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*Corresponding author
Stephen Ntim, PhD, MPhil, MA, BEd
Professor
Faculty of Education
Catholic University of Ghana
P.O. BOX 363, Sunyani
Fiapre, Ghana
E-mail: stephenntim58@yahoo.com; stephen.ntim@cug.edu.gh

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Binary and Ternary Analogy by Children: Testing the Role of Insufficiently Developed Working Memory Capacity (WMC) Executive Functions

Stephen Ntim, PhD, MPhil, MA, BEd*; Mavis Okyere, MPhil, BEd

Faculty of Education, Catholic University of Ghana, P.O. BOX 363, Sunyani, Fiapre, Ghana

ABSTRACT

Background: Ghanaian classroom teachers face consistent challenges asking children to relate classroom interactions with the development of connected thinking in areas such as mathematical proficiency and reading comprehension. Inculcating inference-making ability in children places a cognitive burden on the executive control of the working memory capacity (WMC). Therefore, the purpose of this study was to examine the relationship between WMC and executive function, with specific reference to how inhibition as executive control influenced active retrieval and goal maintenance in the context of analogy distraction making.
Method: Two hundred and eighty-nine kindergarten and primary school children aged between 3-11 years participated in this study. Subjects were tested on four variables on binary and ternary analogy making with distractions.
Results: Even younger children were capable of attending to and making mapping relations. However, they were less likely to overcome misleading object surface similarity and to maintain relational structure especially when an additional level of complexity was imposed.
Conclusion: This was attributed to insufficiently develop executive function constraints, especially inhibition, which was identified as the predicting cause of children's difficulty in binary and ternary analogies.

KEY WORDS: Analogical reasoning; Relational complexity; Error pattern.

ABBREVEATIONS: WMC: Working Memory Capacity; EC: Executive Control; WM: Working Memory; EF: Executive Functions.

INTRODUCTION

Problem-solving along with innovative and adaptive thinking have been perceived to be the core attributes of this millennium.[1] This is largely due to the fact that contemporary global demands from the labor market are increasingly becoming more complex unlike the recent past. The implication is that job recruitments require complex skills, for which children today can no longer be taught with the teacher-centered, lecture approach methods which often fail to assist children to be critical thinkers, problem solvers, innovative and inductive reasoners, or generate hypotheses and test them in order to discover new knowledge. Thus, the knowledge required to drive the present job market is one that has the following two fundamental attributes: a) Knowledge that is essentially inductive and analytical in reasoning; b) Knowledge that supports formulating hypothesis and drawing plausible inferences.[2,3] The ability to reason analogically, to be creative and adaptive and the ability to exhibit a general intelligence constitutes the hallmark of the human species as compared to the chimpanzee.[2,4-7] This fact supports the possibility that one can apply one's knowledge in different contexts. In this respect, helping children to develop analogical thinking is critical especially when many classroom teachers generally have consistent challenges asking children to link classroom interactions to develop

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connected thinking.

Theoretical Framework/Literature Review

What is an Analogy?

The English word analogy is derived (from Greek word ἀναλογία, analogia, "proportion"). It is a cognitive process by which information or meaning is transferred from a particular base (the analogue or source) to another (the target), or a linguistic expression corresponding to such a process. It has been perceived to be at the nucleus of human cognition. In this respect, analogy-making can be defined as the ability to see two or more non-identical objects or situations as being the "'same' at some level of abstraction. For instance, analogy-making is central to teaching students concept formation, categorization and recognition, especially in subject areas such as mathematics, science, and reading comprehension. Children learn to recognize examples of categories such as "dog" or "cat". Even though different dogs often look very different from each other, yet, these differences notwithstanding, children perceive some essential sameness at an abstract level and can differentiate a dog from a cat. Similarly, children not only learn to recognize cats and dogs in books but also in real life, even though on the surface, such images are very different from one another and from the corresponding real-life creatures. Hofstadter[8] explained that even the ability to recognize the letter 'A' in many different type faces and handwritings requires a highly sophisticated analogy-making ability.

Theoretically, an analogy could be conceived as a general cognitive ability of transferring knowledge from a source (a base) to a target. In this sense, it helps people to close a representational gap in a new task (target) by transferring relevant elements from a familiar task referred to as source. Almost three decades after Gentner[9] began pioneering theoretical work in this area, many empirical studies have been conducted including computational models at the beginning of this millennium.[10,11] Gentner consistently highlighted the critical role of relational structure between target and source rather than surface similarities. Empirical findings in analogy making suggest that individual differences exist in both analogy inference and general abstract reasoning. Over the years, testing analogical reasoning was considered one of the best measures of general mental ability[12] (the *g* factor).

