1   The rapid synthesis of integral stimuli

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¹⁴   Abstract

¹⁵ Integral stimuli (e.g. colours varying in saturation and brightness) are classically considered

¹⁶ to be processed holistically (i.e. as undifferentiated stimulus wholes); people analyze such

¹⁷ stimuli into their consistent dimensions only with substantial time, effort, training, or

¹⁸ instruction (Foard & Kemler Nelson, 1984). In contrast, Combination Theory (Wills, Inkster,

¹⁹ & Milton, 2015) argues that the dimensions of integral stimuli are quickly combined.

²⁰ Through an investigation of the effects of stimulus presentation time, we support

²¹ Combination Theory over the classical holistic-to-analytic account. Specifically, using

²² coloured squares varying in saturation and brightness, we demonstrate that the prevalence of

²³ single-dimension classification increases as stimulus presentation time is reduced. We

²⁴ conclude that integral stimuli are not slowly analyzed, they are quickly synthesized.

25   The rapid synthesis of integral stimuli

26   Even the simplest of laboratory-based stimuli tend to vary across more than one

27   stimulus attribute. Monochromatic squares are presented at different sizes and brightnesses

28   (J. D. Smith & Kemler, 1984); pure sine waves at different pitches and intensities (Grau &

29   Kemler Nelson, 1988). For many decades, there has been consensus that one of the ways in

30   which multi-attribute stimuli differ from each other is in the level of separability of their

31   dimensions (Garner, 1976). For highly separable stimulus dimensions, such as size and

32   brightness, adults find it easy to attend to one of the stimulus dimensions while ignoring the

33   other. In contrast, for integral stimulus dimensions such as pitch and loudness, selective

34   attention is difficult (Garner, 1976). Nonetheless, the stimulus dimensions of integral stimuli

35   have psychological reality, as shown by the fact that it is even harder to selectively attend

36   along an arbitrary dimension in stimulus space. For example, for coloured squares of a fixed

37   hue but varying in saturation and brightness, it is easier to classify on the basis of saturation,

38   or brightness, than it is to classify on the basis of arbitrary dimensions that are a 45-degree

39   rotation of the saturation-brightness axes (Foard & Kemler Nelson, 1984). Thus, integral

40   dimension pairs, such as saturation and brightness, are both difficult to selectively attend,

41   and are considered as primary or 'privileged' stimulus dimensions.

42   The study of integral stimuli seems to have been key to the development of a class of

43   theories of processing order in stimulus classification (Lockhead, 1972 et seq.); this class of

44   account being subsequently described as Differentiation Theory (Wills et al., 2015). Under

45   Differentiation Theory, integral stimuli are initially perceived as undifferentiated wholes, or

46   "blobs". It proposes that if the task at hand cannot be completed with this holistic stimulus

47   representation then, with time and effort, people can analyze the stimulus into its

48   constituent dimensions.

49   The domain of Differentiation Theory was widened by subsequent investigators, who

50   argued that even stimuli that were separable for adults under conditions of intentional

unspeeded classification (e.g., grey squares varying in size and brightness) were classified

holistically by children (L. B. Smith & Kemler, 1977), by adults under time pressure (J. D.

Smith & Kemler, 1984; Ward, 1983) or cognitive load (J. D. Smith & Shapiro, 1989), and by

adults who classified under incidental rather than intentional conditions (Kemler Nelson,

1984). Thus, Differentiation Theory was considered to apply quite broadly; people start with

an undifferentiated stimulus whole, which they break down into its constituent components if

they have the time and mental resources to do so. Under this account, separable and integral

stimuli differ in the time or effort required to analyze the stimulus into its component

dimensions; with integral and separable stimuli seen as the two poles of a continuum of

analyzability.

Unfortunately, the application of Differentiation Theory to separable stimuli turned out

to be an over-extension made on the basis of flawed analyses. In correcting these flaws, Wills

et al. (2015) demonstrated that increased time pressure (in terms of stimulus presentation

time and limited response time), cognitive load, and incidental training conditions, *increased*

the likelihood that people would classify separable stimuli on the basis of a single stimulus

dimension (rather than decrease it as predicted by Differentiation Theory). This pattern of

results is predicted by a class of accounts starting with Neisser (1967), which were

subsequently described as Combination Theory (Wills et al., 2015).

