task (allocation), switches attentional priorities (updating) and blocks irrelevant information (inhibition) (Montgomery, Magimairaj, & Finney, 2010). A more recent model proposed by Miyake and Friedman (2012) stated that the central executive focuses on constant monitoring and rapid modification of working memory information (updating), switching flexibility between tasks and mental sets (shifting) and overriding dominant responses (inhibition). Regardless of which model is more

representative, both models have clearly described the limited capacity of working memory and this limited working memory resource is controlled by different processes of the central executive.

The limitations of working memory are often noticeable during motor learning, as is self-evident when a learner-driver loses track of the road rules when paying attention in heavy traffic. To reduce the information load on working memory during motor learning, it has been suggested that instructional information can be presented in a non-propositional manner, rather than explicitly (e.g. Masters & Poolton, 2012). Analogies, for example, have been used to aid learning of a new concept, by relating it to a fundamentally similar concept, without necessity for explicit instruction (Gentner, 1988; Gentner, Anggoro, & Klibanoff, 2011; Newton & Newton 1995; Schustack & Anderson, 1979). Typically, motor analogy learning has been shown to produce performance that is less likely to be disrupted in cognitively demanding conditions that overload working memory, such as psychological stress or multi-tasking (e.g. Lam, Maxwell, & Masters, 2009; Liao & Masters, 2001; Orrell, Eves, & Masters, 2006). Liao and Masters (2001), for instance, showed that learners who were instructed how to impart top-spin to a table tennis forehand shot via an analogy (i.e. move the bat up the hypotenuse of a right-angle triangle) displayed stable performance under a laboratory stressor, compared to learners who were instructed via explicit rules (e.g. keep the wrist firm, complete the swing with the racquet above the ball). Liao and Masters (2001) speculated that analogy instructions present information about the complex rule structures underlying the to-be-learned skill in a form that requires less conscious processing than verbal propositions (see also Masters, 2000; Masters & Liao, 2003).

The benefits of analogy learning appears in the speech motor domain. Tse, Masters, Whitehill, and Ma (2012), for instance, examined the effect of a 'waves at sea' analogy on pitch variation (i.e. intonation) during speech. Pitch variation is a universal feature of speech that is shared by languages of different origins. Participants instructed via analogy achieved better control of their pitch variation than participants instructed explicitly. Importantly, Tse et al. (2014) showed that analogy instructed speech remained more stable under psychological stress than explicitly instructed speech, suggesting that the cognitive demands of analogy instructions may be lower.

In most of these studies, however, the analogy instructions have been presented verbally (i.e. described in words). Although the analogies undoubtedly are visual, it is unclear whether they can be considered to be truly non-propositional (see Liao & Masters, 2001, for the same concern). Researchers (e.g. Dagher, 1995; Donnelly & McDaniel, 1993; Schwartz, 1993) have reported that verbal and visual

presentation modes have a differential impact on understanding of the conceptual information intrinsic to the analogy. For example, Orgill and Bodner (2004) found that people were better able to memorise a visual analogy instruction than a verbal analogy instruction and Mayer and Gallini (1990) showed that recall of conceptual information and the ability to infer its meaning, benefitted from incorporating a visual representation in a verbal analogy instruction, compared to a verbal analogy instruction alone.

The objective of the present study was, therefore, to examine the effect of a verbal analogy, a visual analogy, explicit instructions and no instructions on pitch variation during a speech task. The second objective was to determine if the different forms of analogy place a differential load on (a) the visuospatial sketchpad, a component of working memory that serves to store visual and kinesthetic information, or (b) the phonological loop, a component that stores verbal and acoustic information (Baddeley, 2003; Baddeley & Hitch, 1974). We assessed pitch variation off-line by calculating standard deviation of fundamental frequency ( $SDF_0$ ), a commonly used assessment of pitch variation (Baudonck, D'haeseleer, Dhooge, & Van Lierde, 2011) and estimate of within-participant variability, which we subsequently converted to semitone units (a logarithmic scale of pitch variation).

