LISTEN TO THE GRAPH:
Children's matching of melodies with their visual representations

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Abstract

This paper is a report of matching of melodies with line graphs and music notation by children (aged 10 & 11 years). The study found that children are able to match the up-down contour of melodies with their visual representations, and that matching-task performance is positively related to mathematical ability in the case of line graphs, and musical ability in the case of music notation. The results suggest that visually impaired students and students with a preference for aural learning may be able to perceive the shape of graphs through auditory output of graphical calculators or computers. It was found also that the children used global processing more readily than local analytical processes and were able to detect global features such as overall shape more easily than local details such as interval sizes.

Introduction

This paper is a brief report of a major study of children's ability to match the up-down contour of melodies with the up-down contour of two visual representations, namely line graphs and music notation (Nisbet, 1998). The importance of this research for mathematics education lies firstly in the notion that, if students can perceive up-down contour through auditory perception, then those who are visually impaired, or those students who have a preference for learning in the aural modality, may be able to perceive the shape of a graph through its auditory representation rather than the usual visual representation. Hence these students may gain a richer understanding of the mathematical function normally represented visually by the graph. Secondly, studies in this area may provide some clues to an explanation of findings by researchers (e.g. Geohegan, 1991; Gregory, 1988; Rauscher, Shaw & Ky, 1993; Shaw, 1997) that experience with music assists children to develop mathematical skills, particularly spatial task performance.

Connections between mathematics and music have been of interest to some mathematicians, scientists and musicians for many years dating back to Pythagoras, and there are several reports in the literature of the mathematical foundations of music (e.g. Bronowski, 1976; Nisbet, 1991; Thomsen, 1980). However, research into the matching of melodies with their visual representations has received only limited attention in the fields of music perception and experimental psychology, and even less in the field of mathematics education. Nevertheless some relevant studies from the areas of music perception and experimental psychology provided a stepping-off point for this study.

Firstly, Morrongiello & Roes (1990) found that children's matching of melodies with line graphs is influenced by auditory factors (Western-style tonal melodies were easier to match with graphs than atonal melodies), contour complexity (more changes of up-down direction made matching more difficult), and extent of the children's musical training (children with musical training were more successful with tonal melodies, but not with atonal melodies). Secondly, Balch & Muscatelli (1986) established that the matching of melodies with visual contour markers by young adults is influenced by modality condition (tasks in which the visual stimuli were presented first were performed better than those in which the auditory stimuli were presented first), presentation rate (i.e. matching performance improved as the speed of notes decreased from 5 notes per second to 0.5 notes per second), contour complexity (how many times the up-down contour changed), and musical training (whether or not the subjects learned a musical instrument). Thirdly, in a review of sensory modality studies, Friedes (1974) came to the general (but not universal) conclusion that intramodal tasks (e.g. judging whether two melodies match) are easier than cross-modal tasks (e.g. judging whether the up-down contour of a melody matches that of a graph).

Fourthly, Das, Kirby & Jarman (1979) have refined the Luria model of cognitive processing (Luria, 1973) which describes processing of visual and auditory stimuli in terms of simultaneous processing (i.e. many elements and their inter-relationships at one time) and successive processing (i.e. elements of a sequence one at a time). Fifthly, studies by Navon (1977, 1981) have determined that in visual perception, global processing takes precedence over local analytical processing. In other words, global shape is perceived before local details. Similar results have been found for melodic recognition by Dowling (1982) and Trainor & Trehub (1993). However, by contrast, Schwarzer (1997) claims that analytical processing of melodies takes precedence over holistic processing. Also related to this study is the work of Palmer (1990) who found that task instructions given to subjects positively influence their attention to specific features of visual stimuli. Perhaps instructions to take special note of local details would improve analytical performance. Similarly, instructions to take special note of global shape would improve holistic performance.

In music education circles it has been claimed that music education should develop students' ability to integrate information gained from auditory and visual perception (Walker, 1992). Such an integration is not normally required in mathematics education, however, if the up-down contour of a graph can be represented auditorally and if students are able to perceive its shape through the auditory representation, then this may possibly be a method to assist visually impaired students and students with a preference for aural learning perceive and understand the shape of graphs.