Combination Theory is the inverse of Differentiation Theory. It argues that cognition

begins with the stimulus attributes (e.g., saturation, brightness), and that these attributes

are combined if time and mental resources allow. It provides a sufficient account of the

effects of time pressure, cognitive load and incidental training on the classification of

separable stimuli (Wills et al., 2015). However, it makes a striking and untested prediction

concerning integral stimuli. It predicts that sufficient increases in time pressure will increase

the prevalence of single-dimension classification of integral stimuli. Thus, despite the

difficulty people have in selectively attending to one dimension of an integral stimulus under

77 unspeeded conditions, under sufficiently speeded conditions their classification will

78 nonetheless be more likely to be on the basis of a single stimulus dimension, because they

79 have not yet combined the dimensions. In other words, the properties of integral stimuli

80 under unspeeded conditions come not from the difficulty of differentiating the holistic 'blob'

81 into its constituent dimensions (as Differentiation Theory would predict) but from the

82 rapidity with which the stimulus dimensions are combined. In order to explain performance

83 under unspeeded conditions, Combination Theory must further assume that, once combined,

84 selective attention of dimensions is effortful. This is an existing assumption of Combination

85 Theory, already employed to explain other phenomena (Wills et al., 2015). In summary,

86 Combination Theory predicts that reducing the stimulus presentation time will increase the

87 prevalence of single-dimension classification of integral stimuli, while Differentiation Theory

88 predicts the opposite, or the absence of an effect.

The current experiments

90   A key experimental procedure employed in support of Differentiation Theory is the

91 restricted classification (or "triad") task (Garner, 1976; J. D. Smith & Kemler, 1984; Ward,

92 1983). Participants are presented with three stimuli, for example the stimuli labelled 6 to 8

93 in Figure 1. Stimuli 7 and 8 are identical in brightness but quite dissimilar in saturation

94 ('chroma'). Stimuli 6 and 8 are similar on both dimensions, but identical on neither. The

95 task is to pick the two stimuli that 'go together' (or to pick the odd one out). No feedback is

96 given.

97   A defining characteristic of integral stimuli is that people have a strong preference to

98 group stimulus 6 and 8 together in this task, i.e., the stimuli that are similar, but not the

99 same, on both dimensions. This is known as an *overall similarity* (OS) response. For

100 separable stimuli, under full attention and unspeeded conditions, there is a strong preference

101 for adults to group stimulus 7 and 8 together, i.e., the stimuli that are identical on one

102 stimulus dimension but not the other. This is sometimes called a 'dimensional' response, but

¹⁰³ we prefer the less ambiguous term *identity* (ID) response (Wills et al., 2015). For separable

¹⁰⁴ stimuli, stimulus 7 and 8 are grouped together because the identity on one dimension

¹⁰⁵ overwhelms the fact that stimuli 6 and 8 are more similar overall.
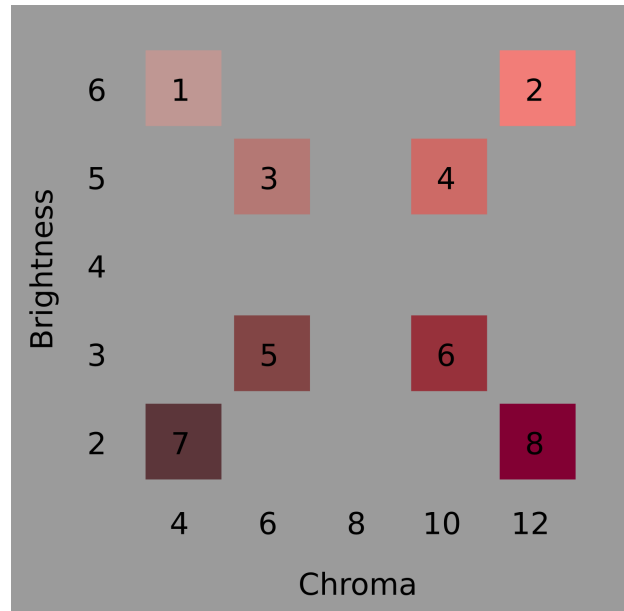
Figure 1. The eight stimuli employed in the current experiments, along with their Munsell Chroma and Brightness values. The text and numbers in this Figure are for reference; only the coloured squares themselves were presented to participants.

¹⁰⁶ An important thing to appreciate about the triad task is that while there is always one

¹⁰⁷ dimension on which two stimuli are identical, which dimension that is varies unpredictably

¹⁰⁸ from trial to trial. For example, while the first trial might involve stimulus triad 6-7-8 in

¹⁰⁹ Figure 1, the next might involve triad 1-3-7. In this case, the identity is on the saturation

¹¹⁰ dimension, and an Identity response involves classifying stimuli 1 and 7 together. Thus, in

¹¹¹ order to classify on the basis of Identity, the participant must be sensitive to both stimulus

¹¹² dimensions, and weigh more heavily the dimension on which there is an identity.

