Contrasting symbolic and non-symbolic numerical representations in a joint classification task

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Both symbolic (digits) and non-symbolic (dots) numerals are spatially represented, with relatively small numbers being responded faster with a left key press and large numbers being responded faster with a right key press (Spatial-Numerical Association of Response Codes). The idea of a format independent SNARC seems to support the existence of a common system for symbolic and non-symbolic numerical representations, although evidence in the field is still mixed. The aim of the present study is to investigate whether symbolic and non-symbolic numerals interact in the SNARC effect when both information is presented simultaneously. To do so, participants were presented with dice-like patterns with digits being used instead of dots. In two separate magnitude classification tasks, participants had to respond either to the number of digits being present on the screen or to their numerical size. In the non-symbolic task, they had to judge whether the digits on the screen were more or less than three, irrespective of the numerical value of the digits. In the symbolic task, participants had to judge whether the digits on the screen were numerically smaller or larger than three, irrespective of the number of digits being present. The results show a consistent SNARC effect in the symbolic task and no effect in the non-symbolic one. More interestingly, congruency between symbolic and non-symbolic numerals did not modulate the response patterns, thus supporting the idea of independent representations and questioning some of the current theoretical accounts.

Keywords:

SNARC, digit, numerosity, Approximate Number System, ANS, ATOM

1.0 Introduction

Extensive evidence indicates that people represent numbers spatially resembling a Mental Number Line (Restle, 1970). A consistently replicated phenomena that supports this view is the Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene et al., 1993). This consists of faster left key responses for small numbers and faster right key responses for large numbers. The direction of this representation seems to be culturally determined, with reading and writing direction, as well as finger counting, being considered as the basis for this long-term association (Fischer & Shaki, 2017; Shaki et al., 2009; Pitt & Casasanto, 2020). However, several studies have demonstrated that contextual manipulations are able to reverse the direction of the Spatial-Numerical Association for numbers (Bachtold et al., 1998; Mingolo et al., 2021).

Although symbolic numerals have been the most commonly investigated stimuli, SNARC-like effects have been revealed in a multitude of non-numerical dimensions. While examples of symbolic non-numerical stimuli are relatively rare and can be found in music notation (Ariga & Saito, 2019; Fumarola et al., 2020; Prpic et al., 2016) and letters of the alphabet (Gevers et al., 2003), non-symbolic stimuli have been widely studied across different modalities. Most common examples are in the visual modality, with the size of pictorial figures (Prpic et al., 2020; Ren et al., 2011), luminance (Fumarola et al., 2014; Ren et al., 2011), angle magnitude (Fumarola et al., 2016) as well as emotional magnitude in facial displays (Holmes & Lourenco, 2011, Holmes et al., 2019; but see also Fantoni et al., 2019 and Baldassi et al., 2021). Numerous are also the examples in the auditory modality with pitch (Lega et al., 2020; Lidji et al., 2007; Pitteri et al., 2017; Prpic & Domijan, 2018; Rusconi et al., 2006), loudness (Bruzzi et al., 2017; Hartmann & Mast, 2017) and temporal aspects of the stimuli (Ishihara et al., 2008; De Tommaso & Prpic, 2020) being commonly investigated. Finally, more recent

72   studies focus also on somatosensory information revealing similar effects for weight (Dalmaso

73   & Vicovaro, 2019; Vicovaro & Dalmaso, 2021) and vibrotactile stimuli (Bollini et al., 2020).

74   The ATOM (A Theory of Magnitude) model (Walsh, 2003; Bueti & Walsh, 2009) has

75   been commonly used as an umbrella to account for SNARC-like effects since the theory posits

76   that space and quantity are processed by a generalized magnitude system. Walsh (2003) also

77   suggested that SNARC should prove to be a SQUARC (Spatial-Quantity Association of

78   Response Codes) effect, thus that magnitudes across different domains should be spatially

79   coded similarly to numbers. The large amount of evidence seems to support Walsh's (2003)

80   prediction, although it is still a matter of debate whether these effects are actually driven by

81   stimulus magnitude or ordinality (see Casasanto & Pitt, 2019 and Prpic et al., 2021).