Theories of Analogical Development

Piaget and collaborators[13] were among the pioneers to conduct studies on analogies. Their findings showed that children below 7-years were more likely to make more errors on formal analogical problems. Their contention was that children consistently and successfully completed analogies after the onset of adolescence. Thus, for Piaget and collaborators, competency in analogies was developmental and hence age-related. In the middle part of the last century, Gentner[14] in her structure mapping theory explained that analogy is the mapping of systems of relations from a base domain to a target. In this relational shift, she claimed those children's analogical reasoning changes from being initially based on surface similarity of object attributes, to gradually including relational information between objects, to finally involving systems of relations. Additionally, in this relational shift, analogical competence also varied from domain to domain, suggesting that the crucial constraint on analogical development also has to do with domain knowledge that children have about relevant relations.[3,15] Contrary to the position of Piaget and collaborators, even much younger children could complete analogies if they had domain knowledge. Indeed, research findings have shown that even 4- and 5-year-olds; when they have sufficient knowledge of relations could complete analogies[16,17] that Piaget and collaborators had earlier suggested that they would fail.[13] Thus, Goswami[16] as well as Ratterman[17] drew similar conclusions that younger children when given the requisite domain knowledge were capable of analogical reasoning.

There was a further shift in the research work on analogies from the age-related competency of Piaget and collaborators, and from the relational shift of Gentner, to focus on the link between developmental age and working memory capacity (WMC) in the late 1990's. Authors such as Halford[18] postulated that changes on analogical reasoning were a reflection of increased working memory capacity. The implication is that the underlying constraints with the age factor in children's analogy making suggested challenges with relational complexity that could be processed in parallel, given the limited capacity and duration of the working memory (WM).

Hypotheses on Analogical Development

Three major hypotheses have been proposed in the literature to explain differences in analogical reasoning: a) The increased domain hypothesis by Goswami et al.[19] Findings from this hypothesis indicated that even four year old children can make analogies when they have some knowledge of relations; b) The relational shift hypothesis of analogical reasoning contends that before a certain level of development is achieved, children tend to focus on surface similarity between objects. It is only after this age, that analogical reasoning is assumed to be based on relational features[17,20]; and c) The relational complexity hypothesis of analogical reasoning mentions that changes in analogical-naming are contingent upon working memory capacity (WMC) constraints. It is these constraints that influence whether or not children are able to process multiple relations simultaneously.

Working Memory Capacity Constraints: Relational Complexity

This third explanation for developmental changes in analogical reasoning puts a premium on the constraints of children's working memory capacity within the context of relational complexity. Authors such as perceived this relational complexity in terms of the quantum or number of related variations that need to be processed in parallel.[21-26] For example, there are different kinds

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of mapping based on the number of relations. Unitary relations are predicates having only one argument. This corresponds to Gentner's[9] terms. Mapping, in this case, is based on one-place and predicates are validated by attribute similarity. This type of mapping is called relational mapping which is based on a two-dimensional structure, such as, A:B::C:D or Woman:Baby:: Mare:Foal. The validation here is by similar relation, namely, mother of in source and target. In addition to relational mapping, there is also system mapping. In this case, elements are mapped to ternary relations. At this level, there need not be any resemblance between the binary relations in the structures. In this respect, system mapping allows for a high degree of flexibility and abstraction. The reason for this high degree of flexibility and abstraction is that they could be used to establish correspondences between structures that have only format similarities. Additionally, this high level of flexibility and abstraction permit analogies to be recognized, but this recognition of analogies is obtained at the cost of higher information processing loads. Moreover, there are also multiple systems mapping which is based on a four-dimensional structure.

Linsey at al[22] examined some examples of these different types of mapping. For instance, they see a binary relation as one between two arguments, both of which are sources of variation. Thus, 'boy chases girl' specifies a single relation (chase) between two arguments (boy and girl). Similarly, a ternary relation includes three arguments as sources of variation as 'mom chases boy who chases girl.' It is on the basis of such metric relational complexity, that Halford[21] made a case for a developmental continuum in children's working memory capacity. This author's contention is that children are capable of processing binary relations (a relation between two objects) after 2 years of age, whereas ternary relations could be processed after 5 years. Other authors using the same relational complexity metric, but with some nuances in the context of 'cognitive complexity and control theory', have also identified similar age related developmental progressions. The difference between the present authors thinking and those mentioned above is that complexity is not defined in terms of numbers of relations or the number of hierarchical rules that children need to be able to accomplish a given task. For example, research has shown that 3- and 4-year-olds were more successful in performing separate sorting tasks than when they were required to switch between tasks, thus integrating these tasks with a higher order rule.[27,28] It is based on such empirical findings that some researchers make the hypothesis that change with age is a function of children's development of executive function and particularly their ability to perceive the relation between two rules in order to develop and use a higher order rule that integrates the rule pair.[29]

Working Memory Capacity and Executive Control

Working memory is a core concept for many theories of control of thought and action in cognitive psychology. Notwithstanding the disagreement among researchers regarding its specific definition, the working memory system is typically viewed as the cognitive architecture responsible for active maintenance and manipulation of information over a brief time period. It is considered as a part of a larger memory architecture, where information is perceived, attended to, and retrieved. The central executive is responsible for controlled processing in working memory, including, but not limited to the following: a) Directing attention, b) Maintaining task goals, c) Decision making, and d) Memory retrieval. Notably, other models of working memory also posit a central executive, or a common attention control mechanism similar to the central executive.