¹¹³ In addition to overall similarity and identity responding, another possible response

¹¹⁴ pattern in the triad task is that the participant's classifications are made on the basis of a

¹¹⁵ single dimension. In other words, a *unidimensional* (UD) strategy. For example, a

116 participant might classify on the basis of stimulus brightness. In this case, they would

117 classify stimulus 7 and 8 together in the triad 6-7-8, and stimulus 1 and 3 together in triad

118 1-3-7. Thus, the classification of any single triad supports at least two hypotheses about the

119 participant's behavior. For example, classifying 1 and 3 together from triad 1-2-3 supports

120 both an Overall Similarity hypothesis, and a single-dimension (brightness) hypothesis. It is

121 thus crucial that the participant's responses are considered as a set across multiple trials,

122 some trials involving brightness-identical triads and others saturation-identical triads. It was

123 the lack of a full appreciation of this point that led to the over-extension of Differentiation

124 Theory to separable stimuli, and the adoption of response-set analysis that resolved this

125 issue (Raijmakers, Jansen, & Maas, 2004; Thompson, 1994; Wills et al., 2015).

126 In the current experiments, we apply response-set analysis of the triad task to the

127 effects of stimulus presentation time on classification of integral stimuli varying in brightness

128 and saturation. Combination Theory predicts an increase in the prevalence of

129 single-dimension classification with a decrease in stimulus presentation time. Differentiation

130 Theory predicts the opposite. A strong preference for overall similarity classification in

131 integral stimuli under low time pressure is already well established, and the application of

132 time pressure makes classification data more 'noisy' (Wills et al., 2015). Here, 'noisy' means

133 being either more erratic in the application of a strategy, or more inconsistent in the

134 selection of a strategy in the first place. Wills et al. measured this using the proxy of the

135 number of responses that fit the winning strategy. For both these reasons, we tested about

136 twice as many participants in our short-stimulus-presentation-time conditions than in our

137 long-stimulus-presentation-time conditions.

138 **Experiment 1**

139 **Method**

140 **Participants.** Forty-six psychology students from XXX University participated for

141 partial course credit; the sample size was determined by the number of course credits

₁₄₂ available at the time of testing. Our experiment had sufficient (80%) power to detect

₁₄₃ medium-to-large effects ($w = 0.40$) in a chi-squared test. An effect size of approximately

₁₄₄ similar magnitude ($w = 0.33$) had previously been observed when applying more subtle time

₁₄₅ pressure to squares varying in size and brightness (Wills et al., 2015). Hence, the sample size

₁₄₆ provided an initial test of our hypothesis within the resources available. Power calculations

₁₄₇ were performed using the R package `pwr` (Champely, 2020). The University of XXX

₁₄₈ Psychology Ethics Committee approved all reported experiments.

₁₄₉ **Stimuli and apparatus.** Eight coloured squares, 8mm on a side, were used (see

₁₅₀ Figure 1). The stimuli were of a red hue (Munsell 5R), and varied in chroma (4-12) and

₁₅₁ brightness (2-6); this is similar to the colour space employed in Nosofsky (1987). Note that,

₁₅₂ in the Munsell system, two units of chroma are psychologically equivalent to one unit of

₁₅₃ brightness (Nickerson, 1936; Nosofsky, 1987; Shepard, 1958). The positioning of the stimuli

₁₅₄ within stimulus space followed our previous experiments (Milton, Longmore, & Wills, 2008;

₁₅₅ Wills et al., 2015). Eight stimulus triads are possible within this stimulus set (1-3-7, 1-5-7,

₁₅₆ 2-4-8, 2-6-8, 1-2-3, 1-2-4, 5-7-8, 6-7-8). There are six different ways in which three stimuli

₁₅₇ can be placed in three spatial locations (e.g., for the 1-3-7 triad, these would be 1-3-7, 1-7-3,

₁₅₈ 3-1-7, 3-7-1, 7-1-3, 7-3-1). Thus, each of the eight triads had six different instantiations,

₁₅₉ resulting in 48 physically different triads per experiment. The three stimuli in each triad

₁₆₀ were presented simultaneously in a horizontal line, with each square separated from the next

₁₆₁ by an edge-to-edge distance of 8 mm. Stimuli were presented on a 22-inch Philips LED

₁₆₂ monitor, against a mid-grey background, using E-prime 2; responses were collected using a

₁₆₃ standard PC keyboard. Participants sat approximately 50cm from the screen; the whole

₁₆₄ stimulus triad thus subtended approximately five degrees of visual angle horizontally, and

₁₆₅ one degree vertically.