82   Non-symbolic numerals have been traditionally less studied than their symbolic

83   counterpart, however they recently gained renewed interest. To our knowledge, Nuerk et al.

84   (2005) published the first study that investigated the SNARC effect for dot patterns. This study

85   used configurations of dots resembling dice patterns and showed that small (vs. large) numerals

86   are responded faster with a left (vs. right) key, independently from the format of numerical

87   stimuli. More recently, this finding has been replicated by using randomly distributed dot

88   clouds with larger numerosities (Nemeh et al., 2018; Zhou et al., 2016). Another recent study

89   (Cutini et al., 2019) more specifically focussed on stimulus arrangements and revealed that both

90   structured and unstructured patterns elicit a consistent SNARC effect in a small numerosity

91   range (i.e., 1-9). These studies suggest that the SNARC effect for non-symbolic numerals is

92   independent from both the range and the spatial arrangement of the stimuli.

93   Evidence of format independent SNARC effects supports the existence of a common

94   system for symbolic and non-symbolic number processing. Traditionally it has been considered

95   that both numerical formats share the same neural representation (Approximate Number

System or ANS) and that non-symbolic numerals provide a foundation for their symbolic counterparts (Dehaene, 1993; Nieder, 2016; Nieder & Dehaene, 2009; Piazza, 2010; Piazza et al., 2007). However, some recent studies provide evidence for independent processing of symbolic and non-symbolic numerals, thus supporting the existence of separate systems (Marinova et al., 2021; Sasanguie et al., 2017). In particular, a study that showed a SNARC effect for both symbolic and non-symbolic numerals in either adult or children managed to demonstrate that the two effects are not correlated, thus suggesting that symbolic and nonsymbolic numerals are independently associated with space (He et al., 2021). Although behavioural evidence is still mixed, a growing number of research seem to be in favour of a dissociation for symbolic and non-symbolic numerical representations, at least for studies using SNARC paradigms (for a review see Buijsman & Tirado, 2019).

A limitation of previous studies that compared symbolic and non-symbolic SNARC effects consists in the fact that these were tested separately. To our knowledge, the present study is the first attempt to directly contrast symbolic and non-symbolic numerical representations by presenting both numerical stimuli simultaneously. To do so we created dicelike patterns but instead of dots we displayed digits. In two separated tasks, participants were required to either respond to the symbolic value of the digits while ignoring their numerosity, or to respond to the number of digits present while ignoring their symbolic value. We hypothesized that, if symbolic and non-symbolic numerals are represented by a shared system, compatible representations should positively interact causing a stronger SNARC effect in the congruent condition, while incompatible representations should negatively interact causing a weaker or absent SNARC effect in the incongruent condition. Conversely, if these two representations are independent, compatibility between numerical stimuli should not impact the SNARC effect.

121 **2.0 Method**

122 **2.1 Participants**

123 An a priori power analysis was conducted using the *wp.kanova()* function from the *WebPower*

124 package (Zhang, Mai, Yang & Zhang, 2018). In order to achieve 80% statistical power for

125 detecting a large effect size ($\eta_!^" = 0.14$) for an alpha criterion of 0.05, a sample size of 50 would

126 be sufficient.

127 Fifty-two students (48 females) from De Montfort University took part in the study and were

128 rewarded with coursework credits. The mean age was 21.0 ($SD = 4.7$). 41 participants were

129 right-handed, whilst seven were left-handed. All participants reported to have normal or

130 corrected-to-normal vision and were naïve about the purpose of the study. Written informed

131 consent was obtained before participation. The study was approved by the Faculty of Health

132 and Life Sciences Research Ethics Committee (Ref: 3488) and was conducted in accordance

133 with the ethical standards established by the Declaration of Helsinki.

