Intuitive Number Evaluation Is not Affected by Information Processing Load

Zohar Rusou, Dan Zakay and Marius Usher

Abstract Numbers play a major role in decisions about vital life issues. This study compared the relative advantage of analytical vs. intuitive numerical processing in numerical average evaluations, while varying information load, complexity of the task and the information presentation formats. Thinking manipulation was based on Dehaene's [5] model, which postulates two pathways for the numerical processing. The complexity level of the task was manipulated by varying the number of items to be averaged. The information presentation format were simultaneous vs. sequential. When few numbers were presented, analytical evaluations were more accurate. When task complexity increased and a sequential presentation was used, intuitive evaluations were more accurate. The results challenge the common position that analytical thinking is always advantageous in numerical evaluations, suggesting instead that the relative efficiency of each thinking mode is mediated by task's factors. The cognitive mechanisms that might underlie our results are discussed.

Keywords Analytical thinking · Decision making · Dual process theories · Intuitive thinking · Numerical cognition

1 Introduction

Nowadays, the importance of numerical information processing in judgment and decision making is increasingly acknowledged by decision making researchers. Numerical information is ubiquitous in the decisions that guide our lives and

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decision quality depends critically on the ability to make effective numerical evaluations [1]. In the field of health—numerical information is almost impossible to avoid: ranging from the cholesterol content noted on a cereal box to the effectiveness of cancer treatments that is expressed as survival rates. Numerical value-integration is at the core of decision and evaluation processes [2]. Such processes are evident when we have to decide between (or evaluate) alternatives (e.g., apartments) that vary on a number of dimensions [3], or when we select between monetary rewards based on a series of returns [4]. The prevalence of numerical information in decision making—calls for the identification of strategies (or pathways) to improve the processing of numerical information.

Research in the field of numerical cognition suggests that there are two parallel and largely distinct number-processing pathways: (a) a symbolic pathway that is used for the sequential application of arithmetic operations, and (b) an implicit pathway, in which Arabic numerals are rapidly and automatically translated from their digital code into a quantity code on a "mental number line" and then processed in the same way as other physical magnitudes such as size or weight [5–7]. The notion of two processing pathways is broadly compatible with the distinction between analytical and intuitive thinking. The symbolic pathway is compatible with analytical thinking which is considered to be rule based, explicit and requiring a high working memory capacity, whereas the analog pathway is compatible with intuitive thinking, which is considered as occupying a position between the automatic operations of perception and deliberate reasoning, and as less demanding [8–15]. To illustrate the distinction between the two number-processing pathways—consider, for example, how people know how much time it takes them to drive home from work. One possibility is to calculate the driving time by summing the total time they spent driving, and then divide the total amount by the number of journeys (symbolic pathway). However, most people will not undertake such a calculation. Yet, after few driving experiences they develop a hunch on the average time it takes (implicit pathway.

The above contention of distinct analytical and intuitive number processing pathways raises the question of whether and when each thinking mode (pathway) is more likely to lead to better numerical processing [16]. The common stance among researchers is that, in numerical judgment tasks, the analytical thinking mode dominates [9, 17]. Even some researchers that advocate the intuitive mode of decision making, embrace this position and maintain that explicit analytical deliberation and strict adherence to rules are mandatory for symbolic numerical operations [9, 18]. The dominance of the analytical mode in numerical processing has been relatively unchallenged, as only few studies directly compared intuitive and analytical numerical evaluations [16], and most of the studies that have actually contrasted the two thinking modes on the same numerical evaluation tasks have found that analytical deliberation leads to more accurate evaluations [19–23]. Yet, some researchers highlight the importance of numeric intuition. For example, the Fuzzy Trace Theory (FTT) has directly challenged the supremacy of analytical numerical processing. According to FTT intuition (gist representations) is more advanced developmentally compared to analytical thinking (verbatim representations) and that reliance on gist often seems to improve judgment and decision making when precise responses (e.g., point estimates) are not required [13, 24, 25]. Similarly, Peters et al. [1], asserts that mental-number-line representations seems to guide decision making. In line with these assertions, recent findings, demonstrate powerful and fairly accurate intuitive numerical evaluations [26–32].

