AN OUNCE OF GOLD WILL NOT BUY AN INCH OF TIME

A study of the neurological processes governing time, space and quantity

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This study examines the relationships between the perceptions of time, space and quantity, in regards to the findings by Walsh (2003) and the theoretical framework that is *A Theory Of Magnitude* (ATOM). We hope to find similar correlations to those shown in previous studies, as it would further support the existence of a centralized neurological system of magnitudes. This system is also believed to be closely linked with dyscalculia. The study consists of two parts, with the first measuring the correlation between time, space and quantity, using two classical tasks and two newly developed ones. The second part of the study is a replication of an experiment conducted by Fabbri *et al.* (2012), measuring these same magnitudes and their interrelating effects. The correlation experiment yielded only a single significant correlation: that between the modalities of quantity and space. In our replication experiment, any significant results were conspicuously absent. Our results leave a persistent uncertainty towards the existence of a centralized neurological system of magnitudes.

Introduction

In 2003, numerous findings in the field of *numerical cognition* were compiled into an over-arching theory by the name of ATOM, or *A Theory Of Magnitude*. Its originator, Vincent Walsh, contended the existence of a centralized neurological system of magnitudes, where the perceptions of time, space and quantity are ”linked by a common metric for action” (Walsh, 2003, p. 484).

The abilities believed to originate from this system, such as arithmetic proficiency and the ability to perceive time and object sizes, have been linked to *dyscalculia* – a neurological disability where such abilities are greatly diminished. These abilities feature regularly in everyday life, and their impairment poses considerable problems for an individual affected by dyscalculia. For instance, regular tests of intelligence usually constitute tasks of a numerical nature, creating a false impression of dyscalculics as less intelligent, rather than acknowledging their impairment of such cognitive domains.

Purpose

The purpose of this study is to examine the cognitive abilities thought to be present in the processing of magnitudes. In line with ATOM, we consider these abilities to be part of a centralized system; a hypothesis we wish to evaluate by performing a correlation experiment, and a replication of an experiment that has previously proven to produce significant results on the matter.

Theoretical Background

In 1974, psychologist Ladislav Kosc presented the first study employing a systematic approach in the exploration of dyscalculia. 66 children showing signs of dyscalculia, but otherwise well within normal IQ-levels, participated in the study, which subsequently served to demarcate the disorder as ”specific arithmetic learning difficulties” (Butterworth in Campbell, 2005, p. 457).

Studying dyscalculia in regards to arithmetic abilities has since proven to be insufficient. A multitude of studies have shown that these math-related deficiencies merely play a small part in a larger system of numerical, cognitive abilities (*Ibid*., p. 459). This has proven to be true in studies employing numerical discrimination tasks, where individuals suffering from dyscalculia have been shown to count rather than estimate the number of dots presented on a screen (*Ibid*.).

ATOM proposes three distinct effects to arise as a result of the proposed general magnitude system. The *SNARC* effect (Spatial-Numerical Association of Response Code), showing an interrelation in the processing of space and numbers; the *STEARC* effect (Spatial-Temporal Association of Response Code), showing an interrelation in the processing of space and time; and, finally, the *TiNARC* effect (Temporal-Numerical Association of Response Code), where time and numbers show interrelated effects. These effects manifest themselves in such experimental paradigms as the *conflict paradigm*, where two interrelated modalities in the system of magnitudes are employed simultaneously, in the same task, serving to either enhance or decrease overall performance. Evidence of the SNARC and STEARC effect has later been shown in Fabbri *et al.* (2012), with indications of an existing, albeit weak, TiNARC effect (pp. 121-22).

Other studies, such as Dormal and Pesenti (2007), show conflicting evidence regarding these three effects. Evidence seems to point to an asymmetry in the interactions of time, space and numbers – causing different levels of correlation depending on which of the three modalities dominate a certain task. Dormal and Pesenti found that overall performance decreased when spatial stimuli interfered in numerical processing tasks. However, this was not the case for number-based stimuli interfering in tasks of a spatial nature (Bueti & Walsh, 2009, p. 1833). This discrepancy seems to indicate a stronger relationship – and thus, a stronger need for a joint system processing – between space and time. This effect, however, doesn’t hold for the seemingly equivalent relationship between time and space. Consequently, these results show that ATOM may very well be fundamentally flawed.

Today, few scientists in the discipline of numerical cognition contend the idea of a magnitude system. Several studies have shown, at the very least, *some* interaction between the different modalities believed to be part of this system. Questions still linger as to how interdependent these modalities are and if they, in fact, affect one another as strongly as ATOM would have us believe.