Following a baseline read-aloud task, participants were instructed to memorise a random sequence of eight visual stimuli and eight verbal stimuli. Immediately after the stimuli were presented, participants completed a second reading task in which they were instructed how to speak with maximum pitch variation via either (1) an analogy of a "choppy" sea that was presented verbally, (2) the same analogy presented visually, (3) explicit instructions about how to speak with maximum pitch variation or (4) no instructions. Based on the superior speech performance of analogy instructed participants in our previous study (Tse et al., 2013), it was hypothesised that analogy instructions, regardless of visual or verbal form, would be more effective (i.e. elicit increased pitch variation) than explicit instructions or no instructions. It was hypothesised, however, that processing visual analogy information would depend upon primarily the visuospatial sketchpad, so recall of previously seen visual stimuli would be disrupted; whereas, processing verbal analogy information or explicit instructions would depend upon primarily the phonological loop, so recall of previously seen verbal stimuli would be disrupted.

## Method

### *Participants*

Forty healthy native Cantonese speakers (20 males, 20 females: mean age = 20.47 years,  $SD = 1.41$ ) were recruited from the University of Hong Kong.

The inclusion criteria were: (1) no history or presence of vision deficits or voice, speech or hearing impairments; (2) no formal public speech or singing training; and (3) total number of correct responses in the Digit Span Test (Wechsler, 1945) equal to or more than 12 out of 16 (mean = 14.37, SD = 0.75). Mean baseline reading SDF<sub>0</sub> of males (mean SDF<sub>0</sub> = 27.51 Hz) and females (mean SDF<sub>0</sub> = 21.34 Hz) was comparable to previous work (Tse et al., 2012). Participants were allocated randomly to a visual analogy instruction group, a verbal analogy instruction group, an explicit instruction group or an uninstructed control group.

*Apparatus and procedures*

Speech samples were recorded by a microphone (Model: Shure Beta 58A) positioned 6 cm from the participant’s mouth corner. The microphone was connected to a computer (Model: Dell 2410 desktop) via an external soundcard (Model: M-audio Mobile PreUSB) in a sound attenuated room, with background noise less than 42.23 dBA. Using the classification scheme of the National Centre for Voice and Speech (Titze, 1995), all speech samples were categorised as Type 1 with periodic voice patterns displayed in the phonetic software of Praat (version: 5.3.04, Boersma & Weenink, 2012). A standardised Cantonese passage *North Wind and the Sun* (International Phonetics Association, 1999), which is commonly used in speech research, was used. The passage was divided into three paragraphs, each of which consisted of 51 Chinese characters. The paragraphs were counterbalanced across participants to minimise possible order effects. The study comprised baseline reading, memorisation task, instructed speech with memory recall and instructed speech without memory recall.

*Baseline reading.* All participants read aloud a paragraph of *North Wind and Sun* once using their habitual speaking voice.

*Instructed speech with memory recall.* After a 3-minute resting period, participants were seated before a computer screen (Dell analogue LCD monitor) wearing headphones (Sennheiser HD280 Pro). Eight visual stimuli (abstract shapes, see Figure 1) and eight verbal stimuli (Cantonese disyllabic words, see Figure 1) were randomly presented for 2 seconds (E-prime version 2.0). Visual stimuli were presented visually and verbal stimuli were presented auditorally. Participants were asked to memorise as many of the items as they could for later recall. To limit involvement of the visuospatial sketchpad in short-term storage of the verbal stimuli and involvement of the phonological loop in short-term storage of the visual stimuli, the stimuli were deliberately abstract. That is, the visual stimuli were difficult to verbalise and the verbal stimuli were difficult to visualise. Pilot work (*n* = 5 participants) suggested that recall of the visual

and verbal items was similar (mean = 6.6, SD = 1.1 and mean = 7.0, SD = 1.4, respectively).