The current study aims at examining whether the view that analytical deliberation is the optimal way to approach numerical judgment tasks is indeed warranted. A pilot study we conducted, suggests that this is not always the case. In our study, 26 participants were asked to evaluate the average value of a set of eighteen two-digit numbers, presented sequentially. Twelve participants were instructed to base their evaluations on numerical rules (i.e. analytically), and the others were instructed to form an impression of the magnitude of the numbers and base their evaluations on that impression, while avoiding the application of numerical rules (i.e. intuitively). The findings were that intuitive evaluations yielded better accuracy $M = 3.43$, $SD = 2.77$ than analytical evaluations $M = 7.75$, $SD = 6.72$ $t(24) = 2.20$, $p < 0.05$.

The outcomes of our pilot study call for the identification of potential factors that might give advantage to one of the thinking modes or the other. This call gains additional impetus by the recent demonstrations of the capability of the intuitive thinking mode to process numeric information. A prominent factor that was highlighted in the literature as influencing the relative efficacy of analytical versus intuitive judgments is cognitive load. The evaluation task given in our pilot study was characterized by high complexity level (due to the large set of numbers) and a sequential presentation of information ("one piece at a time"). Both Task's complexity and a sequential information presentation might engender information load.

1.1 The Information Load Engendered by the Task

A prevalent stance in dual process literature is that cognitive load tends to disrupt effortful analytical but not intuitive thinking [11]. Research has shown that cognitive load impairs rule based analytical strategies demanding high working memory capacity, but not intuitive strategies [33–36]. Although this evidence usually refers to cognitive load induced by concurrent competing tasks, information load engendered by the target task might also produce cognitive load and subsequently disrupt analytical judgments.

1.2 The Complexity Level of a Task

Analytical thinking requires access to a central working memory system of limited capacity, whereas intuitive thinking does not. The low capacity of the working memory constrains analytical processing, making it less suitable for very complex judgments, while intuition can integrate large amounts of information into an evaluative summary judgment [10, 11, 17, 18, 29, 30]. The probability of making errors in deliberate analytical thought is a function of the complexity of the task. The greater the complexity a task exhibits in analytical terms (as measured, for example, by number of variables), the less likely it is that a person will both know the appropriate formula and apply it correctly [16]. In addition, for analytical evaluations, errors increase with the number of elements, due to accumulating errors in the application of the rules [36]. Interestingly, however, some of these researchers noted also that their findings do not hold for numerical problems and that tasks that require precision and strict following of rules are compatible with the analytical processing mode exclusively [17, 18]. Yet, our pilot study demonstrates that under high information load intuitive evaluations can outperform analytic numerical evaluations.

1.3 The Format of Information Presentation: Sequential Versus Simultaneous

Another characteristic of the evaluation task given in our pilot study, is the sequential presentation of information. Only few researchers referred to the question of the effect of sequential versus simultaneous information presentation on analytical and intuitive thinking, and the relevant evidence is ambiguous. Several researchers suggested that choices that are seen as sequential elicit a preference for analytical thinking, while choices that are seen as holistic are perceived as amenable with intuition [17, 29, 37, 38]. Other researchers have demonstrated that the effectiveness of analytical thinking depends not only on the availability of the relevant information, but also on the information's ease of process [39].

Nevertheless, we assume that the sequential presentation of information in our pilot study could have a detrimental effect on the analytical but not on the intuitive average evaluations. We believe that the source of difficulty engendered by the sequential presentation of the numbers is threefold. First, the rule based average calculation of sequentially presented numbers produces a dual task setting, by requiring participants to count the number of elements while computing their sum. Dual tasks tend to disrupt effortful analytical processes, but not effortless intuitive processes [11]. Second, a sequential presentation of the numbers increases the information load of the task by dictating the order in which the numbers have to be summed, thus preventing the use of effort reducing strategies such as coupling numbers that sum to a multiples of ten (such as coupling 27 and 33 that add up to 60). A third source of difficulty may stem from a lack of availability of information. The analytical calculation of averages involves two distinct processing stages: (1) Summation of the given numbers, (2) division of the total sum by the number of items. In the sequential condition, in the second stage of the calculation, the information on the number of items is no longer available. That is, the structured nature of analytical thinking [10] and its dependence on the completeness of information [16], may explain why accuracy declines. In contrast, intuitive thinking has a unique capability to operate when only partial information is available and thus should not affected by the presentation format.