Method

This study consists of five separate tasks assessing relations between the modalities of time, space and quantity. These tasks are divided into two separate experiments, one measuring correlations between tasks of quantity, mental rotation, and estimation of volume and time (Experiment 1); the second serving as a replication of a recent experiment by Fabbri *et al*. (2012), where interrelated effects of time and space were most notably shown (Experiment 2). Our hope is to further corroborate these interrelations by replicating this study.

Experiment 1

The experiment was conducted on the premises of Linköping University and took approximately 40 minutes to finish.

Participants

30 students (N = 30), of which 20 were women, participated in the experiment in exchange for a cinema ticket. The participants had a mean age of 23 years (SD = 1,76) based on information from 25 participants.

Numerical discrimination task

In this computerized test, the participant was to determine which group of differently colored dots were in majority. The two groups were distinguishable by their color, either blue or yellow, and were separated along an imaginary middle line on the screen (figure 1). They were displayed in various configurations of quantities, for a total of 600ms per trial. The keys "F" and "J" – representing the left and right hand side respectively – were then used in answering which side of the screen had displayed the largest amount of dots. The test used was *Panamath*, a well-known numerical discriminations test program used in many previous studies. The dependent variable is a Weber fraction.

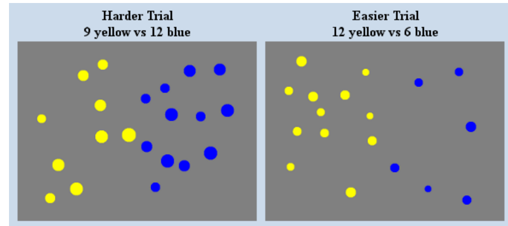

Figure 1. Two trials, one hard and one easy, of the numerical discrimination task.

Mental rotation task

This pen-and-paper-based test required the participants to assess and compare four images of different three-dimensional objects to an image of a similar-looking reference object. Two of these four objects were merely rotated variations of the reference object, while the other two were geometrically different (Figure 2).

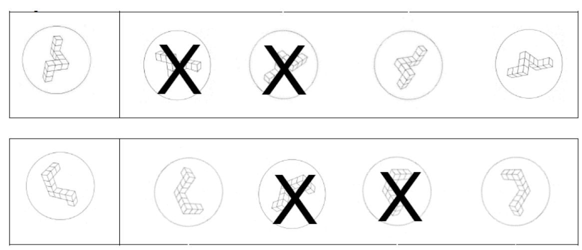

Figure 2. Two trials of the mental rotation task, with the correct answers marked.

The participant was to determine which two were the same – albeit rotated – as the reference object, and mark these with a cross. The participant was allowed four minutes to complete as many of the 16 assessments as possible. The dependent variable is the number of correctly answered assessments. Both correct answers were required for the assessment to count as correct.

Time discrimination task

In this computerized test the participant was shown two balls in succession, one blue and the other red. The balls were displayed in any configuration of the following durations: 1500, 2250, 2400, 2500, 2625, 3000, 3428, 3600, 3750, 4000, 6000ms. Each possible configuration, with an exception of two equal values, was displayed once and in random order. The participant was to determine which of the two balls had been displayed for the longest duration. Two keys on the keyboard were designated for this test, and featured correspondingly colored stickers on top. The dependent variable is the number of correct answers.

Volume estimation task

In this computerized test the participant was shown images of three objects, either cubes or spheres, next to a container of either cubical or cylindrical shape, respectively (Figure 3). The participant was to determine whether or not the three objects would fit in the container. It was reckoned that the three smaller objects fit, if an imaginary lid could be placed upon the container without anything sticking out.

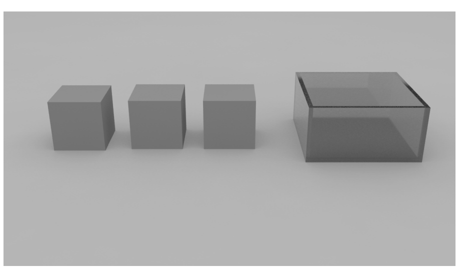

Figure 3. A trial of the volume estimation task. Will the objects fit in the container?

The participant provided an answer by pressing the “y” or “n” key on the keyboard. The image was shown until the participant had provided an answer. In between showing each image, a white-noise image was displayed on screen. The participant was required to consider a total of 48 images, of which half were mirrored copies of their counterparts. The dependent variable is the number of correct answers.

