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Relatedness of Auditory Instructions is Important for Motor Performance in Persons with Down Syndrome

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Abstract

Participants with Down syndrome (DS), and typical chronological and mental age-matched (MA) participants, completed a three movement sequence in response to visual (e.g., illumination of objects), verbal (e.g., name of objects), directly related auditory (e.g., sound of objects), and indirectly related auditory (e.g., different tones for each object) instructions. Our results indicated that participants with DS and the MA group were slowest and made the most errors in the indirectly related auditory condition indicating that the amount of meaning associated with the method of instruction is an important determinant of motor performance in persons with DS and young children. These results demonstrate the importance of auditory stimulus and response compatibility for motor performance, especially in persons with low mental age.

Auditory stimuli are a valuable source of information in everyday life. In fact, many messages that require immediate action and universal understanding are communicated in this manner. Sirens on emergency vehicles, a car horn, a referee's whistle, fire alarms, and buzzers on timers are all examples of auditory signals with which everyone is familiar. Thus, auditory information can be communicated quickly and easily regardless of verbal ability and without visual attention. Such a source of pertinent information has great potential for persons with Down syndrome (DS). While research with persons with DS has consistently demonstrated that visual demonstration results in superior performance and learning on a variety of motor tasks and that verbal instruction results in a deficit, due to atypical cerebral lateralization and callosal morphology (Maraj, Bonertz, Kivi, Furler, Ringenbach, & Mulvey, 2007), there is a lack of research regarding purely auditory information.

Evidence of verbal-motor deficits for persons with DS (Maraj et al., 2007) has been well documented over the past 30 years and explained with Elliott and colleagues model of atypical cerebral specialization for speech perception in persons with DS (Elliott, Edwards, Weeks, Lindley, & Carhahan, 1987; Elliott, Weeks, & Elliott, 1987; Elliott & Weeks, 1993; Maraj et al., 2007). Briefly, this model suggests that in the non-DS population, both speech perception and movement production are lateralized in the left hemisphere, thus the two centres can communicate directly within the same cerebral hemisphere on verbal-motor tasks. In the DS population, however, speech perception is atypically lateralized in the right hemisphere whereas movement production remains typically lateralized in the left hemisphere (Hartley, 1981; Elliott, Gray & Weeks, 1991). As a result, verbal-motor tasks necessitate communication between the hemispheres for persons with DS; this interhemispheric communication both delays and degrades the motor response. Although this model has fuelled much of the research in this area (Maraj et al., 2007) it remains somewhat limited in its scope. Systematic research regarding both visual-motor and verbal-motor performance for persons with DS has been conducted; however, the results regarding auditory information are less clear.

Ringenbach and colleagues (Ringenbach, Chua, Maraj, Kao, & Weeks, 2002, Ringenbach, Allen, Chung, & Jung, 2006; Robertson, Van Gemmert & Maraj., 2002) are the only researchers to systematically study auditory instruction as it relates to motor performance for persons with DS. However, this line of research has focused primarily on coordination measures for continuous bimanual tasks whereas the bulk of the literature with respect to the model of atypical cerebral specialization has focused on response times and movement errors for discrete and serial unimanual tasks. It also appears, however, that related information presented in a less contrived situation produces the pattern of results dictated by the model of biological dissociation. Specifically, Ringenbach et al. (2006) demonstrated a visual-motor advantage for continuous drumming when the information used was specific to the task (e.g., video of drumming) and therefore related. Verbal information resulted in the poorest performance with auditory information in between the two. This same visual, auditory, verbal pattern of results did not appear for the discrete task of a single drumbeat whereby suggesting that related information and task appropriateness is of greater importance as the complexity of the task increases.

It is important to note that while visual demonstration and verbal instruction appear inherently related, varying levels of meaning can enhance motor performance in persons with DS. For example, Bunn, Roy, and Elliott (2007) demonstrated that children with DS performed significantly worse than comparison participants when asked to pantomime an action but equivalently when asked to perform the same action with the aid of a tool. The authors argue that the presence of a tool provides individuals with context to their actions, therefore reducing demand on their short-term memory. So, by providing context/relatedness to the motor task to be performed the experimenters created a situation in which the verbal instruction's meaning was enhanced, improving performance for participants with DS. Thus, our purpose is to examine the level of relatedness associated with different types of auditory instruction and compare them with visual instructions.

