THE CONTRIBUTION OF MULTISENSORY INTEGRATION TO WORKING MEMORY PERFORMANCE IN CHILDREN (0-12-YEARS): A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract - Multisensory integration processing is known to enhances perception, cognition and behavioural abilities though how multisensory processing such as auditory-visual integration compares with the role of unisensory processing in working memory performance (WM) in children from birth to adolescence is less clear. The current work aimed to systematically review and meta-analyse the vast literature associated with the development of multisensory integration (MSI) and WM during childhood (birth to 12-years), to examine (a) how nonverbal and verbal (semantic-non semantic) multisensory processing compared to unisensory (auditory or visual alone) contribute to and correlate with speed and extent of encoding in working memory for both auditory and visual WM; and (b) the developmental changes by exploring if there are similarities or differences in working memory capacity to incorporate MSI as compared to unisensory information across different age groups. A comprehensive search of multiple electronic databases was performed using PsycINFO (Ovid), MEDLINE (Ovid), EMBASE (Ovid), PubMed, CINAHL (EBSCO), Web of science (ISI) and Cochrane Library. Eighteen out of 3909 unique articles met the inclusion criteria. Results show that MSI is closely associated with visualand auditory WM performance compared to unisensory information "where verbal semantic and nonverbal information are presented'. The faster processing speed of MSI is associated with greater WM capacity performance in late childhood. In terms of age, evidence indicates that timing for MSI is more pronounced later in childhood and that this ability increases working memory capacity as compared to visual and auditory-alone. The limitations and directions for future research are also discussed

Keywords - Multisensory Integration, Working Memory, Children, Meta-Analysis.

I. INRODUCTION

Successful construction of meaningful representations of the environment requires multiple sensory systems to integrate inputs from different sensory modalities [1].Multisensory process has been shown to be advantageous as it enhances perception, cognition and behavioural abilities [4], which in turn, improve higher-level cognitive function, such as learning, working memory and intelligence [7,11].Indeed multisensory integration is defined as the neural interaction of multiple streams of information, resulting in faster speed of processing with higher accuracy together than for either sense alone. Multisensory integration also facilitates learning and memory throughout childhood [10]. Thus, proficient multisensory processing of information in children is likely to be associated with the development of various cognitive processes such as working memory. However, to the best of our knowledge, no review has investigated the effects of multisensory integration on children's memory performance, highlighting the need for this review of the literature to better understand the associations and developmental differences among multisensory processes, and working memory abilities (visual and auditory) in children from birth to 12 years old.

Development of multisensory processing may be modulated by changes in sensory dominance and modality preference. For example, in a study conducted by Constantinidou, Danos, Nelson, and Baker[6] investigated modality preferences using multisensory information. Results showed that children aged 7-13 years, were significantly better and more accurate in recalling pictures and words when using unisensory visual-only rather than auditory-only or multisensory audiovisual condition. This study, in particular, found that audiovisual presentations created a distraction, causing a reduction in recall information in auditory working memory (AWM) compared to pictures alone, but audio-visual representations resulted in better performance than when auditory stimuli were presented alone. Interestingly, this finding may be interpreted to provide evidence for the pictorial superiority hypothesis supporting the use of images during encoding and remembering in WM tasks.Nava andPavani [12] also found that visual dominance does not emerge before the age of seven. In general the dominance of visual attention, eye movements and vision in primates and the early dominance of vision rather than audition and language during infancy in human children and the greater volume of cortex and brainstem areas dedicated to rapid processing of visual information lend support for visual dominance[14]. However, the auditory brainstem response to non-semantic loud noise is incredibly fast and does dominate for 10m It may be advantageous when recalling items when are presented auditorily as compared to visually in children aged 8- 11 years old [9]. According to the Modality Appropriateness Hypothesis, the influence of each domain "visual and

auditory" is task-dependent. Thus, the largest multisensory processing is observed for associated multisensory stimuli in close spatial and temporal proximity. In visual-auditory spatial tasks, vision should dominate with higher spatial precision, whereas, in visual-auditory temporal tasks, audition dominates with higher temporal precision [15].