The study

This study was conducted in three stages and addressed the following specific research questions:

- Do visual factors influence the matching of melodies with line graphs to the same extent as auditory factors?
- What is the role of mathematical ability and experience in the matching process?
- What is the role of sensory modality in the matching process?
- What is the role of cognitive processing ability in the matching process?
- Do children use global processing more than local processing in the matching process?
- Do instructions to attend to local and global features improve matching-task performance?

Participants

The participants in the experiments of the study were children (aged 10 to 11) in Grade 5 and 6 classes at two government primary schools in suburban Brisbane.

Materials

The auditory materials used for the study were recordings of nine-note melodies played on an electronic keyboard using a familiar piano sound. The visual materials were line graphs and samples of music notation - some which matched the up-down contour of the recorded melodies and others which did not match. To investigate the effect of visual factors in the matching process, two formats were used for the graphs and music notation: (i) conventional format which had melodic pitch represented on the vertical axis (low pitch below high pitch) and time shown on the horizontal axis from left to right, and (ii) non-conventional format which had pitch on the horizontal axis (low pitch to the right of high pitch) and time on the vertical axis (from top to bottom). The non-conventional music notation also used different note symbols and staves to the conventional notation. See Figures 1 and 2.
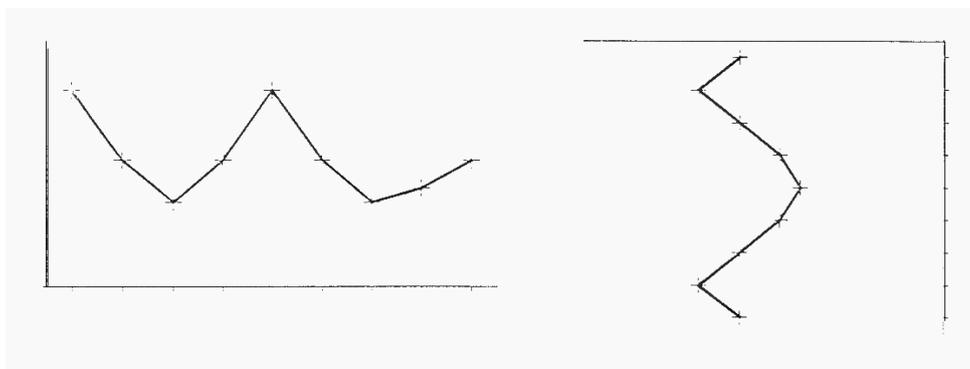

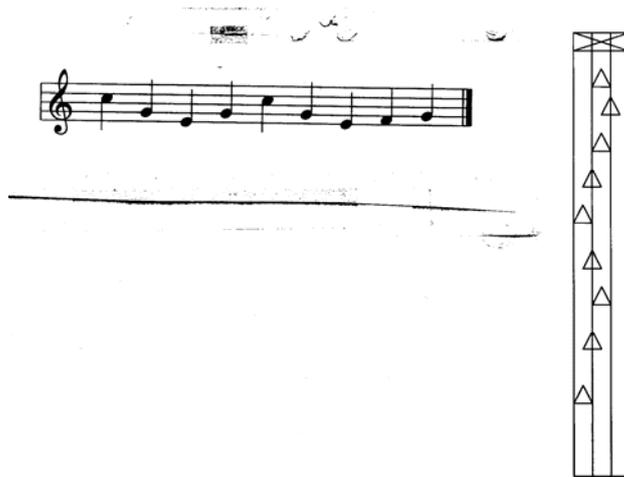Figure 1: Conventional (left) and non-conventional (right) line graphs

Figure 2: Conventional (left) and non-conventional (right) music notation

Experiment 1: Matching melodies with line graphs

The purpose of this experiment was to determine (a) whether visual factors influence the matching of melodies with line graphs to the same extent as auditory factors as demonstrated by Morrongiello and Roes (1990), (b) the role of mathematical ability and experience in the matching process, and (c) the effect of sensory modality in the matching process. Children in Grade 5 were asked to match melodies and line graphs presented in four sensory-modality conditions – melody to graph, graph to melody, graph to graph and melody to melody. ('Melody to graph' means that the melody was presented to the child first followed by the graph.) Half of the melody/graph pairs matched, and half did not. The procedure was that a pair of stimuli were presented to the child, and then the child was asked if the two matched or not, and the child's response subsequently recorded.