Method

Participants

Participants for this study were seven young adult men and women with DS (chronological age range 16.4–30.9 years, M = 22.9; mental age range 6.4–10.9 years, M = 7.9) as well as an equal number of typically developing chronological age match (CA; range 17.1–28.8 years, M = 23.0 years) and mental age match (MA; range 6.0–8.7 years, M = 7.2) comparison groups. Mental age was assumed to be the same as chronological age for all typical participants. All protocols were approved by the Faculty of Physical Education and Recreation, Faculty of Agricultural, Life, and Environmental Sciences, Faculty of Native Studies Research Ethics Board at the University of Alberta.

Prior to participation in the study all participants, along with their parents or guardian (in the case of MA participants and participants with DS), read/or were read the participant information letter and informed consent/assent form, which was then signed. All participants met the following criteria: (1) were right-handed, (2) had normal, or corrected-to-normal, vision, and (3) had no known hearing impairments. Visual acuity was assessed using the Snellen Visual Acuity and Colour Vision Chart. Handedness was determined using a shortened six-item handedness inventory (Oldfield, 1971) in which participants demonstrated writing with a pen, drawing a circle with a pen, cutting paper with scissors, throwing a tennis ball, eating with a spoon, and brushing their teeth. The latter two items were "pretend." Hearing was assessed using a Maico 24 audiometer.

Assessment of mental age using the Peabody Picture Vocabulary Test (3rd ed.; PPVT-III) for participants with DS followed experimental protocols to decrease motivational and attentional demands prior to testing.

Task

Participants were seated in an adjustable office chair and were required to perform an upper limb serial movement. The participants used a mouse to move a cursor and stop briefly on each target on a computer screen directly in front of them. The targets were arranged vertically on a computer screen directly in front of their midline. At the bottom of the screen was the home position, represented by a circle, from which all trials began. Once the mouse was in the circle, the participants were instructed to start. The start signal varied depending on condition. Specifically, the visual start signal was the fill colour of the home position switching from red to green. There was no difference in illumination or shape of the visual start signal. The verbal start signal was an audio file of the experimenter's voice saying "go." The directly related auditory start signal was an audio file of the sound of a clap. The indirectly related auditory start signal was a tone distinct in pitch and quality from those in the required sequence. A variable fore period of 0.5, 1.0, 1.5, or 2.0 seconds was placed prior to the start signal so that participants could not anticipate the onset of a trial. No pressing of mouse buttons was required. As can be seen in Figure 1, the next closest in proximity to the home position was a whistle, followed by a trumpet, and a bell. Starting from the home position there were three distinct movement sequences: 1 (bell, trumpet, whistle), 2 (trumpet, bell, whistle), and 3 (trumpet, whistle, bell). Each movement sequence was equivalent in total distance travelled. All trials were conducted with the participants'r dominant (right) hand.

Participants reproduced the three movement sequences in response to each of four different conditions, each with its own mode of presentation. Condition 1 was visual instruction with the targets becoming brighter one at a time displaying the movement pattern to be performed. Condition 2 was verbal instruction with a recorded audio file of the experimenter's voice saying the movement pattern to be performed.

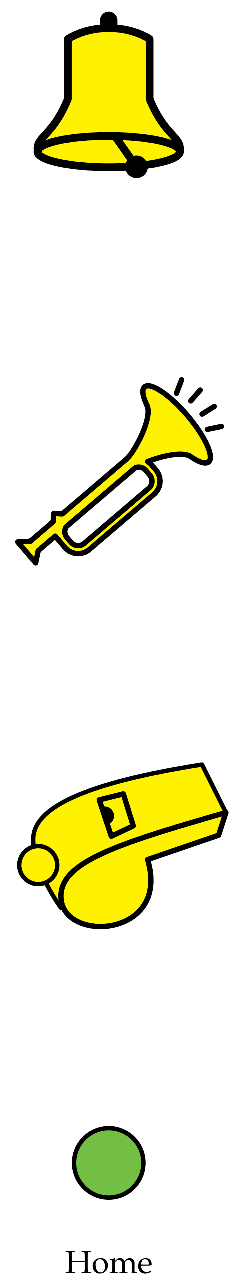

Figure 1. Visual representation of computer screen during experimental protocols in visual condition

Condition 3 was directly related auditory instruction with recorded audio files of sounds corresponding to the instruments played one at a time signifying the movement pattern to be performed. Condition 4 was indirectly related auditory instruction with audio files of high, medium and low tones (explained as representing top, middle, and bottom, respectively) played one at a time to signify the movement pattern to be performed. All audio files were professionally recorded at a recording studio and digitally engineered to control stimulus intensity and duration.