2 The Current Study

Based on our pilot study and the theoretical assertions described above, we assumed that the relative advantage of the two thinking modes in numerical evaluations is dictated by the information load that is engendered by the complexity level of the task and the format of information presentation. We assumed that (1) when under low information load (task involving fewer numbers, easy calculation and a simultaneous presentation of the information) analytical evaluations will be more accurate, but high information load (engendered by increased task complexity, and a sequential presentation of the information) would yield an advantage for intuition, (2) a sequential presentation of the information will impair analytical evaluation but not intuitive evaluations and (3) increased task complexity will hinder the quality of analytical evaluations but not of intuitive evaluations.

To test our hypotheses, we pitted intuitive and the analytical number processing pathways against each other on the same numerical averaging tasks. In two experiments, participants were presented with sets of two-digit numbers, and were asked to evaluate the average value of each set. In a factorial design, instructions aimed to stimulate either more intuitive or more analytical thinking were given, and information load was manipulated. The manipulation of information load was done by varying task complexity (the number of elements in the set and the complexity of the computation) and information presentation format (simultaneous vs. sequential) were manipulated. To assess performance on the tasks, the accuracy of the evaluations was calculated by computing the absolute deviations of participants' evaluations from the actual average value of the numbers.

3 Experiment 1

Experiment 1 aimed at examining the effect of the information load (that is engendered by the information presentation format- simultaneous vs. sequential) on the relative advantage of the two thinking modes. In this experiment, sequences of 18 numbers were presented either simultaneously or sequentially.

4 Method

Participants. Twenty-eight undergraduate students from the Interdisciplinary Center (IDC) in Herzliya, Israel were randomly assigned to two thinking conditions: intuitive (general impressions) and analytical (calculations).

Materials. Each participant was presented with 2 sets of eighteen 2-digit numbers: (1) *18-simultaneous*: The numbers "69, 64, 68, 70, 75, 74, 46, 57, 41, 50, 55, 51, 69, 62, 65, 60, 50, 54" (average: 60) were presented simultaneously, in 3 rows of 6 numbers each, and remained on the screen for the entire evaluation interval (i.e., until the participant made the evaluation). (2) *18-sequential:* The numbers "54, 47, 50, 45, 35, 39, 31, 42, 26, 35, 40, 36, 54, 49, 53, 55, 60, 59" (average:45), was presented sequentially, in a random order, at a pace which was self- determined by each participant. When a participant felt ready, s/he pressed any key and the number was replaced by the following number.

Procedure. Participants were told that they would be presented with two sequences of 2-digit numbers, and requested to evaluate their averages. The term "evaluate" was selected since it does not direct participants to use a specific thinking mode. The manipulation of the thinking modes was based on Dehaene's observation of two distinct numerical processing routes. Participants in the analytical thinking condition were asked "to base their evaluation on numerical rules, and avoid reliance on general impressions". Participants in the intuitive thinking condition were asked "to form an impression of the magnitude of the numbers, and base their evaluation on that impression". They were also asked "to avoid the application of rules". After the initial instructions, each participant was administered with the two evaluation tasks, in a random order. After estimating the average value, participants were asked to describe how they reached their evaluation.

5 Results and Discussion

Participants' verbal reports (provided in their debriefing) confirmed that they followed the instructions to use rules, or form impressions, respectively. The evaluations of one participant that reported calculating the sum instead of the average value, were eliminated from the analysis.

We first examine RT, as an indication of compliance with the mind-set instructions. A 2 (thinking mode) x 2 (presentation format) repeated measures ANOVA for the time elapsed from the beginning of stimulus presentation until evaluation was made (Fig. 1) generated a main effect for thinking mode $F[1, 25] = 23.13$, $p < 0.0001$, $\eta^2 = 0.51$, and a main effect for presentation format $F[1, 25] = 7.08$, $p = 0.014$, $\eta^2 = 0.24$. Post- hoc tests found that the time interval required for the analytical evaluations was significantly longer than for the intuitive evaluations both under the *"18-simultaneous"* ($p = 0.003$) and *"18-sequential"*