Manipulation of the visual format (conventional versus non-conventional graphs) and contour complexity showed that the matching process was influenced by visual/graphical factors as well as by auditory/melodic factors. Matching of melodies with conventional format graphs was superior to matching with non-conventional graphs. It was also found that intramodal tasks were superior to cross-modal tasks, in accord with much of the sensory-modality literature (Friedes, 1974) rather than with the *contour abstraction hypothesis* of Balch and Muscatelli (1986), which proposed that visual-first items are performed better than auditory-first items. However, within the intramodal and cross-modal categories, visual-first tasks were superior to auditory-first tasks. As a result of this, it was proposed that the matching process involved a comparison of an abstraction of the first-presented stimulus and the second stimulus, with the need for recoding from one modality to the other in the case of cross-modal tasks.

A positive effect of mathematical ability was revealed in this first experience, and evidence relating to type of visual format pointed towards the effect being attributable to mathematics experience (e.g. experience with graphs), rather than just mathematical ability. A close relationship between mathematics experience and mathematical ability was noted. Mathematics experience is a component of the mathematics ability measure used, and hence the role of mathematics experience is implied in the effects of mathematics ability. Positive effects of musical ability and musical training were observed also (as found in the study by Balch & Muscatelli, 1986) but the effects were limited to high-complexity visual-to-melody tasks (similar in part to the analogous mnelodic conditions in the study by Morrongiello & Roes, 1990). It was noted that as with mathematics ability and experience, a close relationship existed between these two factors, music experience and musical ability. Music experience is a component of the musical ability measure, and hence the role of music experience is implied in the effects of music ability. Despite the existence of these ability/experience factors in the matching process, they were overshadowed by the effects of sensory-modality condition and contour complexity.

Experiment 2: Matching melodies with music notation

The effect of visual factors on the matching process was further investigated in Experiment 2 with the use of music notation as the basis of the visual materials. Again, it was demonstrated, through the manipulation of notation format and contour complexity, that the matching process was influenced by visual as well as auditory factors. Also, the sensory-modality effects noted in the first experiment were observed again (intramodal tasks were performed better than cross-modal tasks), although performance levels indicated that matching melodies with music notation was more difficult for the children than with line graphs. Results for the visual-to-melody condition demonstrated children's greater difficulty of abstracting contour from music notation (compared to line graphs) and confirmed previous claims that the process of reading music is more complex than the cross-modal transfer of auditory and visual information.

Musical ability and music experience were positive factors only in the melody-to-visual condition, not surprising for that condition given that music students would be familiar with the task of listening to a melody and studying the music notation. The children would be no more familiar with that than reading music notation and performing the notes, so it appears that the difference in music ability/experience effects between notation-to-melody and melody-to-notation conditions may be explained by the difficulty the children (even the musically able) have with abstracting contour from notation compared with a likely advantage musically able children have with abstracting contour from melodies.

Overall, the effects of ability factors were again overshadowed by the effects of modality condition and contour complexity. The fact that musically experienced

children did not significantly outperform their inexperienced counterparts overall suggests that, generally speaking, children who have been studying a musical instrument for one or two years find reading music notation a difficult task despite the fact that they learn music.

Experiment 3: The role of cognitive processing

The issue of abilities was continued in Experiment 3 which examined the matching of melodies and their visual representations this time with respect to abilities in simultaneous and successive cognitive processing, based on the Luria model of cognitive processing (Das, Kirby & Jarman, 1979; Naglieri & Das, 1990). This model was shown to be a basis for understanding children's abilities in the matching process, but the relationships between sensory-modality condition and simultaneous and successive processing were not as well defined as originally proposed. Simultaneous cognitive processing was a significant positive factor in the performance of tasks in the two visual-first modality conditions (visual to visual and visual to melody) and the low-complexity melody-to-melody condition, whereas successive cognitive processing was a significant positive factor in all four sensory-modality conditions.

The results indicate that simultaneous processing was involved not only with the inter-relating of features of visual stimuli but also with the "chunking" of melodic phrases (in the case of low complexity examples). The effect of successive cognitive processing ability was attributed firstly to the processing of the sequence of notes of a melody, and secondly to the consecutive presentation of the two stimuli. The results show that the cognitive processing required for matching tasks can be determined by considering the modality of the first-presented stimulus, and the consecutive nature of the presentation of pairs of stimuli. This conclusion also was consistent with the matching-process model arising from Experiments 1 and 2, which proposed that matching entailed abstraction of the contour of the first-presented stimulus and comparison with the second stimulus. Experiment 3 also confirmed the assertion made in consideration of the results of Experiments 1 and 2, that music notation is more complex visually than line graphs, and thus requires a higher level of simultaneous cognitive processing to abstract the contour given the complications of the perceptual and symbolic features.