Recent evidence for the development of multisensory facilitation and cognitive abilities such as working memory over the primary school years comes from Barutchu and colleagues [1, 2, 3] who have used various psychophysical methods and motor reaction time tasks to show how multisensory processing can facilitate various cognitive processes in childhood. Using a simple audiovisual detection paradigm of 88 school children, Barutchu[1] failed to find significant relationships between multisensory reaction time (MRTs) and working memory ability. A more recent study of 38 children aged 8-11 years-old, also conducted byBarutchu [2] concluded that enhanced multisensory integration is highly associated with the development of general intellectual than WM abilities. However, different conclusions were garnered from the works ofDenervaud and Gentaz[7], the authors found that multisensory processes are tightly related to higher-level cognitive processes such as working memory in children from 4.6-15.5 years old using a simple detection task. This systematic variation in the relationships between multisensory processing and working memory could be related to the nature of the stimuli utilized in multisensory tasks and may have influenced the results.

It is also important to note that multisensory processing abilities related to language processing in children may be associated with how verbal material such as semantic information or non-semantic "meaningless information" is presented [1, 2, 6]. For example, the performance of semantically audiovisual information enhanced memory encoding in school-aged children, but the performance of non-semantic stimuli did not [10]. These outcomes suggest that the use of meaningless stimuli did not allow the semantic associations to occur during memory encoding of multisensory stimuli and might not benefit working memory. Additionally, previous studies have also investigated the influence of encoding in working memory by comparing the efficiency of verbal and nonverbal audiovisual format in both children[2, 9] and adults [2]. A study conducted byTremblay [13] with 5-19- year-olds investigated speech-based (i.e., McGurk Effect) and multisensory illusory processes involving nonspeech (i.e., flash-beep effect). The authors found audiovisual integration is stronger with verbal stimuli than non-verbal and these support the idea of independent maturational processes underlying verbal and non-verbal effects.

In sum, verbal and non-verbal multisensory integration (either semantic or non-semantic) represent an important variant of working memory, as the simultaneous processing of multisensory verbal and non-verbal information in working memory tasks, particularly in children, could affect the ability to learn and recall information [1, 6].Therefore, it is important to clarify whether multisensory integration of linking verbal information whether semantic or non-semantic to nonverbal information contributes to the performance of (visual and auditory) working memory during childhood.

There is a pressing need for a systematic review and meta-analysis of the literature to determine whether and how multisensory integration (visual, auditory and audiovisual) contribute to working memory performance in children as the clarification of these contributions could potentially provide a basis for enhancing the child's early cognitive development.This meta-analysis focused solely on children from birth to 12 years old and excluded adolescents and adults, this was done because we expected that multisensory integration(MSI) emerges early in life and reaches its maturity during late childhood based on previous reviews[5, 8]. Additionally, we excluded adolescents and adults to remove potential bias associated with the differing cognitive and developmental abilities of the adult population. Therefore, the purpose of the present study was first, to examine how multisensory (auditory, visual and audiovisual), that contains verbal semantic/non-semantic or nonverbal information, could influence and contribute to visual working memory (VWM) and auditory working memory (AWM) in children. Second, we sought to elucidate effect sizes to identify if there are similarities or differences in working memory capacity for MSI as compared to unisensory information across different age groups. The findings from this review will help to bridge the divide in research and provide critical information to the understanding of the development MSI and WM and may have implications for educational practices.

II. METHOD

2. 1.Protocol and Registration

This study was performed in accordance with recommended protocols for conducting systematic review and meta-analysis (the PRISMA guideline; Moher, Liberati, Tetzlaff,, Altman, & The Prisma Group, 2009). Our protocol was pre-specified and registered in the International Prospective Register of Systematic Reviews (PROSPERO) under existing number CRD42020148110.

2. 2. Literature Search Strategy

In this review, a search strategy was developed in collaboration with a qualified academic librarian and executed in seven electronic databases: PsycINFO (Ovid), MEDLINE (Ovid), EMBASE (Ovid), PubMed, CINAHL (EBSCO), Web of science (ISI) and Cochrane Library, for all available years.

2. 3. Study Selection Criteria

An a priori set of criteria were established to determine appropriate studies for inclusion in the review. Studies were eligible for inclusion if they directly investigated the effects of multisensory integration (visual, auditory and audiovisual) on memory performance in typically-developing children. Multisensory integration was defined as any audiovisual, audio-only and/or visual-only tasks aimed to affect working memory performance. Cross-sectional studies of typically-developing children in the appropriate age group 0-12 were included in this review. Thus, we excluded studies of children with a neurodevelopmental disorder (e.g., ADHA, ASD, Language Disorder) or Hearing or Visual Impairment. Furthermore, studies met inclusion criteria if they included at least one measure of multisensory processing integration (audiovisual), and at least one measure of working memory. Additionally, studies were included if they used one measure of audiovisual memory but reported a separate result for each modality (i.e., auditory-only, visual-only, and auditory-visual memory on the same task).