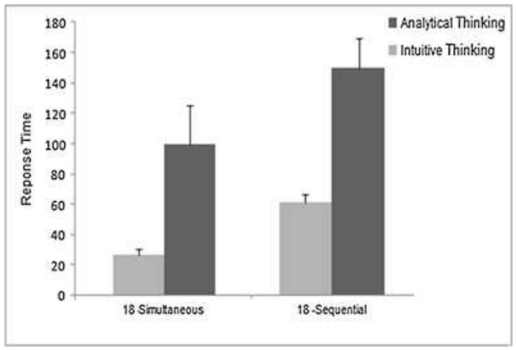

Fig. 1 Response times in experiment 1

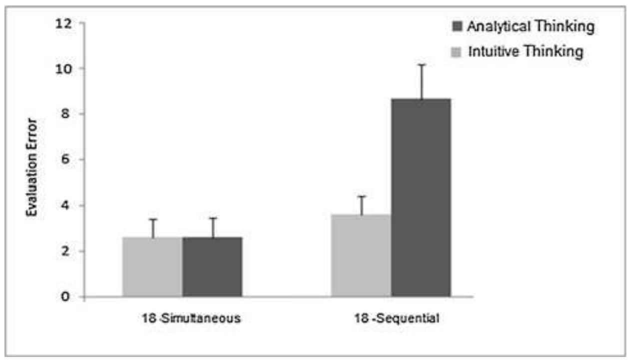

Fig. 2 Accuracy of evaluations in experiment 1

($p = 0.00038$) tasks. Thus, the longer RTs in the analytical than in the intuitive conditions indicate that the observers complied with the mind-set instructions.

We now turn to the critical measure of evaluation accuracy. The mean absolute deviations of the evaluations are presented in Fig. 2.

A 2 (thinking mode: analytical or intuitive) x 2 (presentation format: simultaneous or sequential) x 2 (task order: sequential first or simultaneous first) repeated measures ANOVA for the absolute deviations from the actual average produced a significant main effect of the thinking mode $F[1, 23] = 6.07$, $p = 0.02$, $\eta^2 = 0.21$, a significant main effect of the presentation format $F[1, 23] = 15.74$, $p = 0.0006$, $\eta^2 = 0.41$, and a significant interaction between the thinking mode and the presentation format $F[1, 23] = 7.11$, $p = 0.01$, $\eta^2 = 0.24$. Task order did not produce a significant effect, nor an interactions with other variables. Planned comparisons found that under the "*18-simultaneous*" task there was no significant difference between intuitive and analytical deviations $F[1, 23] = 0.03$, $p = 0.85$, but under the "*18-sequential*" task, the deviations of the intuitive evaluations from the actual average value were significantly smaller than the analytical deviations

F[1, 23] = 9.57, p = 0.005. Specifically, the sequential presentation led to poorer analytical evaluations F[1, 23] = 21.34, p = 0.0001, but did not have a significant effect on the intuitive evaluations F[1, 23] = 0.87, p = 0.36.

The results correspond our first and second assumptions. In line with our first assumption, under high information load (18 numbers in a sequential presentation), participants were much more accurate in their numerical average evaluation when given intuitive compared to analytic (rule-following) instructions, despite the fact that in the latter they employed mathematical rules and took more time to look at the numbers. When the task involved 18 numbers presented simultaneously, analytical evaluations were more accurate, but the difference was not significant. In support to our second hypotheses, a sequential presentation of the information (as opposed to a simultaneous presentation) disrupted analytical but not intuitive evaluations.

Although the results obtained in experiment 1 conformed to the pattern hypnotized, it also appears possible that this pattern reflects an alternative explanation of a difficulty effect. That is, the "18-simultaneous" and "18-sequential" conditions differed not only in the mode of presentation but also in the numbers used (as a different set of numbers was used for each of the two conditions). It might have been that both sets of numbers are not equally difficult to average. If they differ in difficulty, this is a methodological confound and might threat the validity of the conclusions. This possibility will be addressed in experiment 2.

Experiment 2 aimed at examining the effect of information load (engendered by the number of items) on the relative advantage of the two thinking modes. Information load was varied by varying the number of items (three versus eighteen) to be averaged and the average value of each sequence (45 or 60 in the high load and 25 or 30 in the low load condition).

In addition, in order to address the possible confound engendered by the presentation of two different sets of numbers in experiment 1, both sets of numbers were included in experiment 2, under the same presentation format. If the effect in experiment 1 reflects that both sets of numbers are not equally difficult to average, a similar effect should emerge also when the same presentation format is employed for both

6 Method

Participants. Forty undergraduate students from the Interdisciplinary Center (IDC) in Herzliya, Israel were randomly assigned to two thinking conditions: intuitive (general impressions) and analytical (calculations).