134

135 **2.2 Apparatus and stimuli**

136 The online experiment was designed using PsychoPy (Peirce et al., 2019), version 2020.2.5 and

137 then conducted on Pavlovia through the participants' personal computers. Responses were

138 collected using the 'A' and 'L' keys on the participants' computer 'qwerty' keyboards.

139 Stimuli consisted of four numbers (1,2,4 and 5) presented in white against a grey background

140 with the letter height set at 0.08 height units. Each trial presented only one number out of the

141 four, and in each trial, the numbers were displayed as a dice-like formation (see Figure 1).

142 When only one number was shown, it was positioned in the centre of the screen (0,0), two

143 numbers were positioned with the co-ordinates (-.08,0) and (.08,0), four numbers were

144 positioned at (-.08,.08), (.08,.08), (-.08,-.08), and (.08,-.08), whilst five numbers were

145 positioned at (0,0), (-.08,.08), (.08,.08), (-.08,-.08), and (.08,-.08). Between each trial, there was

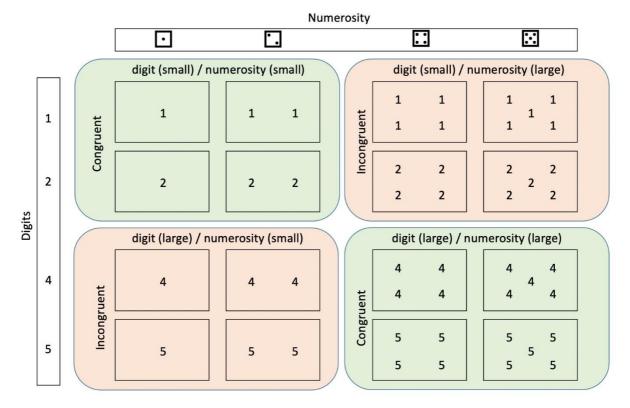146 a fixation cross set at the centre of the screen with a height of 0.1.

147

149 *Figure 1. A depiction of the stimuli and the experimental manipulations. Symbolic (digits) and*

150 *non-symbolic (numerosity) numerals were combined to create congruent (small digit/small*

151 *numerosity; large digit/large numerosity) and incongruent (small digit/large numerosity; large*

152 *digit/small numerosity) conditions.*

153

154 **2.3 Procedure**

155 The experiment took place online and participants were required to complete the experiment in

156 a quiet room without distractions. Participants were instructed to place their right index finger

157 on the rightmost key 'A' and their left index finger on the leftmost key 'L'. Each trial started

158 with a blank screen and was followed by a fixation cross that was presented at 500ms and

159 stayed for 500ms. 1500ms after the start of the trial, the target numbers were presented for

160 3000ms, the keyboard response was activated simultaneously and had a duration of 3500ms.

161 For this task, all participants completed two conditions that had two separate blocks of trials

162 each. In one condition, participants were required to judge symbolic numerals (digits) and

163 ignore non-symbolic numerals (numerosity). They had to determine if the digit was larger or

164 smaller than the reference standard (3); when the digit was larger, participants had to press the

165 'L' key; when the digit was smaller, participants had to press the 'A' key. After completing the

166 first block in the first condition, the keys were switched for the second block; if the digit was

167 smaller, the 'L' key was pressed, and if the digit was larger, the 'A' key was pressed. The

168 instructions were the same for the second condition, where the task required the participant to

169 determine whether there were more or less than three digits on the screen (non-symbolic

170 numeral/numerosity) while ignoring the digits' magnitude (symbolic numerals). Similar to the

171 first condition, the response keys for the second block of the second condition were switched.

172 Participants were randomly split into four groups where the order of the two conditions and

173 their consequent blocks was counterbalanced across all participants. Each block started with

174 16 practice trials before the participant completed 80 trials for the main trials. Trials in each

175 block were randomised and all four numbers were equally presented in each of the four dice-

176 like positions. Additionally, there were an equal number of 'smaller'/'larger' responses in each

177 block. This resulted in each participant completing 320 main trials. Participants were allowed

178 a break between each block until they were ready to continue to the next block. Both speed and

179 accuracy of responses were stressed in the instructions.