Procedure

In order to familiarize the participants with the required procedure, the researcher demonstrated the protocol to each participant and had each participant complete three practice trials in each of the four conditions prior to the onset of experimental trials. Acquisition data consisted of 48 trials broken into two blocks with each block consisting of six trials (two for each possible movement sequence) across the four conditions. The presentation of movement patterns within each condition as well as the order of presentation of the conditions within each block was counterbalanced across participants to rule out order of presentation effects that could possibly influence the results. Descriptive, summary feedback in milliseconds was provided following completion of each condition (i.e., six trials) during acquisition trials. Average time of testing was two hours for comparison participants and two and a half hours for participants with DS.

Data Collection and Analysis

All trials were collected and recorded with E-Prime 2.0 which captured all movement data. The dependent measures recorded were, total time (TT) and errors. Total time was defined as the time from the stimulus onset to task completion or zero displacement. Errors were defined as any movement order other than the required sequence or a missing element from the required sequence.

Data analyses for TT was performed exclusively on error free trials using a 3 group (DS, MA, CA) $\times$ 4 condition (visual, verbal, directly related auditory, indirectly related auditory) mixed analysis of variance (ANOVA) with repeated measures on the last factor. Post hoc analysis of main effects and interactions were conducted using Tukey's HSD with alpha level set at $p < .05$ for all analyses. Corresponding effect sizes are also reported for all statistical tests. All outliers were corrected to the mean plus or minus 2 standard deviations. Outliers were identified using the Kolmogorov-Smirnov Test for normality of distribution and Levene's Test of Equality of Variances. Following the correction of outliers these tests were repeated to make sure that there were no remaining outliers that would affect the results. All statistical analyses were performed using SPSS version 15.0 or STATISTICA version 8.

Data analysis for errors was performed by converting the raw error scores into percentages to obtain an error rate. The conversion of the raw scores into an error rate was necessitated by the ordinal nature of the original data and allowed for statistical comparison (Hays, 1994). Error rates were then analyzed using the same procedures as the other dependent variable described above.

Results

Total Time

Analysis of total time data revealed a main effect for group, F (2, 18) = 22.735, $p < .001$, $\eta 2 = .716$, with post hoc analysis indicating that the CA group (M = 1420 ms) was significantly faster than both the DS (M = 2890 ms, $p < .001$) and MA (M = 2925 ms, $p < .001$) groups. Further, there was also a main effect for condition, F (3, 54) = 4.226, $p = .009$, $\eta 2 = .19$. As can be seen in Figure 2 and confirmed by post hoc analysis, the indirectly related auditory condition (M = 2591 ms) was significantly slower than the visual condition (M = 2361 ms, $p = .035$), verbal condition (M = 2354 ms, $p = .029$), and directly related auditory condition (M = 2341 ms, $p = .019$). Again, no other effects or trends were found.