Experiment 4: Recognising local and global features during the matching process

The local and global features of the melodic and visual materials and their associated processing strategies were the major issues investigated in this experiment and the following one. Children's recognition of differences in the materials at the local and global levels was examined with respect to analytical and global processing, and presentation rate. Experiment 4 provided limited evidence for the global precedence hypothesis (Navon, 1977, 1981). Under both modes of instruction global changes were distinguished from local changes, and were detected at faster presentation rates.

Moreover, children appeared to have difficulty in recognising interval changes which don't violate the overall up-down contour. The results showed that children were more sensitive to changes in line-graph items compared to music-notation items, and that processing instructions did have some effect on the children's responses. Limitations in the methodology restricted the extent to which the results could be interpreted in terms of global precedence and the effect of instructions. The next experiment sought to remedy these limitations.

Experiment 5: Global or local processing?

Subsequent to the noting of the limitations to Experiment 4, the methodology was refined in terms of materials, tasks and methods of response. The children were asked to indicate whether pairs of melodies and graphs presented concurrently were (i) identical, (ii) had different overall shape, or (iii) had the same overall shape but had changes to interval sizes. Two types of instructions – global and local - were used to direct the children's attention to the global or local features, and only two presentation rates were employed – fast (4 notes per second) and slow (1 note per second).

It was found that global processing took precedence in the matching of melodies and line graphs, confirming Navon's (1971, 1981) global precedence hypothesis. Global information with respect to overall contour was accessed more easily and more quickly than local information in the form of interval sizes. This is consistent with results from studies in melodic perception which have shown that children prefer to use global attributes such as contour rather than local attributes such as interval sizes (Dowling, 1982; Trainor & Trehub, 1993). Attention to local and global properties was able to be manipulated by mode of instruction (as predicted by the work on the role of attention by Palmer, 1990), but only at the faster presentation rate. The recognition of global changes (changes to overall contour) was reinforced by instructions to act holistically and hindered by instructions to act analytically, and the recognition of local changes (changes to interval sizes) was reinforced by instructions to act analytically, and hindered by instructions to act holistically.

Decreasing the presentation rate appeared to lead to a loss of cohesion of local and global melodic information in terms of the children's perception of relative interval sizes. Although the children recognised global-change items reasonably well, they incorrectly reported more differences for global-change items compared to local-change items. The children perceived differences between the two types of items but interpreted them quantitatively as well as qualitatively. Overall, it was shown that, in the matching of short melodies with line graphs, global information is accessed more easily and more quickly than local information, and that children's matching strategies can be manipulated through instructions.

Conclusions and implications

The main conclusion from this study is that children are able to *listen to a graph* and detect the overall shape of the graph. The up-down contour of a graph can be abstracted from visual and auditory stimuli. This suggests the possibility of using auditory representations of graphs to assist visually impaired students and students with a preference for aural learning perceive the shape of a graph and comprehend the mathematical function underlying it. With the advances in mathematical technology (e.g. graphical calculators and computer software) it seems feasible to produce auditory as well as visual output from a mathematical function. Further research is required into how this technology may assist visually impaired mathematics students in understanding functions in algebra, calculus and statistics.

Other conclusions from the study include the following:
- Children's performance at matching melodies and their visual representations is influenced by visual as well as auditory factors.
- Reading music notation is a difficult task for children, even after two or three years' musical tuition. Music notation contains much abstract as well as perceptual information. This information is contained in the local detail of the melodies and their visual representations, and it is not as easily detected as the global shape.
- Experience with the respective visual materials assists in the matching-task performance – mathematics experience for matching with line graphs and musical experience for matching with music notation.
- In the matching tasks with line graphs, children use global processes more readily than analytical processes, and perceive global features more easily. This result corresponds with the claim of the van Hieles (1958) that, in terms of visual stimuli, children first learn to recognise overall geometric shape (Level 1), and at a later stage are able to analyse specific local properties (Level 2).

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