Materials. Each participant was presented with 4 evaluation tasks: 2 sets of eighteen 2-digit numbers (the same sequences of numbers that were used in experiment 1) and 2 sets of three 2-digit numbers: (1) *18-numbers 1-* The sequence "69, 64, 68, 70, 75, 74, 46, 57, 41, 50, 55, 51, 69, 62, 65, 60, 50, 54" (average: 60). (2) *18-numbers 2:* The sequence "54, 47, 50, 45, 35, 39, 31, 42, 26, 35, 40, 36, 54, 49, 53, 55, 60, 59" (average:45). (3) *3-numbers 1-* The sequence "28, 32, 15" (average: 25). (4) *3-numbers 2-* The sequence "12, 48, 30" (average: 30). The numbers of each sequences were presented sequentially in a random order, at a pace which was self- determined by each participant. When a participant felt ready, s/he pressed any key and the number was replaced by the following number.

Procedure. The order of the tasks was random. The instructions and the thinking manipulation were identical to those of Experiment 1.

7 Results and Discussion

The evaluations of three participants in the analytical condition and two participants in the intuitive condition were eliminated from the analysis, because some of their evaluations were not 2-digit numbers.

First, we compared the patterns of evaluation errors within the two eighteen numbers sequences and within the three-numbers sequences under each mode of thought in order to examine the possibility of an effect of task difficulty. Planned comparisons did not find any significant difference between the two eighteen-numbers sequences under the analytical condition $F(1,33) = 2.78$, $p = 0.14$ nor under the intuitive condition $F(1,33) = 0.007$, $p = 0.93$. Similarly, no significant difference was found between the two three-numbers sequences under the analytical condition $F(1,33) = 0.002$, $p = 0.97$ or under the intuitive condition $F(1,33) = 0.33$, $p = 0.57$.

We now examine the effects of thinking mode and task complexity. The mean absolute deviations of the evaluations are presented in Fig. 3.

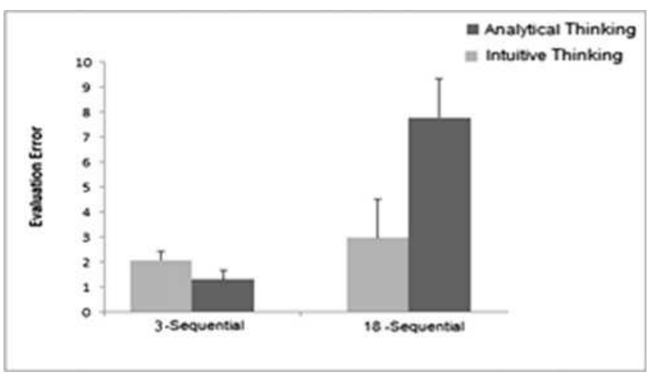

Fig. 3 Accuracy of evaluations in experiment 2

A 2 (thinking mode: analytical or intuitive) x 2 (task complexity: 18 numbers or 3 numbers) repeated measures ANOVA for the absolute deviations from the actual average produced a significant main effect of the complexity $F(1,33) = 10.63$, $p = 0.003$, $\eta^2 = 0.24$, and a significant interaction between the thinking mode and the complexity $F(1,33) = 6.12$, $p = 0.02$, $\eta^2 = 0.16$. Planned comparisons found that under the "*3-numbers*" tasks there was no significant difference between intuitive and analytical deviations $F(1,33) = 2.54$, $p = 0.12$, but under the "*18-numbers*" task, intuitive evaluations were more accurate than the analytical deviations $F(1,33) = 4.83$, $p = 0.04$. Specifically, the increased complexity led to poorer analytical evaluations $F(1,33) = 15.99$, $p = 0.0003$, but did not have a significant effect on the intuitive evaluations $F(1,33) = 0.32$, $p = 0.58$.

The obtained results thus provide additional support for our first assumption and conform to our third assumption. In addition, our analysis eliminates the possibility that the effect obtained in experiment 1 is due to differences in the sets of numbers. When the two sets of numbers were presented under an identical presentation format, No effect of different accuracy emerged. Hence, it is safe to assume that the effect obtained in experiment 1 is due to the presentation format rather than the due to specific set of numbers.