The above hypothesis of relational complexity is closely linked with working memory and executive control that is also recognized in the literature.[30-32] In other words, there is a link between WMC and the efficacy of executive control (EC). WM is a relatively basic (in comparison to reasoning) cognitive mechanism responsible for the active maintenance of information to promote its ongoing processing. Working memory capacity is usually defined as the maximum number of items (a span) that can be recalled or recognized immediately after a WM task. According to relational complexity theory,[18] the representation of a relation (conceptualized as a tensor product relational symbol and its arguments) grows exponentially as the number of interacting variables (i.e., vectors) needed to be processed in parallel rises, resulting in a decrease in processing accuracy.[23]

In this respect, perceived high-WMC individuals should be able to process more complex analogies, as their more capacious WM allows for more bindings (i.e., tensor products of more vectors) than does the WM of low-WMC individuals. To establish a relation between the representations, direct access to corresponding memory chunks is required; so WMC, operationalized as the number of chunks that can be directly accessed, provides a possible constraint on reasoning processes.[33] Another model explaining individual differences in analogical reasoning focuses on the constraints on one's ability to control one's cognitive processing. In instructional psychology, this is similar to cognitive strategies that are self-management strategies to distinguish between relevant and irrelevant information. Executive control is assumed to be responsible for the organization and co-ordination of these types of mental states and processes in accordance with the internal goals of an individual. The main functions of executive control in this type of cognitive process include active retrieval and maintenance of a goal in the face of distraction and interference, the updating of information actively held in the working memory, the inhibition of inadequate responses, and the capacity to shift between tasks. Considerable numbers of studies have shown that such processes significantly correlate with reasoning.[22-24,29]

Present Study

The underlying phenomenon assumed to implicate children's analogical inference from the above literature review is associated with the following: a) Increased domain knowledge, b) Relational shift, c) Relational complexity; and d) As a correlate to this third model, the link between working memory and executive control. The purpose of this study is to investigate this

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fourth dimension, namely, to measure the relationship between WMC and executive function with specific reference to the extent to which executive control, especially inhibition, influence active retrieval and goal maintenance in the context of analogy distraction and interference. In this study, we take the position that there is a common attention control factor that underscores executive control and WMC (analogy) tasks, even though, these different analogy tasks are also likely to be induced by specific abilities tied to a developmental age factor. Consequently, this study validates the hypothesis that for older age groups (9-11) as compared to younger ones, (3-7) there would be a significantly higher number of correct responses for ternary analogies. This hypothesis is based on empirical studies that show that younger children below the age of five were more successful in performing tasks separately or serially, but performed poorly when asked to switch between tasks to integrate tasks with higher order rules.[27-29]

RESEARCH METHODOLOGY

Sample

This study was performed using the purposive experimental sampling design from an estimated 289 kindergarten and primary school children aged between 3-11 years. These were randomly selected from four communities in two out of the ten administrative regions of Ghana: The Ashanti and the Brong Ahafo regions. In the Ashanti region, one hundred and forty-four children from two kindergarten and two primary schools were selected from the Kumasi Metropolis and Nkawie districts. In the Brong Ahafo region, another 145 children were sampled from another two kindergartens and two primary schools from Berekum and the Sunyani municipalities. The various age groups were in the following categories: There were ninety-six 3-4 year old children, there were ninety-eight 5-8 year old children and ninety-five 9-11 year old children. Participants were equally divided by sex. The demographic data of these children (not tabled here) mostly belonged to civil service, working class, self-employed, and farming parental backgrounds. Children recruited from Sunyani, Berekum, and Nkawie were all Ghanaians, whereas few of the children from the Kumasi Metropolis were of Lebanese and Nigerian parentage. All these children and their parents considered English as their second language. This study met all the specific requirements of the Faculty of Education of the Catholic University of Ghana's Institutional Review Board regarding ethical considerations in research. All children voluntarily participated after parental consent.