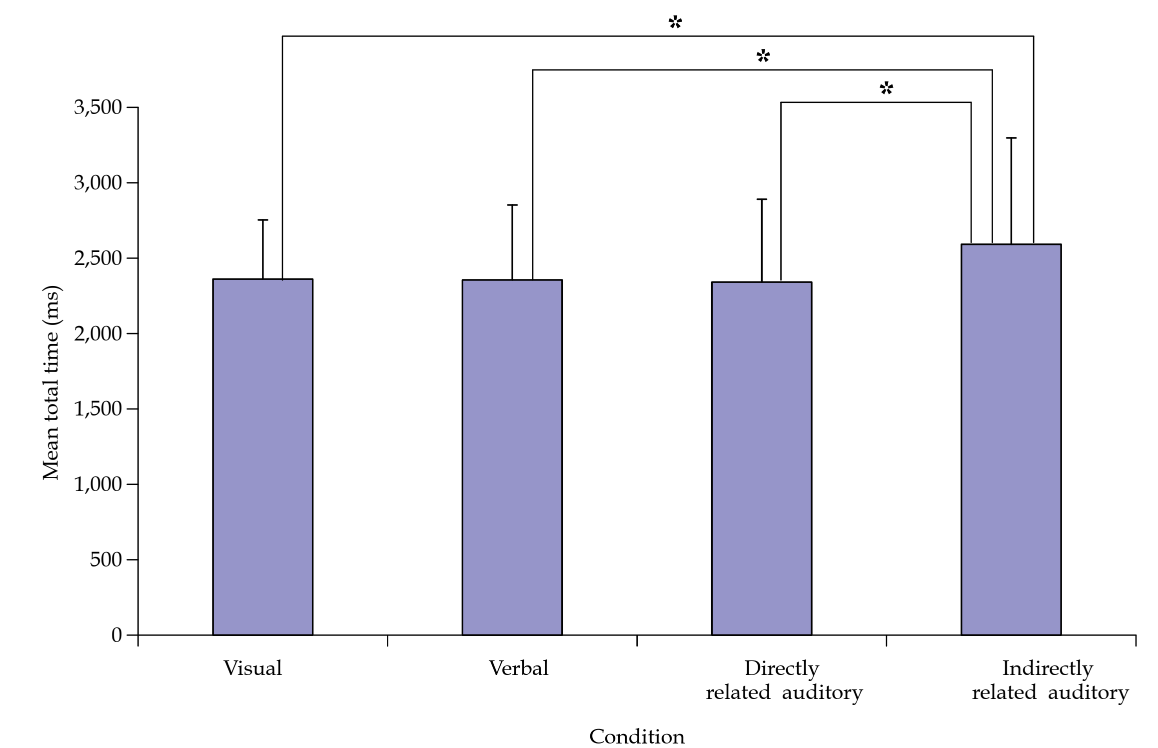

Figure 2. Mean total time as a function of condition

Errors

Analysis of error rate produced a main effect for group, F (2, 18) = 13.499, $p < .001$, η2 = .6, with post hoc analysis indicating that the CA group (M = 6.7) made significantly fewer errors than both MA (M = 25.6) and the DS (M = 34.5) groups (p < .001) who did not differ from each other. There was also a main effect for condition, F (3, 54) = 15.71, $p < .001$, η2 = .466, with post hoc analysis indicating that participants committed significantly more errors in the indirectly related condition (M = 38.1) than in the visual (M = 14.3), verbal (M = 18), and directly related auditory (M = 18.8) conditions ($p < .001$). These main effects were superseded by a 2 way interaction between group and condition, F (6, 54) = 4.543, $p < .001$, η2 = .335. As can be seen in Figure 3 and confirmed by post hoc analysis the DS group made significantly more errors in the indirectly related condition (M = 19.8) than they did in the directly related conditions; auditory (M = 31.7, p = .01), verbal (M = 28.6, p = .003), and visual (M = 19.8, $p < .001$). This pattern of committing significantly more errors in the indirectly related auditory condition (M = 50.0) compared to the directly related auditory (M = 20.6, p = .003), verbal (M = 15.9, $p < .001$) and visual (M = 15.9, $p < .001$) conditions was repeated similarly for the MA group. In CA, there were no significant differences between any condition (indirectly related auditory, M = 6.4; directly related auditory, M = 4.0; verbal, M = 9.5; visual, M = 7.2) for the CA group ($p > .05$).

Discussion

The purpose of the present study was to examine the effect of directly related and indirectly related auditory information compared to visual and verbal information on motor performance for persons with DS. In general, indirect auditory information resulted in more errors for both the DS and MA comparison groups and longer processing and movement time for everyone. Specifically, for TT, indirectly related auditory information resulted in significantly longer total response times compared to each of the three directly related conditions (e.g., auditory, ver-