Experiment 2

The experiment was conducted on the premises of Linköping University and took approximately 20 minutes to finish.

Participants

10 students (*N* = 10), of which 3 were women, participated in the experiment in exchange for a cinema ticket. The participants had a mean age of 22 years (*SD* = 1,53) based on information from 7 of the participants.

Combined time discrimination task

In this computerized test, the participant was to determine whether the duration of a target stimulus was shorter or longer than that of a reference cue. The reference cue was either the number “5” or the letter “E”, and was displayed for 400ms. A blank screen, appearing for 700-800ms, followed. The target stimulus was one of numbers 1, 2, 8 or 9, or letters A, B, H or I. The stimulus was displayed in either 200 or 300ms, which counts as short durations, or 500 or 600ms, which counts as long durations. A response screen followed – one with nothing but a question mark centered on screen – at which the participant was supposed to input his or her answer. This response screen did not disappear until an answer was given.

If the participant regarded the target stimulus as shorter in duration compared to the reference cue, the answer was given by using the “A” key. If, on the contrary, the stimulus was regarded to have been shown for a longer amount of time, the “*” key was used. The participant was to use the left hand when pressing the “A” key and the right hand when using the “*” key, as well as keep both hand on the keyboard at all times. This was repeated 128 times whereupon the keys were reversed and the same procedure was repeated another 128 times. The dependent variables are short as well as long durations, for both left and right hand, respectively.

Results

A significant correlation was found when comparing the results of the mental rotation task and the number discrimination task, $r = -0,462$; $p = 0,015$. No other, statistically significant correlations were found in the first experiment, as depicted in table 1.

Table 1. Correlations in experiment 1

		Quan.	Time	Vol.
1. Quantity	Pearson Correlation			
	Sig. (2-tailed)			
2. Time	Pearson Correlation	-,108		
	Sig. (2-tailed)	,590		
3. Volume	Pearson Correlation	,153	-.354	
	Sig. (2-tailed)	,446	,055	
4. Mental	Pearson Correlation	-,462*	,200	-,219
Rotation	Sig. (2-tailed)	,015	,289	,245

* $p < 0,05$

Table 2 depicts the mean values and standard deviations gathered in three parts of the first experiment. Reaction times have no significant effect on the overall correlation and are thus presented for purely informative purposes.

Table 2. Mean values and standard deviations for reaction times (ms) in experiment 1.

	Standard deviation	Mean value
Quantity	316,264	915,487
Time	408,062	964,203
Volume	1392,817	2830,825

Tables 3 and 4 show the data from experiment 2, which was then utilized in a repeated two-way ANOVA. The experiment rendered no statistically significant results.

Table 3. Mean values and Standard Deviations for reaction times (ms) in experiment 2.

	M	SD	N
SD, right hand	870,002	332,177	10
SD, left hand	1014,774	457,681	10
LD, right hand	974,798	548,111	10
LD, left hand	890,870	363,479	10

SD: Short Duration; LD: Long Duration

Table 4. Results extracted from a repeated two-way ANOVA.

	SS	df	MS	F	p
Time	912,808	1	912,808	,021	,889
Hand	9255,285	1	9255,285	1,172	,207
Time*Hand	130758,310	1	130758,310	1,95	,268

Discussion

Guided by ATOM and a handful of studies indicating the existence of the effects predicted by Walsh – *STEARC*, *SNARC,* and *TiNARC* – we expected to find definitive proof in the form of consistent and correlating overall performance. Alas, our correlation experiment only generated significant correlations when comparing the results of the tasks involving mental rotation and number discrimination – that is, the modalities of space and quantity. Of importance, however, is the questionable validity of the tasks for volume and time estimation, both of which have never before been performed in this exact fashion. The results, which may or may not be inconclusive, nevertheless give rise to doubts regarding the acuity of ATOM. Our second experiment rendered no significant correlations whatsoever, instilling some assurance to the results presented in the first experiment.

Our current results and their conflicting nature with other, major studies on the subject, indicate that some extraneous problems may have occurred during the process of preparing or performing the experiments and the subsequent data analysis. These problems may originate from such things as duration of stimuli, number of trials, incoherent instructions or a shortage of participants needed to generate significant results.

On a positive note, the correlations we indeed *did* find show *some* relationship between various modalities of numerological cognition. However, their degree of interrelation is yet to be established and requires further investigation.

Acknowledgements

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