MATERIALS AND DESIGN

This study tested the sampled children on the basis of the following two measures: a) Relational complexity with specific reference to binary; and b) Ternary relations in scene analogy. They were tested on different scene analogies that involved fruits, animals, inanimate objects, and humans. All these were assumed to be familiar to the children selected for this study. The analogies were varied in four ways: a) The number of examples of relevant relations that needed to be mapped either in binary or ternary analogies were varied. The aim was to understand how these children would be able to figure out the correct inference from base analogy to target notwithstanding some distracters. For example, in a one-relation analogy, there is an inactive object (dog) watching a cat chasing a mouse. In the two-relation, on the other hand, the dog now becomes active by joining the cat to chase the mouse; b) As a control measure to ensure that the children's thought control processes within the WMC executive functions (especially inhibition) was on course, distractors and non-distractors such as a long pole were also included. For instance, extra objects that were either similar or dissimilar were made a part of the items to be mapped in the source; c) To ensure reliability and validity of the experiment, distracters were varied as much as possible between inanimate objects and non-inanimate objects; d) The scene analogies contained additional items that did not indicate the relevant relations. For example a dad reading to the girl who is reading to a teddy bear. They were asked to map this to a target: Mom is reading to a boy who is reading to the doll. In this scene, there was also a duster which had nothing to do with the relations.

Experiment

This experiment used scene analogy problems to seek some answers to the two research questions of this study, namely:

1. How do difficulties in binary and ternary relations influence analogy making among selected Ghanaian children?
2. Is analogical reasoning a function of the ability to integrate multiple relations, relational knowledge and inhibitory control over surface similarities?

Relations used in these scene analogies were assumed to be familiar to the children and used motional and other verbs known to them such as kiss, chase, feed.[22,27-30] Moreover, objects used in the analogies were those known to school children in Ghana.

Procedure

The procedure was as follows:

a. Children were given papers in which two pictures had the same pattern taking place; b) Children were instructed to determine the action occurring in the two pictures, even if they looked very dissimilar; c) They were given some examples before starting the mapping. For instance, they were shown a picture on the top with a two-relational pattern: A dad reading to the girl who is reading to a teddy bear. They were asked to map this to a target: Mom is reading to a boy who is reading to the doll. In all, children were given ten pairs of similar scene analogies but eight (8) pairs of analogies were actually tested due to fatigue on the part of respondents. Each pair was given a raw score of 25 points,

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making 200 points of 8 out of the 10 that were actually tested. These tested eight (8) pairs of analogies were randomized.

b. Children were asked to determine the correct answer by drawing a line from the base analogue to the target analogy. All the raw scores on the four variables were computed as mean and deviation scores.

RESULTS

The overall results in this experiment are suggestive of three fundamental factors as the underlying force of analogical reasoning among these selected children: a) Developmental age-related factor, b) The load of relational complexity; and c) The effect of distraction. As indicated in Table 1 above, the mean scores of the different age groups on the four variables were related to the number of analogies, the number of distractors, and age. Younger children aged between 3-4 years scored their highest mean of 50.84 (SD=2.564) when there was only one-relation with no distracters compared with their mean scores on one-relation with distracters of 33.94 (SD=2.508). The scores fell to 36.14 (SD=2.106) and 31.49 (SD=1.118) with a two-relation analogy with no distracters and a two-relation analogy with distractors, respectively. However, it was not exactly the same in the two other groups, namely 5-7 and 9-11 year age groups. Nevertheless, the scores of these two groups (that is 5-7 and 9-11) on one-analogy without distracters were relatively higher than their scores on two analogies without distracters. This seems to imply that the more the number of analogy, the lesser the scores. However, with the case of analogies with distracters, the pattern was not like that of the first group that is 3-4 year olds. Thus, for all the measures in the experiment, the underlying deciding factor that confirms the implication of analogical reasoning of these children whether in binary or ternary analogies, distraction and relational complexity, was undoubtedly the age factor.

Regarding the level of relational complexity (whether or not the analogy was binary or ternary), the data indicate that older children performed comparatively better when analogies were ternary than (compared to when they were binary) did younger children. For example, the 9-11 year olds on the measure of two-relation analogy with distracters performed relatively better with mean scores of 54.94 (SD=1.712), whereas 5-7 year olds scored 41.81 (SD=1.648) and 3-4 year group 31.49 (SD= 1.188). On ternary analogies, any time there was a distracter, the means decreased for all groups. This suggests that the more complex the analogy with distracters, the lower the scores; and b) The less complex the relation with no distracters, the higher the scores across the three age groups as indicated in the scores in Table 1. We interpreted this to be the main effect of distraction which was also indicative of two key patterns: Indicating two error patterns: a) Substantial effect of relational complexity: The more complex the analogy with distracters, the lower the scores; and b) The less complex the relation with no distracters, the higher the scores across the three age groups as indicated in the scores in Table 1.

Distraction as shown in Table 1 was more potent for younger children than it was for older ones. For example, in two-analogy with distraction, 3-4 year olds scored a mean of 36.14 (SD=1.188) compared with 46.14 (SD=1.759) for 5-7 year olds and 62.20 (SD=1.265) for 9-11 year olds, respectively. To test whether there was a statistically significant difference between the mean scores of the different age groups on the four variables: One-relation analogy with no distracter, one-relation analogy with distracters, two- relation analogy with no distracter, and two-relation analogy with distracter, one-way analyses of variance (ANOVA) were used. The results, as shown in Table 2, indicated statistically significant differences among the performances of the three age groups on the four variables.