Following presentation of the stimuli, participants again completed a 1-minute reading aloud task; however, they were instructed to speak with maximum pitch variation. Participants in the visual analogy instruction group were presented with an image of a “choppy sea” (Figure 2) and were instructed to “read aloud the paragraph like this picture”, whereas participants in the verbal analogy instruction group were instructed to “read aloud the paragraph like a choppy sea”. Participants in the explicit instruction group were instructed to “read aloud the paragraph with maximum pitch variation . . . that is, read aloud with extremely high and low pitch variability” and participants in the uninstructed control group were asked to “read aloud the paragraph”, without any instruction. Immediately after the reading task, participants were asked to recall as many of the stimuli as possible, by drawing the visual stimuli or saying the verbal stimuli. Recall of a visual stimulus was considered to be correct if the participant correctly replicated the identical shape and

		影像 (image) jeng2 zoeng6	花卉 (flower) faa1 wai2
		週期 (period) zau1 gei1	症狀 (symptom) zing1 zong6
		颱風 (typhoon) toi4 fung1	廚房 (kitchen) ceoi4 fong4
		吵鬧 (noisy) caau2 naau6	病毒 (virus) beng5 duk6

Figure 1. Visual stimuli (displayed on the computer screen at a rate of 2 seconds per shape) and verbal stimuli (broadcast through the headphone at a rate of 2 seconds per disyllabic word).

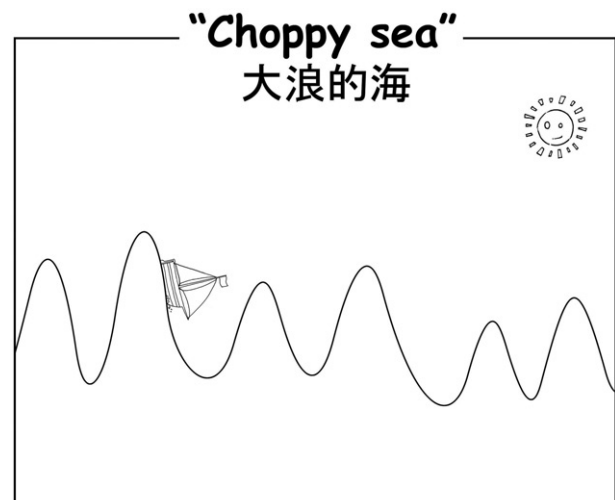


Figure 2. Visual analogy instruction.



orientation of the stimulus. Recall of a verbal stimulus was considered correct if the participant repeated the identical Cantonese disyllabic word.

*Instructed speech without memory recall.* Finally, after a 3-minute resting period, participants were asked to read aloud a new paragraph with maximum pitch variation, using the same instructions that were provided in the previous condition. No memory recall was required.

#### Dependent measures

Praat software was used to measure the mean  $SDF_0$  of the speech samples. Females tend to speak with higher pitch than males (Grieser & Kuhl, 1988), so the absolute values of  $SDF_0$  (in the unit of Hertz) were converted to a logarithmic scale (in the unit of semitone relative to an arbitrary musical note A1 or 55 Hz) to permit gender comparisons. All spectrograms were examined for mistracking errors of pitch by visually inspecting the narrowband spectrogram using the pitch analysis function provided by the Praat software. Any mistrackings were smoothed and filtered based on 20 Hz (minimum) and 2000 Hz (maximum), using the Praat software (Styler, 2013). Each speech sample was extracted manually and pauses (i.e. the period of time that the signal fell below 95% of peak intensity in the intensity envelope shown in Praat) during reading were removed.

#### Reliability

As manual segment extraction of speech samples involves subjective judgement, inter- and intra-experimenter reliability was determined. Inter-experimenter reliability was examined by having a research assistant repeat the segment extraction for 50% of the audio-recorded clips (speech samples of 20 participants). The extractions were considered to be correct if their duration did not differ by more than 5%. The overall inter-experiment agreement was 96.26%. Intra-experimenter reliability was

determined by the first author who repeated the calculations on all samples 1 week after the first calculation; agreement was 95.81%.