180

3.0 Results

3.1 Pre-processing

183 Reaction times less than 150ms were removed (Brenner & Smeets, 1997). Data from two

184 participants were also removed for having a high number of errors (over 20%). The remaining

185   sample made few errors (0.93-13.47%) with average error percentage being 5.70%. Because of

186   this, accuracy was not analysed. 34 trials where participants failed to make a response were

187   removed from the analysis alongside all incorrect responses. For outliers, we specified a

188   threshold of 3 standard deviations and calculated the individual means and standard deviations

189   within each condition. This approach detected 304 outlier trials, which were removed from the

190   sample before analysis. Data and analysis scripts are available on the Open Science Framework

191   (https://osf.io/e7rj3/).

192

193   **3.2 Symbolic task**

194   Individual mean reaction times were entered into a response hand (left vs. right) X number

195   magnitude (small vs large) X congruency (congruent vs incongruent) Repeated Measures

196   ANOVA. A main effect of congruency [$F(1, 51) = 25.06$, $p < 0.001$, $\eta_p^2 = .330$] was found,

197   suggesting that reaction times were faster when the numerical information was congruent

198   (small/large digits were presented in small/large numerosity). A main effect of magnitude [$F(1,

199   51) = 4.96$, $p = 0.03$, $\eta_p^2 = .089$] was also found, suggesting that participants were faster in

200   responding to smaller numerical magnitude. Most importantly, a significant hand X magnitude

201   interaction was found [$F(1, 51) = 7.53$, $p = 0.008$, $\eta_p^2 = .129$] which is clear evidence of a

202   SNARC effect (Figure 2). No other interactions were significant and, in particular, there was

203   no evidence of a 3-way interaction between hand, magnitude and congruency, suggesting that

204   the SNARC effect was not modulated by congruent/incongruent non-symbolic numerals.
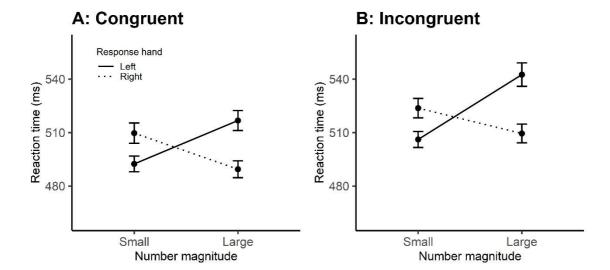
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A: Congruent   **B: Incongruent**

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214   *Figure 2: Mean reaction times with error bars representing standard error of the mean (SEM)*

215   *for congruent (A) and incongruent (B) conditions in the symbolic task.*

216

217   We further assessed the SNARC effect by means of a regression analysis for repeated measures

218   (Fias 1996; Lorch & Myers, 1990). The dRTs (right – left responses) were calculated and used

219   as the criterion variable, while the predictor variable was the symbolic numerical magnitude.

220   A one samples t-test comparing the individual β parameter values against 0 for congruent [t(51)

221   = -2.65, p = 0.01, *d* = -0.36, *BF* = 3.53] and incongruent [t(51) = -2.37, p = 0.02, *d* = -0.33, *BF*

222   = 1.94] conditions were both significant (Figure 3). The Bayes Factors both indicated moderate

223   evidence in favour of the alternative hypothesis. A two samples t-test comparing the individual

224   β parameter values for congruent versus incongruent conditions did not reach significance

225   [t(51) = .22, p = 0.826, *d* = 0.01, *BF* = 0.20], further suggesting that the SNARC effect was not

226   modulated by non-symbolic numerals.