To determine the appropriate post-hoc test among the means of the three age groups, Levene's test of equality of variances was computed and the results are shown in Table 3.

There was no statistical difference in variance with respect to performance on the first variable, namely, one-relation analogy with no distracter as indicated in the test for equality of variance shown in Table 3. Consequently, the variances were assumed to be equal, and so the Bonferroni post-hoc test was used

Table 1: Means of the Scores of the Different Age Groups on the Four Variables.

Age of participant		Scores on two- relation analogy with no distracter	Scores on two-relation analogy with distracter	Scores on one-relation analogy with no distracter	Scores on one-relation analogy with distracter
3-4	Mean	36.14	31.49	50.84	33.94
	N	96	96	96	96
	Std. Deviation	2.106	1.188	2.564	2.508
5-7	Mean	46.14	41.81	63.24	41.90
	N	98	98	98	97
	Std. Deviation	1.759	1.648	2.565	1.699
9-11	Mean	62.20	54.94	73.45	51.96
	N	95	95	95	95
	Std. Deviation	1.268	1.712	2.041	2.068
Total	Mean	48.10	42.70	62.48	42.56
	N	289	289	289	288
	Std. Deviation	10.846	9.690	9.528	7.662

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Table 2: One Way Analysis of Variance on the Scores of the Different Age Groups on the four Analogies.

		Sum of squares	Df	Mean square	F	Sig.
Scores on one-relation Analogy with no distractor	Between groups	24493.830	2	12246.915	2.117E3	.000
	Within groups	1654.316	286	5.784		
	Total	26148.145	288			
Scores on one-relation Analogy with distractor	Between groups	15570.449	2	7785.225	1.738E3	.000
	Within groups	1276.426	285	4.479		
	Total	16846.875	287			
Scores on two- relation analogy with no distractor	Between groups	33004.848	2	16502.424	5.410E3	.000
	Within groups	872.440	286	3.050		
	Total	33877.287	288			
Scores on two-relation analogy with distractor	Between groups	26368.277	2	13184.139	5.603E3	.000
	Within groups	672.927	286	2.353		
	Total	27041.204	288			

to test the differences between the mean scores of the three age groups on the first variable as shown below. The Games-Howell Post-Hoc test, however, was used to test the differences in the remaining three variables because the test revealed statistically significant differences among the variances of the three age groups. Thus, the variances of the three age groups on the three remaining variables were not equal.

The post-hoc tests in Tables 4 and 5 indicated that the older group (9-11year olds) scored significantly higher on all four variables compared to the other age groups. For instance, on 'one relation analogy with no distracter', the mean difference between the 9-11 year olds and the 3-4 year olds was 22.609, whereas between 9-11 year olds and 5-7 year olds, the difference is 10.208. The 5-7 year olds also did better on this variable than

Table 3: Test of Homogeneity of Variances.

	Levene Statistic	df1	df2	Sig.
Scores on one-relation Analogy with no distracter	2.799	2	286	.063
Scores on one-relation Analogy with distracters	5.490	2	285	.005
Scores on two- relation analogy with no distracter	9.794	2	286	.000
Scores on two-relation analogy with distracter	7.557	2	286	.001

Table 4: Bonferroni Post-Hoc Test on the First Variable.

Dependent Variable	(I) Age of participant	(J) Age of participant	Mean Difference (I-J)	Std. Error	Sig.
Scores on one-relation Analogy with no distractor	5-7	3-4	12.401*	.345	.000
	9-11	3-4	22.609*	.348	.000
	9-11	5-7	10.208*	.346	.000

The mean difference is significant at the 0.05 level.

Table 5: Games-Howell Post-Hoc Test on the Remaining Three Variables.

Dependent Variable	(I) Age of participant	J) Age of participant	Mean Difference (I-J)	Std. Error	Sig.
Scores on one-relation Analogy with distractors	5-7	3-4	12.401*	0.345	0.000
	9-11	3-4	22.609*	0.348	0.000
	9-11	5-7	10.208*	0.346	0.000
Scores on two-relation analogy with no distractor	5-7	3-4	10.007*	0.279	0.000
	9-11	3-4	26.065*	0.251	0.000
	9-11	5-7	16.057*	0.220	0.000
Scores on two-relation analogy with distractor	5-7	3-4	10.317*	0.220	0.000
	9-11	3-4	23.447*	0.213	0.000
	9-11	5-7	13.131*	0.242	0.000

The mean difference is significant at the 0.05 level.

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3-4 year olds. The mean difference was 12.401.