8 An Integrated Information Load Analysis of Experiments 1 and 2

Our results suggest that the accuracy of analytical evaluations is contingent on the information load that is induced by the complexity level of task and the information presentation format. The accumulated data from these two experiments allowed us to further examine whether there was a linear trend for the effect of information load on the accuracy of analytical or intuitive evaluations. According to our first hypothesis, we anticipated that higher levels of information load would disrupt the accuracy of analytic but not intuitive evaluations. To test our assumption, we looked into the data gathered in the two experiments and examined the relations between information load and errors of each of the thinking modes.

8.1 Data Analysis Method

Our data included three types of experimental conditions: (1) *"Eighteen numbers presented sequentially"* contained the data gathered in the "*18-sequential*" condition in experiment 1 and in the "*18-numbers-1*" and "*18-numbers-2*" conditions in experiment 2. (2) "Eighteen numbers presented simultaneously" contained the data gathered in the "*18-simultaneous*" condition in experiment 1. (3) *"Three numbers*

Table 1 Tasks administered in experiments 1 and 2

Number of items	Presentation format	Level of information load (mean and SD)
3	Simultaneous	2.6 (1.58)
3	Sequential	5.4 (3.13)
18	Simultaneous	6.8 (1.9)***
18	Sequential	8.2 (1.8)**

presented sequentially" contained the data gathered in the "*3-numbers-1*" and "*3-numbers-2*" conditions in experiment 2.

In order to assess the information load involved in each of these conditions, we asked an independent group of ten psychology students to perform four tasks of average evaluation: 3 numbers presented simultaneously, 3 numbers presented sequentially, 18 numbers presented simultaneously and 18 numbers presented sequentially. Each student performed all four tasks in a random order. The sequences of numbers to be evaluated were the same sequences that were presented in experiments 1 and 2 and were counterbalanced between task conditions. After participants completed all evaluations, they were presented again with the tasks and asked to rate the degree of information load induced by each evaluation task on a 9-point scale ranging from 1 = "not difficult at all" to 9-"very difficult" (Table 1).

Information Load refers to the average load as evaluated by 8 PhD and MA students

8.2 Data Analysis Results

First we examined the effect of task complexity and presentation format on the perceived levels of information load. A 2 (complexity: 3 versus 18 numbers) x 2 (presentation format: simultaneous versus sequential) repeated measures ANOVA for the estimations of perceived load produced a significant main effect of the complexity $F(1,9) = 38.02$, $p = 0.0002$, $\eta^2 = 0.81$, a significant main effect of presentation format $F(1,9) = 11.89$, $p = 0.007$, $\eta^2 = 0.57$, and no interaction between complexity and format. Hence, both the level of complexity and the presentation format affected the perceived levels of information load.

Now we examined the relationship between information load and the quality of analytic and intuitive evaluations. Figure 4 presents the accuracy of the evaluation as a function of thinking mode and information load.

A factorial regression analysis yielded a significant main effect of thinking mode $F(1,120) = 7.7$, $p = 0.006$, $\eta^2 = 0.06$, a significant main effect of information load $F(1,120) = 11.07$, $p = 0.001$, $\eta^2 = 0.08$ and a significant interaction between thinking mode and information load $F(1,120) = 10.92$, $p = 0.001$, $\eta^2 = 0.08$. Simple regression analysis of the evaluation error, with the level of information

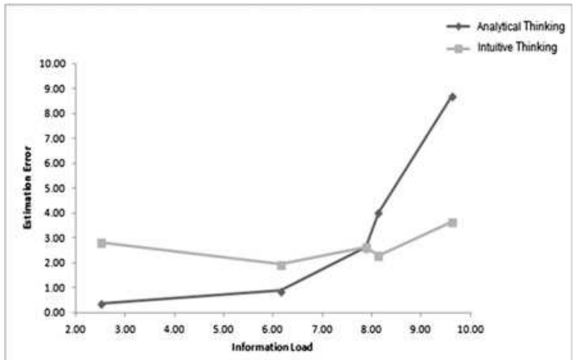

Fig. 4 Evaluations errors as a function of information load

load as an independent variable showed a significant effect of load on the accuracy of the analytical evaluation $F(1,58) = 17.26$, $p = 0.0001$ $\eta^2 = 0.23$, but no effect on the accuracy of intuitive evaluations $F(1,62) = 3.16$, $p = 0.08$, $\eta^2 = 0.05$.