#### Data analysis

For pitch variability using semitone as dependant measurement, a two-way ANOVA with repeated measures was used to examine the difference in pitch variability for the four groups (non-instructed, explicit instructions, verbal analogy instructions and visual analogy instructions) in the three testing conditions (baseline reading, instructed speech with memory recall and instructed speech without memory recall). Correlations between overall digit span test and recall measures were examined using Pearson correlational coefficient. For memory recall analysis, non-parametric data analysis using Wilcoxon's tests was used to examine within-group differences in the number of visual and verbal stimuli recalled. Kruskal-Wallis one-way analysis of variance was used to examine between-group differences in recall of visual stimuli and verbal stimuli separately. Also, Mann-Whitney tests with a Bonferroni adjustment ( $p = 0.05/6 = 0.0083$ ) were used to examine if there were any pairwise differences. Non-parametric tests were used because the data (i.e. number of visual and verbal stimuli recalled) was nominal in nature.

## Result

#### Pitch variation

The two-way ANOVA revealed a main effect of Condition ( $F(2, 72) = 46.52, p = 0.001, \eta^2 = 0.56$ ) and Group ( $F(3, 36) = 5.90, p = 0.002, \eta^2 = 0.33$ ) and a significant interaction between Condition and Group ( $F(6, 72) = 11.94, p = 0.001, \eta^2 = 0.50$ ) (Figure 3). Separate one-way ANOVAs showed no differences in the non-instructed control group or the explicit instructions group ( $p > 0.05$ ); however,

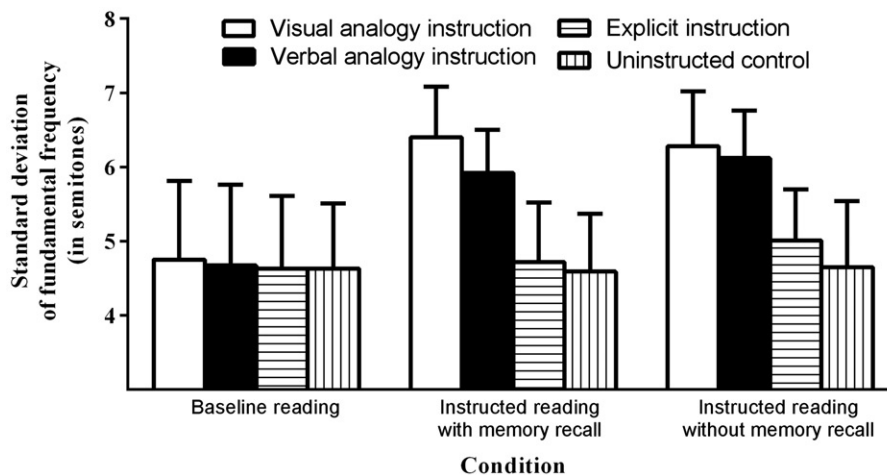


Figure 3. Standard deviation of fundamental frequency (in semitones) of different groups in three speech conditions. Bars display the variability in  $SDF_0$  across the group.

differences were evident in both analogy instruction groups ( $p < 0.05$ ). Bonferroni adjusted ( $p = 0.05/3 = 0.0167$ ) for three pairwise comparisons showed that  $SDF_0$  of participants in both analogy instruction groups increased significantly from baseline reading to instructed speech with memory recall and instructed speech without memory recall ( $p < 0.001$ ).  $SDF_0$  did not differ in the instructed speech with memory recall and instructed speech without memory recall conditions ( $p > 0.0167$ ).

*Memory recall*

Significant correlations between overall digit span test and recall measures were not evident ( $r = 0.47-0.69$ , all  $ps > 0.05$ ), indicating that spurious effects of baseline working memory ability did not influence memory recall. The number of visual and verbal stimuli recalled in each group is presented in Table I. With the use of Wilcoxon’s tests, significantly fewer visual stimuli were recalled than verbal stimuli in the visual analogy group (median = 3.0 and 4.0, respectively;  $T = 0.00$ ,  $p < 0.05$ ,  $r = -0.64$ ). Differences in recall of visual or verbal stimuli were not evident in the other groups ( $p > 0.05$ ).

For recall of visual stimuli, significant differences were evident by Kruskal-Wallis one-way analysis of variance,  $H(3) = 9.91$ ,  $p < 0.05$ . Mann-Whitney tests with a Bonferroni adjustment ( $p = 0.05/6 = 0.0083$ ) revealed that participants in the visual analogy instruction group recalled significantly fewer visual stimuli than those in the uninstructed control group ( $U = 16$ ,  $r = -0.59$ ,  $p < 0.0083$ ), but no other differences emerged ( $p > 0.05$ ).