DISCUSSION

Critical to analogical reasoning undoubtedly, is the developmental age-related factor. However, this does not necessarily imply that younger children are less likely to reason analogically until adolescence. The data in the above experiment also suggest that even much younger children were able to do some of the less complex analogies except, that they attended more too surface/featural distractions. This is a possible implication of WMC executive functions especially inhibition. Much younger children appeared to have been constrained mentally, especially in parallel processing, as a result of mental load. This in our view is interpreted as giving plausibility to the relational complexity theory[18] with respect to the efficiency in processing mental load. The abysmal performance of much younger children in more complex analogies with distractions may have been precipitated by inhibitions which *de facto* suggest that the representation of a relation (conceptualized as a tensor product of relational symbol and its arguments) grows exponentially as the number of interacting variables (i.e., vectors) that need to be processed in parallel rises, thus resulting in a decrease in processing accuracy.[23]

The findings of this study corroborate several recent research findings positing that, although knowledge of relations is necessary to do analogies, executive functions are also involved in solving analogical problems. Younger children in this study were familiar with the objects used in the analogy. Their decreased processing accuracy, however, could not be attributed to lack of domain knowledge. The more plausible explanation is likely to be due to insufficiently developed executive functions. This thesis confirms the findings of Thibaut,[34] and Linsey[22] indicating that younger children's difficulties with analogy making are due to insufficiently developed executive functions, specifically inhibition. Additionally, the findings of this paper also strengthen recent studies showing that these processes largely depend on working memory functions.[35-39] Given the fact that older children perform better than younger ones in all of the measured variables, one can assume that the better performance of older children relative to younger children is due to better management of the working memory capacity. Thus, one can infer that the older the one grows, the better the one develops WMC functions. Hence, older children process mental load more effectively than the younger ones.

The findings also confirm those research studies in the area of WMC that postulate the theory of the number of chunks that can be directly accessed.[21-26] The number of variations provides possible constraints on reasoning processes.[33] This implies that high-WMC individuals (typical with older children) should be able to process more complex analogies. This is because their more capacious WM allows for more bindings (i.e., tensor products of more vectors) than does the WM of low-WMC individuals (typically with much younger children). Moreover, findings by Kroger[40] and Waltz[41] support the idea that the ability to map multiple relations in an analogy is linked to working memory capacity and the prefrontal context. That idea is corroborated by the findings in this study. Thus, the increase in capacity to cope with relational complexity[21,29] would be expected to lead to increased analogical ability. The findings in this study support this assertion in the sense that, decreased capacity to cope with relational complexity especially given two or more analogies, led to decreased analogical ability across the three age groups.

CONCLUSION

This study sought to seek answers to two questions: a) How do difficulties in binary and ternary relations influence analogy making among selected Ghanaian children; and b) Is analogical reasoning a function of the ability to integrate multiple relations, relational knowledge, and inhibitory control over surface similarities? The findings of this study provide support for the relational primacy hypothesis in analogical reasoning. That is, children have the capability to attend to and make mapping relations. However, they are less likely to overcome misleading object surface similarity and are also less likely to maintain relational structure, especially when an additional level of complexity is imposed. This underscores what has been established in other studies, namely that children can attend to any analogy provided it is within their knowledge base and working memory capacity, and not so much on age per se.[9,14,16,17] Even though, some of the data in this study are consistent with the age-related factor as underscored many years back by Piaget, it is also evident from this study that besides the age-related factors, working memory capacity executive functions, such as inhibitory factors, including the level of development of certain parts of the brain also mediate analogy making. Therefore, in predicting analogical reasoning in children, WMC executive functions are also critical.

DEFINITION OF TERMS

WMC: Working Memory Capacity: A core executive function, of the cognitive system with a limited capacity and duration. It is responsible for the transient holding, processing, and manipulation of information.

Working Memory: It is the part of short-term memory which is concerned with immediate conscious perceptual and linguistic processing. In the area of computing, it is an area of high-speed memory used to store programs or data currently in use. Working memory is an important process for reasoning and the guidance of decision making and behavior.

EF: Executive Functions: It isalso known as 'cognitive control' and 'supervisory attentional system' They are a set of cognitive processes-including attentional control, inhibitory control, working memory, and cognitive flexibility, as well as reasoning, problem solving, and planning -that are necessary for the cognitive control of attention, comprehension monitoring especially in parallel processing.

Inhibition: Inhibition in cognitive psychology refers to the mind's

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ability to tune out stimuli that are irrelevant to the task/process at hand or to the mind's current state. Cognitive inhibition can be done either in whole or in part, intentionally or otherwise. Cognitive inhibition in particular can be observed in many instances throughout specific areas of cognitive science.