9 General Discussion

Our findings show that contrary to previous theoretical claims that analytical thinking is more suitable than intuitive thinking for rule-governed computation, under certain conditions intuitive average evaluations can even outperform analytical evaluations. Together, the two experiments and the integrated analysis reported here set boundary conditions on the advantage of analytical thinking in numerical evaluations, and illustrate the impact of information load on the relative accuracy of intuitive vs. analytical averaging. Intuitive evaluations were more accurate than analytical evaluations under high information load (i.e., when the task involved many numbers and a sequential presentation), whereas no differences in accuracy were found under medium levels of information load. This pattern of results is compatible with past assertions that reliance on intuition often leads to better performance than analysis [13, 24, 32] and with recent findings of fast intuitive numerical value integration [26, 27, 29, 30, 32], and might illuminate why intuitive representations of the mental number line influence valuations across multiple decision contexts [1].

These findings support the theoretical contention that tasks that involve high information load are less compatible with analytical thinking [11, 16, 17] and extend previous empirical findings by demonstrating that the advantage of intuitive thinking in complex settings holds even when numerical judgment tasks are involved.

Interestingly, the detrimental effect of the sequential presentation of information on analytical evaluations runs exactly counter to the claim that the sequential presentation of information is compatible with analytical thinking, and simultaneous presentation is compatible with intuition [17, 29, 38]. This effect might stem from the structured nature of analytical thinking [10] and its dependence on the completeness of information [16], and from the information load that is engendered by the sequential processing in an average estimation task.

References

1. Peters, E., Slovic, P., Västfjäll, D., Mertz, C.: Intuitive numbers guide decisions. Judgm. Decis. Mak. **3**, 619–6352008))
2. Reyna, V.F., Nelson, W.L., Han, P.K., Dieckmann, N.F.: How numeracy influences risk comprehension and medical decision making. Psychol. Bull. **135**(6), 943 (2009)
3. Roe, R.M., Busemeyer, J.R., Townsend, J.T.: Multialternative decision field theory: a dynamic connectionist model of decision making. Psychol. Rev. New York **108**(2), 370–392 (2001)
4. Hertwig, R., Erev, I.: The description-experience gap in risky choice. Trends Cogn. Sci. **13** (12), 517–523 (2009)
5. Dehaene, S.: Varieties of numerical abilities. Cognition **44**, 1–4 (1992)
6. Dehaene, S.: Symbols and quantities in parietal cortex: elements of a mathematical theory of number representation and manipulation. In: Haggard, P., Rossetti, Y. (eds.) Attention & Performance XXII. Sensori-Motor Foundations of Higher Cognition, pp. 527–574 (2007)
7. Dehaene, S., Molko, N., Cohen, L., Wilson, A.: Arithmetic and the brain. Curr. Opin. Neurobiol. **14**, 218–224 (2004)
8. Brainerd, C.J., Reyna, V.F., Ceci, S.J.: Developmental reversals in false memory: a review of data and theory. Psychol. Bull. **134**(3), 343 (2008)
9. Epstein, S.: Integration of the cognitive and psychodynamic unconscious. Am. Psychol. **49**, 709–724 (1994)
10. Evans, J.S.B.T.: Dual-processing accounts of reasoning judgment and social cognition. Annu. Rev. Psychol. **59**, 255–278 (2008)
11. Kahneman, D.: A perspective on judgment and choice: mapping bounded rationality. Am. Psychol. **58**, 697–720 (2003)
12. Kahneman, D.: Thinking, fast and slow. Farrar, Straus and Giroux, New York (2011)
13. Reyna, V.F., Brainerd, C.J.: Fuzzy-trace theory: an interim synthesis. Learn. Individ. Differ. **7** (1), 1–75 (1995)
14. Sloman, S.A.: The empirical case for two systems of reasoning. Psychol. Bull. **119**, 3–21 (1996)
15. Stanovich, K.E., West, R.F.: On the relative independence of thinking biases and cognitive ability. J. Pers. Soc. Psychol. **94**, 672–695 (2008)
16. Hogarth, R.M.: Deciding analytically or trusting your intuition: the advantages and disadvantages of analytic and intuitive thought. In: Betsch, T., Haberstroh, S. (eds.) The routines of decision making, pp. 67–82. Mahwah: Erlbaum (2005)
17. Hammond, K.R., Hamm, R.M., Grassia, J., Pearson, T.: Direct comparison of the relative efficiency on intuitive and analytical cognition. IEEE Trans. Syst. Man Cybernet. **17**, 753–770 (1987)
18. Dijksterhuis, A.P., Nordgren, L.F.: A theory of unconscious thought. Perspect. Psychol. Sci. **1**, 95–109 (2006)
19. Armstrong, J.S., Denniston, W.B., Gordon, M.M.: The use of the decomposition principle in making judgments. Organ. Behav. Human Perform **14**(2), 257–263 (1975)
20. MacGregor, D.G., Armstrong, J.S.: Judgmental decomposition: when does it work? Int. J. Forecast. **10**, 495–506 (1994)
21. MacGregor, D.G., Lichtenstein, S., Slovic, P.: Structuring knowledge retrieval: an analysis of decomposed quantitative judgments. Organ. Behav. Hum. Decis. Process. **42**, 303–323 (1988)