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A: Congruent

B: Incongruent

dRT (ms)

50

0

-50

1 2 3 4 5
Number

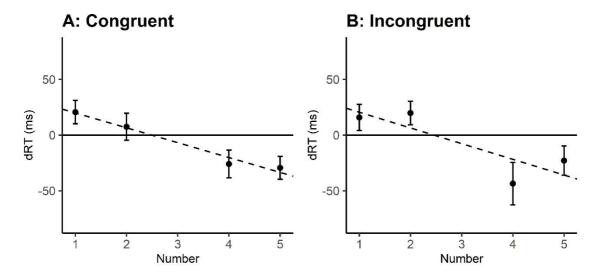dRT (ms)

50

0

-50

1 2 3 4 5
Number

Figure 3: Mean dRTs (right – left responses) as a function of number for the congruent (A)

and incongruent (B) conditions in the symbolic task. Error bars represent SEM.

3.3 Non-symbolic task

Individual mean reaction times for the numerosity condition were entered into a response hand (left vs right) X non-symbolic numerical magnitude (small vs large) X congruency (congruent vs incongruent) Repeated Measures ANOVA. A significant main effect of congruency was found [$F(1, 51) = 28.44$, $p < 0.001$, $\eta_p^2 = .358$]. Once again this suggests that participants were faster to react when the numerosity stimuli were congruent. We also found a significant main effect of response hand [$F(1, 51) = 5.13$, $p = 0.02$, $\eta_p^2 = .091$). This suggests that participants were significantly faster at responding when using their right hand. Finally, we find a significant main effect of magnitude, whereby responses to large magnitudes were faster [$F(1, 51) = 13.32$, $p < 0.001$, $\eta_p^2 = .207$). However, no interactions were significant in the ANOVA, therefore there was no evidence of a SNARC effect (hand X magnitude interaction) [$F(1, 51) = 0.38$, $p = 0.542$, $\eta_p^2 = .007$)] (Figure 4).
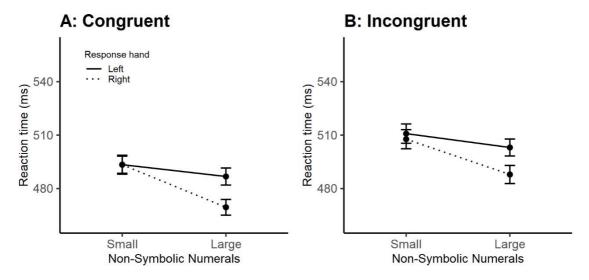
A: Congruent

B: Incongruent

Figure 4: Mean reaction times with error bars representing SEM for congruent (A) and incongruent (B) conditions in the non-symbolic task.

One samples t-tests comparing individual β parameter values against 0 for congruent [$t(51) = -1.01$, $p = 0.31$, $d = -0.14$, $BF = 0.24$] and incongruent [$t(51) = -0.21$, $p = 0.82$, $d = -0.03$, $BF = 0.15$] conditions, with non-symbolic numerical magnitude as the predictor variable, did not reach significance (Figure 5). A t-test comparing the individual β parameter values for congruent versus incongruent did not reveal a statistically significant effect [$t(51) = -0.90$, $p = 0.37$, $d = -0.10$, $BF = 0.23$). Taken together these analyses show that a SNARC effect was not elicited by non-symbolic numerals, independently from their congruency with symbolic values.
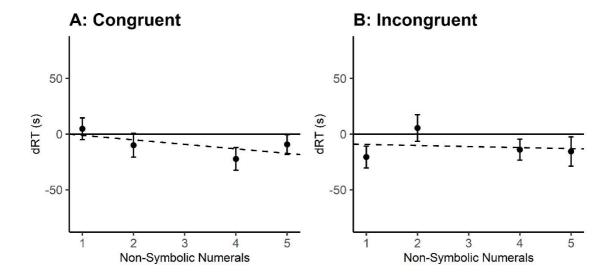
A: Congruent

B: Incongruent

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267 *Figure 5: Mean dRTs (right – left responses) as a function of number for the congruent (A) and*

268 *incongruent (B) conditions in the non-symbolic task. Error bars represent SEM.*

269
270 **4.0 Discussion**

271   The aim of this study was to directly contrast the SNARC effect for symbolic and

272 nonsymbolic numerals within the same experiment. To do so we created a novel set of stimuli

273 consisting of dice-like patterns with digits being displayed instead of dots. Therefore, both

274 symbolic (numerical value of digits) and non-symbolic (number of digits on the screen)

275 numerals were simultaneously present within the same stimuli. This resulted in congruent

276 (small numerosity/small digits or large numerosity/large digits) and incongruent (small

277 numerosity/large digits or large numerosity/small digits) conditions.