Parallel Processing: Parallel processing is a method of simultaneously breaking up and running program tasks on multiple microprocessors, thereby reducing processing time. Parallel processing may be accomplished *via* a computer with two or more processors or *via* a computer network. Parallel processing is also called parallel computing. It is used in cognitive psychology especially in information processing theory of learning to refer to the ability of simultaneously attending to multiple information (simultaneously in a given time) without losing track of thought and attention and in so doing saving resources in the working memory. This is opposed to serial processing where information is processed single by single and therefore spending more time and resources in the working memory.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. National Research Council. *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century*. Washington, DC, USA: The National Academies Press; 2012.

2. Gentner D. Bootstrapping the mind: Analogical processes and symbol systems. *Cogn Sci*. 2010; 34(5): 752-775. doi: 10.1111/j.1551-6709.2010.01114.x

3. Cattell RB. *Abilities: Their Structure, Growth, and Action*. Boston, USA: Houghton Mifflin; 1971.

4. Sternberg RJ. *The Nature of Creativity: Contemporary Psychological Perspectives*. New York, NY, USA: Cambridge University Press; 1988.

5. Boysen ST, Berntson GG. Numerical competence in a chimpanzee (Pan troglodytes). *J Comp Psychol*. 1989; 103(1): 23-31. doi: 10.1037/0735-7036.103.1.23

6. Markman AB, Wood K. *Tools for Innovation: The Science Behind the Practical Methods That Drive New Ideas*. New York, NY, USA: Oxford University Press; 2009.

7. Penn DC, Holyoak KJ, Povinelli DJ. Darwin's mistake: Explaining the discontinuity between human and nonhuman minds. *Behav Brain Sci*. 2008; 31(2): 109-178. doi: 10.1017/S0140525X08003543

8. Hofstadter DR. *Metamagica Themas*. New York, USA: Basic Books; 1985.

9. Gentner D. Structure-mapping: A theoretical framework for analogy. *Cogn Sci*. 1983; 7(2): 155-170. doi: 10.1207/s15516709cog0702_3

10. Holyoak KJ, Gentner D, Kokinov BN. Introduction: The place of analogy in. cognition. In: Gentner D, Holyoak KJ, Kokinov BN, eds, T*he Analogical Mind: Perspectives from Cognitive*. Cambridge, MA, USA: 2001: 1-9

11. Kokinov B, French RM. Computational models of analogy-making. In: Nadel L. ed. *Encyclopedia of Cognitive Science. London*. UK: Nature Publishing Group; 113-118.

12. Snow RE, Kyllonen CP, Marshalek B. The topography of ability and learning correlations. In: Sternberg RJ, ed., *Advances in the Psychology of Human Intelligence Hillsdale*. NJ: Erlbaum 1984: 47-103.

13. Piaget J, Montangero J, Billeter J. La formation des correlats. In: Piaget J, ed. *RecherchessurL' abstraction Reflechissante I.* Paris: Presses Universitaires de France; 1977: 115-129

14. Gentner D. Structure-mapping: A theoretical framework for analogy. *Cogn Sci*. 1983; 7(2): 155-170. doi: 10.1207/s15516709cog0702_3

15. Gentner D. The mechanisms of analogical learning. In: Vosniadou S, Ortony A, eds. *Similarity and Analogical Reasoning*. New York, USA: Cambridge University Press; 1989: 199-241.

16. Goswami U, Brown AL. Melting chocolate and melting snowmen: Analogical reasoning and causal relation. *Cognition*. 1989; 35(1): 69-95. doi: 10.1016/0010-0277(90)90037-K

17. Rattermann MJ, Gentner D. More evidence for a relational shift in the development of analogy: Children's performance on a causal-mapping task. *Cogn Devel*. 1998; 13(4): 453-478. doi: 10.1016/S0885-2014(98)90003-X

18. Halford GS, Wilson WH, Phillips S. Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behav Brain Sci.* 1998; 21(6): 803-864. Web site. https://www.cambridge.org/core/journals/behavioral-and-brain-sciences/article/processing-capacity-defined-by-relational-complexity-implications-for-comparative-developmental-and-cognitive-psychology/D2388E89B8614A0605D9EE55C6E47F18. Accessed March 4, 2017.

19. Goswami U, Leevers H, Pressley S, Wheelwright S. Causal reasoning about pairs of relations and analogical reasoning in young children. *Br J Dev Psychol*. 1998; 16(4): 553-569. doi: 10.1111/j.2044-835X.1998.tb00771.x

20. Rattermann MJ, Gentner, D. The effect of language on similarity: The use of relational labels improves young children's

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performance in a mapping task. In: Holyoak K, Gentner D, Kokinov B, eds. *Advances in Analogy Research: Integration of Theory and Data from the Cognitive, Computational, and Neural sciences*. Sophia, Bulgaria: New Bulgarian University; 1998: 274-282.

21. Halford GS. *Children's Understanding: The Development of Mental Models*. Hillsdale, NJ, USA: Lawrence Erlbaum; 1993.