For recall of verbal stimuli, Kruskal-Wallis one-way analysis of variance showed that significant differences were also evident between groups,  $H(3) = 15.51$ ,  $p < 0.05$ . Mann-Whitney tests, using the same Bonferroni adjustment, indicated that participants in the explicit instructions group recalled significantly fewer verbal stimuli than those in the visual analogy instruction group ( $U = 9.0$ ,  $r = -0.72$ ,  $p < 0.0083$ ) or the uninstructed control group ( $U = 5.5$ ,  $r = -0.77$ ,  $p < 0.0083$ ). There were no other significant differences ( $p > 0.05$ ).

Overall recall was also significantly different between the groups,  $H(3) = 10.87$ ,  $p < 0.05$ . Mann-Whitney tests indicated that participants in the explicitly instructed group recalled significantly fewer stimuli (Mean = 5.10; SD = 1.71) than in the

uninstructed control group (Mean = 8.90; SD = 1.70),  $U = 12.0$ ,  $r = -0.65$ ,  $p < 0.0083$ , but that no other differences were evident ( $p > 0.05$ ).

**Discussion**

The purpose of the present study was to examine speech motor performance (i.e. reading with maximum pitch variation) following different types of instructions and to examine the nature of the cognitive demands imposed on working memory by the instructions. With this purpose, it would enable us to have a better understanding on how analogy works from the theoretical framework of working memory; that is, whether analogy instruction requires less working memory as suggested by previous studies (e.g. Liao & Masters, 2001; Lam et al., 2009). Not surprisingly, uninstructed control participants displayed no change in pitch variability between baseline reading and reading with or without memory recall. Significantly increased pitch variability in response to both modes of analogy instruction (verbal, visual) occurred with and without the memory recall task, suggesting that participants were able to memorise the requirement to speak with greater pitch variation, despite the demands of the recall task. In previous motor learning studies, robust performance under secondary task loading has also been demonstrated following analogy instructions (e.g. Lam et al., 2009, Liao & Masters, 2001). However, these effects have always been demonstrated after a period of practice/learning. Here the effects of analogy instructions were evident post-instruction, without the need for practice. Limb and speech motor control share many commonalities in terms of motor planning and execution (Grimme, Fuchs, Perrier, & Schöner, 2011), but one distinctive feature of speech motor control is that the motor goals follow each other in a rapid sequence of articulatory events, which require advanced planning and coordination to enable fast anticipatory adjustments to predictable articulatory challenges (Grimme et al., 2011).

Surprisingly, participants who were instructed explicitly displayed no increase in pitch variability compared to baseline. The cognitive demands associated with conceptualising and executing the explicit instructions may have been greater than in the analogy instruction conditions. Consistent with this possibility, the explicitly instructed participants displayed the poorest overall recall of stimuli, although the differences only reached statistical significance for the the uninstructed control group. More telling, the explicitly instructed participants recalled the fewest verbal stimuli, implying that demands associated with processing the instructions targeted the phonological component of working memory.

As expected, participants instructed by visual analogy recalled significantly fewer visual stimuli

Table I. Number of visual and verbal stimuli recalled of different groups.

Group	Visual memory stimuli		Verbal memory stimuli	
	Mean	SD	Mean	SD
Visual analogy instruction	2.40	0.84	4.30	0.95
Verbal analogy instruction	3.30	1.57	3.40	1.71
Explicit instruction	2.80	1.23	2.60	0.84
Uninstructed control	4.30	1.70	4.26	1.07

than verbal stimuli and displayed significantly poorer recall of visual stimuli than the uninstructed control participants. Their recall of verbal stimuli, however, was not different to the uninstructed control participants, suggesting that presentation of the analogy visually, reduced demands on the phonological component of working memory.