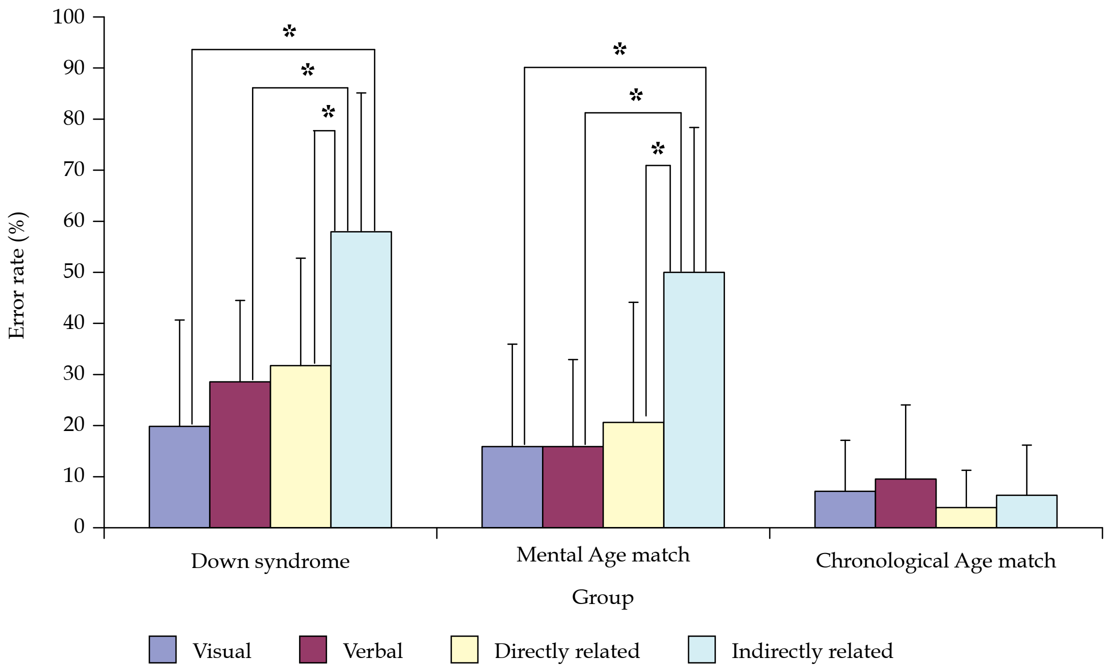

Figure 3. Mean error rate for each group as a function of condition

bal, visual). This demonstrates a clear division between directly and indirectly related information regardless of the modality of presentation. These results are consistent with the concept of stimulus-response compatibility, which is the degree to which people perceive instructions to be consistent with the actions they need to take (Proctor & Reeve, 1985). While there is much research investigating stimulus-response compatibility in typical populations, there is less in developmental or special populations.

One study reported that while both typical adults and children were slower to respond to incompatible stimulus, the children were significantly worse (Casey, Thomas, Davidson, Kunz, & Franzen, 2002). This is consistent with the paradigm interpretation that the incompatible stimulus-response requires greater cognitive control than compatible situations. Thus, poorer performance in the stimulus incompatible situation (e.g., indirectly related auditory instructions) in our low mental age groups of MA and DS are expected considering the lower cognitive function of these groups. In another study with children (6–9 years) with ADHD, the results showed that children with ADHD made fewer correct responses than typical children, but did not show a larger incompatibility effect on response speed and accuracy (Yong-Liang et al., 2000). The results in our study are consistent with this in that there was a trend for persons with DS to make more errors than the typical children, while both demonstrated a much worse performance when the stimulus was indirectly related or less compatible with the task. Similarly, in previous research with visual stimuli with persons with Down syndrome there was only a visual advantage over verbal and auditory instructions when the visual stimulus was directly related to the task, which was a video of drumming movements (Ringenbach, et al., 2006). Furthermore, in a previous study, when the visual instruction was indirectly related (e.g., a blinking circle indicating the timing of when to draw a circle), there was no benefit of visual instructions over verbal or auditory instructions (Robertson et al., 2002). Thus, these results support the argument that directly related information leads to a processing and performance advantage relative to indirectly related information.

The speed accuracy tradeoff, or trading speed for accuracy in movement tasks is very robust and has been shown in many populations (Schmidt & Wrisberg, 2008). It has also been shown to exist in persons with DS, although with slower movements and more errors than typical participants (Lam, Hodges, Virji-Babul, & Latash, 2009). Our results are consistent with this because both our participants with DS and their peers of similar mental age, moved slower than the CA group, but also committed the most errors, especially in the indirectly related condition. This demonstrates that this condition was more difficult and that relatedness of information is particularly important for reducing errors.

Practical Application

The results of this study indicate that the most accurate movements occur when the instructions to move are most directly related to the action. This is extremely important when teaching, providing rehabilitation, coaching and creating products and techniques for performing activities of daily living for persons with lower cognitive functioning, including persons with DS.

Key Messages From This Article

People with disabilities: Because you process information slower, take your time and pay close attention to all of the information provided before making a response (e.g., you must see the walk picture before crossing street).

Professionals: It is important to make sure instructions/information for people with low mental age are highly meaningful and related (e.g., information in green would always be connected with a "go" response). This will result in the most accurate response and the least amount of frustration for the professional and person with low mental age.

Policymakers: Policy should require that information should be highly similar to the action that is required especially with people of low mental age. This could eliminate errors and potentially improve safety of this special population.

Author Note

Address correspondence concerning this article to Shannon D. R. Ringenbach at Shannon.ringenbach@asu.edu. Thank you to the Edmonton Down Syndrome Society. This research was supported by the Social Sciences and Humanities Research Council.

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