22. McMackin, J., Slovic, P.: When does explicit justification impair decision making? J. Appl. Cogn. Psychol. **14**, 527–541 (2000)
23. Rusou, Z., Zakay, D., Usher, M.: Pitting intuitive and analytical thinking against each other: the case of transitivity. Psychon. Bull. Rev. 1–7 (2013)
24. Reyna, V.F., Brainerd, C.J.: Numeracy, ratio bias, and denominator neglect in judgments of risk and probability. Learn. Individ. Differ. **18**(1), 89–107 (2008)
25. Reyna, V.F., Estrada, S.M., DeMarinis, J.A., Myers, R.M., Stanisz, J.M., Mills, B.A.: Neurobiological and memory models of risky decision making in adolescents versus young adults. J. Exp. Psychol. Learn. Mem. Cogn. **37**(5), 1125 (2011)
26. Ariely, D.: Seeing sets: representation by statistical properties. Psychol. Sci. **12**, 157–162 (2001)
27. Betsch, T., Kaufmann, M., Lindow, F., Plessner, H., Hoffmann, K.: Different principles of information integration in implicit and explicit attitude formation. Eur. J. Soc. Psychol. **36**(6), 887–905 (2006)
28. Betsch, T., Glöckner, A.: Intuition in judgment and decision making: extensive thinking without effort. Psychol. Inq. **21**, 439–462 (2010)
29. Glöckner, A., Betsch, T.: Multiple-reason decision making based on automatic processing. J. Exp. Psychol. Learn. Mem. Cogn. **34**(5), 1055 (2008)
30. Glöckner, A., Betsch, T.: Decisions beyond boundaries: when more information is processed faster, than less. Acta Psychol. **139**, 532–542 (2012)
31. Peterson, C.R., Beach, L.R.: Man as an intuitive statistician. Psychol. Bull. **68**(1), 29–46 (1967)
32. Tsetsos, K., Chater, N., Usher, M.: Salience driven value integration explains decision biases and preference reversal. Proc. Natl. Acad. Sci. **109**(24), 9659–9664 (2012)
33. Hoffmann, J.A., von Helversen, B., Rieskamp, J.: Deliberation's blindsight—How cognitive load can improve judgments. Psychol. Sci. **24**(6), 869–879 (2013)
34. Morewedge, C.K., Kahneman, D.: Associative processes in intuitive judgment. Trends Cogn. Sci. **14**(10), 435–440 (2010)
35. Reyna, V.F.: A theory of medical decision making and health: fuzzy trace theory. Med. Decis. Making (2008)
36. Zakay, D., Wooler, S.: Time pressure, training, and decision effectiveness. Ergonomics **27**, 273–284 (1984)
37. Inbar, Y., Cone, J., Gilovich, T.: People's intuitions about intuitive insight and intuitive choice. J. Pers. Soc. Psychol. **99**(2), 232–247 (2010)
38. Söllner, A., Bröder, A., Hilbig, B.E.: Deliberation versus automaticity in decision making: which presentation format features facilitate automatic decision making? Judgm. Decis. Making **8**(3), 278–298 (2013)
39. Russo, J.E.: The value of unit price information. J. Mark. Res. **14**, 193–201 (1977)