The verbal analogy instructed participants did not display differences in recall of visual and verbal stimuli. We expected that processing the descriptive content of the verbal analogy would utilise the phonological component of working memory and thus impair recall of verbal stimuli; however, it is likely that the multimodal nature of the “visual” representation potentially evoked by the verbal analogy (e.g. Donnelly & McDaniel, 1993) utilised the visuospatial component of working memory, thus impacting recall of visual stimuli equally.

Given the human ability for multimodal representation and integration of objects and words (e.g. Stein & Meredith, 1993), it is perhaps not surprising that the visual and verbal modes of analogy had an identical effect on overall stimulus recall. Our work suggests, however, that the mechanisms underlying that effect may differ with respect to the mode in which the information is initially presented. Theories of embodied cognition propose that human cognition and the manner in which we represent objects, experiences or abstract phenomena, such as analogies, is influenced by our physical interactions with the environment (e.g. Wilson, 2002). In particular, the visual modality integrates information from other senses (e.g. Roach, Heron, & McGraw, 2006; Witten & Knudsen, 2005), so it is perhaps not surprising that the visual analogy had a differential effect on memory recall, appearing to load the visuospatial component of working memory more heavily.

Our findings may have implications for treatment of clinical populations such as individuals with dysarthria (Schlenck, Bettrich, & Willmes, 1993) or speakers with athetoid dysarthria (Darley, Aronson, & Brown, 1975), who are known to struggle with the demands of controlling pitch variation during speech. However, speech-language pathologists should be aware of the finite working memory capacity. For example, the working memory deficits exhibited by some of the children with specific language impairment are closely associated with their language impairments (Marton, & Schwartz, 2003; Montgomery et al., 2010). It is, therefore, important to assess working memory capacity in the speech language impaired population so as to develop the most suitable treatment strategy (e.g. phonological short-term memory training) for them (Montgomery et al., 2010). Our findings may also have implications for experts and novices. Schlapkohl, Hohmann, and Raab (2012), for example, showed that explicit instructions were more effective than analogy instructions when teaching expert table tennis players to acquire a new hitting

style. The experts acquired significantly more declarative knowledge about the task, but the knowledge did not appear to overload working memory or disrupt performance. Analogy instructions were more effective for novices, however. Analogy instructions may therefore be suitable for patients who display cognitive deficits that reduce their ability to process verbal information, or for children whose working memory components were shown to be separable. Alloway, Gathercole, and Pickering (2006) showed that the storage components (visuospatial sketchpad and phonological loop) and processing component (the executive control) were separable in a child population. Therefore, we speculated that analogy of either visual or verbal modes may be equivalently useful for children to learn the similar speech motor tasks as in the present study. Analogy in both presentation modes may lower the workload of executive control (i.e. processing component) without interfering with the storage capacity on visuospatial and phonological components (i.e. the storage component) as a result of the separability (Alloway et al., 2006). Further investigation on this speculation in a child population is warranted.

#### *Limitations*

One of the limitations in using analogy is the indigenous culture background of the learners. Poolton, Masters, and Maxwell (2007) suggested that, if the content of an analogy is not appropriate for the indigenous culture, the advantage (i.e. the lower cognitive demand in this case) can be lost. It is, important for speech-language pathologists to adopt culturally suited analogical instructions to convey their desired message to clients. We acknowledge also that analogies and metaphors may play very different roles within cultures and languages, which modifies their potential impact on conceptual understandings derived from logic or reasoning. Another limitation is the generalisability of the result due to the language nature between Cantonese and English. As Cantonese is a tonal language that carries different meanings with different tones, cognitive load, particularly demands on the phonological loop during change of pitch, may be different to other non-tonal languages, such as English. Future research comparing cognitive load associated with analogy instructions in different languages is warranted. Caution is needed, however, when drawing conclusions about the analogy instructions in terms of visual stimuli recall. There was no visual memory test before the experiment, so poor visual memory may have compromised recall of visual stimuli.

#### *Conclusion*

Our data suggest that analogical instructions potentially provide an effective alternative medium of



instruction to explicit propositions in motor tasks. In cases where critical information from multiple modalities must be processed, visually presented analogies may be more effective because they appear to load primarily visuospatial components of working memory, leaving phonological components free to memorise other verbal information.

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### Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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