2. 4. Data Extraction

Studies that reported correlation or/and age differences between multisensory integration processing (visual and/or auditory and audiovisual,) and (visual/auditory) working memory were included and extracted using Microsoft Excel. The following Information from each study was extracted:

1. Study details (author(s), year of publication)
2. Study purpose (primary aim and other aims)
3. Participant information (number of total participants, age in years "mean and standard deviation (SD)"
4. Measure of multisensory integration and the sensory modal "auditory and/or visual and audiovisual" with details of task and stimuli.
5. Measure of working memory with details of task and stimuli.
6. Outcome (the multisensory integration processing effect on working memory performance).

2. 5. Risk of Bias and Quality Assessment

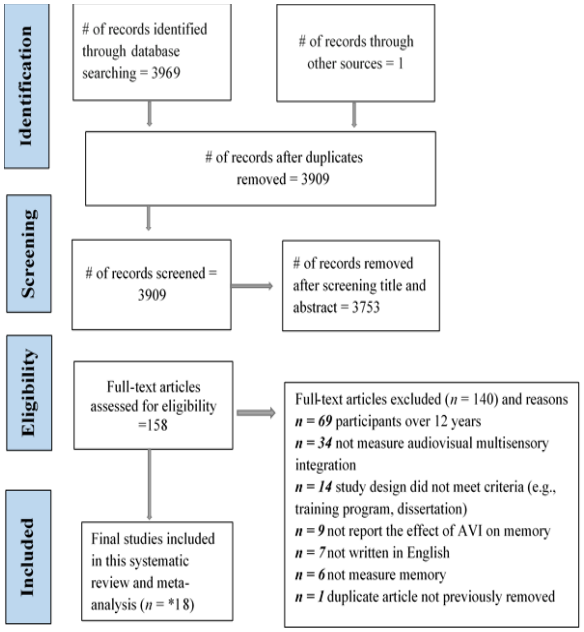
The methodological quality of each the included studies was assessed utilizing the AXIS tool (Appraisal Tool for Cross-Sectional Studies; Downes, Brennan, Williams, & Dean, 2016). The AXIS tool was successfully developed to evaluate the quality of the study design and risk of bias in cross-sectional studies (CSSs). A total of 20 items are included which clarify the study aims/objectives, assess the appropriateness of the study design and methodology and validity of results, to determine whether the discussion and conclusion are justified by the results and whether the study was ethical approval. The quality of each study was assessed by the first author (AA) and then reviewed by co-authors (HP, SC and MM).

Items that met the criteria were rated "yes", items that did not meet the criteria were rated "no", items that were not clear were rated either "unclear" or "not applicable". Differences in ratings were resolved through further discussion with a co-authors (SC) and (MM). If there was insufficient information to assess the risk of bias, communication with the corresponding author was attempted to provide more details.

III. RESULTS

3.1. Study selection

Fig.1. PRISMA flow diagram of study selection process for review



3.2. Risk of bias within studies

Quality assessments of the included studies were conducted to assess the extent to which studies were free of bias and a large degree of confidence could be placed in the results. No papers were excluded due to poor quality in this review, seven studies were moderate quality and eleven were high quality. All studies stated clear aims/objectives and had an appropriate study design for the stated aims. Ethical approval and consent forms were reported in teen studies.

3.3. Meta-analyses Result

All tasks of the verbal semantic MSI required children to verbalize response and identify a property of each stimuli when semantic information was provided and that are presented audiovisually and in unisensory visual and auditory only.

Audiovisual Integration. MSI and AWM have been most frequently tested (four studies contributed 5 correlations of interest to this meta-analysis). These tasks assessed multisensory integration processing relating to words that are considered meaningful. AWM has been assessed with Digit Span Task and Listening Span Task. The results showed that the overall correlation were (pooled correlation: 0.50, 95% CI [0.34, 0.66]), indicating a positive correlation between the semantic association tasks and AWM increase. Heterogeneity was low (24.00%), indicating a low possibility for I^2 based effect.