22. Linsey ER, Robert GM, Keith JH. Children's development of analogical reasoning: Insights from scene analogy problem. *J Exp Child Psychol*. 2006; 94(3): 246-273. doi: 10.1016/j.jecp.2006.02.002

23. Halford GS, Baker R, McCredden JE, Bain JD. How many variables can humans process? *Psychol Sci*. 2005; 16: 70-76. Web site. http://journals.sagepub.com/doi/abs/10.1111/j.0956-7976.2005.00782.x. Accessed March 4, 2017.

24. Andrews G, Halford GS. A cognitive complexity metric applied to cognitive development. *Cogn Psychol*. 2002; 45(2): 153-219. doi: 10.1016/S0010-0285(02)00002-6

25. Andrews G, Halford GS, Bunch KM, Bowden DJ. Theory of mind and relational complexity. *Child Development.* 2003; 74(5): 1476-1499. doi: 10.1111/1467-8624.00618

26. Halford GS, Andrew G, Daltoin C, Boag C, Zielinski T. Young children's performance on the balance scale: The influence of relational complexity. *J Exp Child Psychol*. 2002; 81(4): 417-445. doi: 10.1006/jecp.2002.2665

27. Frye D, Zelazo PD, Brooks PJ, Samuels MC. Inference and action in early causal reasoning. *Developmental Psychology.* 1996; 32(1): 120-131. doi: 10.1037/0012-1649.32.1.120

28. Zelazo PD, Frye D. Cognitive complexity and control: The development of executive function. *Curr Dir Psychol Sci*. 1998; 7: 121-122. Web site. http://journals.sagepub.com/doi/abs/10.1111/1467-8721.ep10774761?journalCode=cdpa. Accessed March 4, 2017.

29. Zelazo PD, Muller U. The balance beam in the balance: Reflections on rules, relational complexity, and developmental processes. *J Exp Child Psychol*. 2002; 81(4): 458-465. doi: 10.1006/jecp.2002.2667

30. Holyoak KJ, Gentner D, Kokinov BN. Introduction: The place of analogy in. cognition. In: Gentner D, Holyoak KJ, Kokinov BN, eds. *The Analogical Mind: Perspectives from Cognitive*. Cambridge, MA, USA: MIT Press; 2001: 1-19.

31. Kokinov B, French, RM. Computational models of analogy-making. In: Nadel L, ed. *Encyclopedia of Cognitive Science*. London, UK: Nature Publishing Group; 2003: 113-118.

32. Snow RE, Kyllonen CP, Marshalek B. The topography of ability and learning correlations. In: Sternberg RJ, ed. *Advances in the Psychology of Human Intelligence*. Hillsdale, NJ, USA: Erlbaum; 1984: 47-103.

33. Oberauer K, Süß HM, Wilhelm N. Individual Differences in working memory capacity and reasoning ability. In: Jarrold C, ed. *Variation in Working Memory*. USA: Oxford University Press; 2007: 49-75.

34. Thibaut JP, French RM, Vezneva M. Cognitive load and analogy-making in children: Explaining an unexpected interaction. *Proceedings of the Thirty-first Annual Cognitive Science Society Conference*. 2009: 1048-1053.

35. Thibaut JP, French RM, Vezneva M. The development of analogy making in children: Cognitive load and executive functions. *J Exp Child Psychol*. 2010; 106(1): 1-19. doi: 10.1016/j.jecp.2010.01.001

36. Thibaut JP, French RM, Vezneva M. Cognitive load and semantic analogies: Searching semantic space. *Psychon Bull Rev*. 2010b; 17(4): 569-574. doi: 10.3758/PBR.17.4.569

37. Thibaut JP, French RM, Vezneva M, Gérard Y, Glady Y. Semantic analogies by young children: Testing the role of inhibition. In: Kokinov B, Karmiloff-Smith A, Nersessian NJ, eds. *European Perspectives on Cognitive Science*. Sofia, Bulgaria: New Bulgarian University Press; 2011.

38. Morrison RG, Thinking in working memory. In: Holyoak KJ, Morrison RG, eds. *Cambridge Handbook of Thinking and Reasoning*. Cambridge, UK: Cambridge University Press; 2005: 457-473.

39. Morrison RG, Holyoak KJ, Truong B. Working memory modularity in analogical reasoning. In: Gray WD, Schunn CD, eds. *Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society.* Mahwah, NJ, USA: Lawrence Erlbaum; 2001: 663-668.

40. Waltz JA, Lau A, Grewal SK, Holyoak KJ. The role of working memory in analogical mapping. *Mem Cognit*. 2000; 28(7): 1205-1212. doi: 10.3758/BF03211821

41. Kroger JK, Sabb FW, Fales CL, Bookheimer SY, Cohen M, Holyoak KJ. Recruitment of anterior dorsolateral prefrontal cortex in human reasoning: A parametric study of relational complexity. *Cerebral Cortex*. 2002; 12(5): 477-485. doi: 10.1093/cercor/12.5.477