278   When participants were required to process symbolic numerals a robust SNARC effect

279 was found, with small digits being responded faster with the left key and large digits with the

280 right key. Contrary to what should be expected from a shared numerical representation, the

281 SNARC effect for digits was not modulated by task irrelevant non-symbolic numerals and

282 seem to support the idea of independent representations. Alternatively, we could hypothesise

283 that non-symbolic numerals did not modulate the SNARC effect simply because they were

284 task irrelevant, thus adding to other studies that have failed to show a SNARC effect for

285 numerosity in these circumstances (Cleland et al., 2020; Pellegrino et al., 2021). That said, our

286 data also show slower response times for the incongruent conditions which indicates that

287 irrelevant nonsymbolic numerical information was processed and did impact participants'

288 responses, but did not interact with the SNARC effect.

289 When participants were required to process non-symbolic numerals, a SNARC effect

290 was not detected. This is apparently in contrast with previous studies that revealed a SNARC

291 effect for dots arranged either as dice patterns (Cutini et al., 2019; Nuerk et al., 2005) or

292 distributed randomly in the visual field (Cutini et al., 2019; Nemeh et al., 2018; Zhou et al.,

293 2016). The absence of a SNARC effect for numerosity might be ascribed to our 'atypical'

294 nonsymbolic stimuli which contained symbolic numerals instead of dots. However, if the

295 symbolic nature of the stimuli would have driven our results, we would expect a SNARC

296 pattern in the congruent condition since digits are known to elicit SNARC effects even when

297 irrelevant to the task (e.g., Fias et al., 2001). Conversely, our data show that digits did not

298 modulate the response pattern for non-symbolic numerals. However, similarly to the symbolic

299 task, slower responses were detected in the incongruent condition suggesting that irrelevant

300 symbolic numerals were still processed during the task.

301 Our results for numerosity judgment seem to add to recent evidence suggesting that,

302 differently from digits, non-symbolic numerals do not offer a direct route to spatial-numerical

303 associations (Cleland et al., 2020; Pellegrino et al., 2021). Furthermore, this evidence questions

304 the ATOM model (Walsh, 2003) which posits that magnitudes across different domains and

305 formats should be spatially coded similarly to digits. Conversely, in our study, SNARC seems

306   to be closely related to symbolic numerals, thus failing to prove to be a SQUARC effect as

307   predicted by Walsh (2003).

308   Taken together, the fact that 1) non-symbolic numerals did not modulate the SNARC

309   effect for digits, 2) symbolic numerals did not interact with the response pattern for numerosity,

310   seem in contrast with the idea of a common system for number processing (ANS) (Dehaene,

311   1993; Nieder, 2016; Nieder & Dehaene, 2009; Piazza, 2010; Piazza et al., 2007). Indeed, if

312   symbolic numerals are directly mapped into their non-symbolic counterparts, we should expect

313   compatible representations to positively interact in the congruent condition and incompatible

314   representations to negatively interact in the incongruent condition. However, our data show

315   that this was not the case. Furthermore, our evidence also show that irrelevant numerals were

316   processed and did impact overall response times in both tasks, thus ruling out the possibility

317   that these were simply ignored.

318   To conclude, our results support recent evidence in favour of two independent

319   processing systems for symbolic and non-symbolic numerals (Marinova et al., 2021; Sasanguie

320   et al., 2017) and are in line with previous research suggesting separate brain areas being

321   involved in the processing of these numerical formats (Kadosh et al., 2007; Kadosh & Walsh,

322   2009).

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328   **5.0 References**

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