Rection Time Tasks. MSI and AWM was assessed in two studies using RT tasks in which children make a timed response to audiovisual integration stimuli. The meta-analysis of correlation studies with RT tasks also showed a significant effect (pooled correlation: -0.42, 95% CI [-0.54, -0.30]), indicating faster reaction time of multisensory processing with higher AWM performance for both digits and span. There was a low heterogeneity score across studies (0.00%).
Publication bias was conducted using Egger's test to explore possible publication bias, and a low likelihood of publication bias was found, with no evidence of small-study effects ($p = 0.300$).

Verbal Non-semantic MSI Tasks and AWM. Non-semantic MSI and AWM was assessed in only two studies. These tasks assessed arbitrary associations using stimuli are not readily verbalized. Results showed a low correlation between MSI and AWM (pooled correlation: 0.03, 95% CI [-0.16, -0.22]), and with reaction time (RT) (pooled correlation: 0.06, 95% CI [-0.18, -0.29]).

Non-verbal MSI Tasks and AWM. Five studies tested non-verbal using a variety of tasks. The nonverbal detection task required a child to discriminate stimuli that were presented audiovisually, while Change-Detection design using an audio-visual binding experiment was also assessed where participants were required to detect if the test shape-sound pairing is the same or different, results found moderate to high correlation between non-verbal MSI and AWM (pooled correlation: 0.49, 95% CI [0.13, 0.85]). Heterogeneity was moderate (56.78 %), indicating possible statistical and methodological variation between studies.

Verbal and Nonverbal MSI Tasks and VWM. verbal and non-verbal MSI tasks and VWM were utilized in two studies The overall correlation across those studies showed medium-to-large correlation (pooled correlation: 0.56: 95% CI [0.36; 0.76]), indicating a positive correlation between audiovisual integration tasks both verbal and nonverbal and VWM increase with a low I2 (0.00%) among studies. As this includes only two studies, no Egger's regression test could be calculated.

IV. DISCUSSION

The present study systematically reviewed the published studies that met the inclusion criterion and acceptable levels of bias. The 18 studies included 1,012 participants and all investigated first the contribution of multisensory integration to working memory performance during childhood, and meta-analysed the relationships between verbal (semantic- nonsemantic) and non-verbal MSI and WM both auditory and visual. We also sought to determine if there are similarities or differences in working memory capacity for multisensory integration processing as compared to unisensory information across different age groups. The results of the meta-analysis demonstrated positive correlations between semantic multisensory integration and measures of AWM using listening span and digit span tasks. A cross the literature to date, there is evidence of a significant association between the semantic information that is presented audiovisually and the performance of working memory, such that better multisensory integration tends to be associated with an increase of WM performance. These findings suggest that when the audiovisual presentation involve semantically associations, working memory can increase and be more accurate on subsequent retrieval and encoding. It is possible that memory benefits can be further enhanced in cases where the encoded object matches semantically. For example, the sound of a meowing cat presented with the image of a cat are more easily remembered due the semantics and may require participants to activate information from long-term memory. Two studies assessed reaction time (RT) as an outcome, demonstrating faster RT of multisensory processing in semantic association tasks lead to higher AWM performance for both digits and span. Additionally, this supports the predictions that children with faster multisensory processing are more able to recall or/and process larger amounts of information in the same amount of time than those who process slower. These findings suggest that general processing speed and storage are significantly contribute and are associated with children's memory performance.

Together, the results indicate that multisensory processing is efficient in improving working memory performance than unisensory visual only and may allow for stimuli to be recognized and remembered more accurately. Further studies assessing the speed of multisensory processing would help elucidate the benefit of sensory integration on memory and learning in children. Although only initial conclusions can be drawn regarding the benefits of multisensory processing speed to working memory performance due to the small number of studies, results can be considered to be more substantial due to very low heterogeneity and low publication bias.

V. CONCLUSION

Our study provides three main insights. First, verbal semantic and non-verbal multisensory stimuli are most highly associated with AWM and VWM. Second, consistent with expectation that faster processing speed of MSI tasks are more likely to increase WM performance, this meta-analysis found that multisensory integration results in faster information processing than for either sense alone. Finally, with regards to age differences, we found that multisensory stimuli are more pronounced later in childhood and this ability increases working memory capacity as compared to visual and auditory-alone.

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