₁₆₆ **Procedure.** Participants were arbitrarily assigned to one of two conditions, short

₁₆₇ presentation time or long presentation time. The stimulus presentation times used were 100

₁₆₈ ms and 2000 ms. At the beginning of each trial, the screen displayed the message "Ready?"

169 and the participant pressed a key to continue. After this, a small fixation cross was

170 presented in the centre of the screen, for 500 ms. The stimulus triad was then presented for

171 the appropriate duration, and then immediately replaced by the message "Odd one out?"

172 The participant pressed the number key 1, 2 or 3 to indicate the left, middle, or right

173 stimulus, respectively. The next trial began immediately upon detection of a response.

174   Each of the 48 physically different stimulus triads were presented twice, with order of

175 presentation randomized for each participant. The randomization was constrained such that

176 each block of eight trials contained exactly one of the eight logical triads (1-3-7, 1-5-7, etc.).

177 At the end of each block, the participants received an on-screen reminder of the instructions,

178 and pressed a key when they were ready to continue.

179   **Strategy analysis.**   To determine the strategy used by each participant, the

180 participants' responses were compared to each of the three categorisation strategies

181 mentioned above: unidimensional (UD), overall similarity (OS), and identity (ID).

182 Additionally, we checked to see whether any participants were based described by a Response

183 Bias strategy (Bias). To determine the strategy used by each participant, we first determined

184 for each of the 48 possible triad stimuli what the response should be given each of these

185 strategies. For the UD strategy, the response would be the pair that was be closest on a

186 particular dimension. For the OS strategy, the response would be the pair that was the most

187 similar overall. For the ID strategy, the response would be the pait that shared an identical

188 feature. For the Bias strategy, the response would be where the participant pressed the same

189 key throughout the experiment. We then counted, for each strategy and participant, how

190 many of the participant's responses matched the predicted response of that strategy. Then,

191 the participant's strategy was the strategy that best matched the participant's responses

Table 1

Number of participants best fit by a unidimensional (UD), overall similarity (OS), identity (ID), or response bias (Bias) model, as a function of stimulus presentation time, in Experiment 1.

Time	UD	OS	ID	Bias
100 ms	1	27	0	1
2000 ms	0	17	0	0

Results and discussion

Table 1 shows, as expected, that there was a strong preference for overall similarity classification at 2000 ms. However, shortening the presentation time to 100 ms appeared to have little effect. One participant was best fit by a response-bias model (i.e., always pressing the same key), one by the assumption they were responding on the basis of a single dimension. All the other participants remained best fit by an overall similarity account. Bayesian analysis, conducted with the `BayesFactor` R package (Morey & Rouder, 2022), indicated that the ratio of unidimensional to overall similarity classifiers was unaffected by our time pressure manipulation, $BF_{10} = 0.14$. This result is not diagnostic between Combination Theory and Differentiation Theory. Differentiation Theory can attribute the lack of increase in overall-similarity classification to a ceiling effect, and Combination Theory can attribute it to the manipulation being insufficiently potent to produce a detectable effect.

In a further, exploratory, analysis we fitted the same response models to each eight-trial block of responses separately, deriving the number of blocks which, for each participant, were best fit by each model. Although this analysis is a novel one for the triad task, we have employed it in previous experiments using the match-to-standards procedure (Wills, Milton, Longmore, Hester, & Robinson, 2013). We speculated that this analysis might be more sensitive to low levels of unidimensional classification, assuming that, due to

210 both internal and external noise, participants sometimes successfully classified on the basis of

211 both dimensions but other times did not have time to combine both dimensions and hence

212 responded on the basis of a single dimension. This analysis was conducted on 45

213 participants, as one participant had been found to best fit a response-bias model.

214 Response-bias models can only be fit at a whole-participant level, not an individual-block

215 level, because it is only at the participant level that the physical position of the stimuli on

216 the screen is counterbalanced.

Table 2

Mean proportion of unidimensional (UD), overall similarity (OS), and identity (ID) blocks,
as a function of stimulus presentation time, in Experiment 1.

Time	UD	OS	ID
100 ms	0.119	0.881	0.000
2000 ms	0.018	0.975	0.007

217   On 13% of blocks, models tied for first place; these blocks were removed from further

218 analysis. Table 2 shows the results of this by-block analysis. The crucial result is that

219 participants in the 100 ms condition produce more classification blocks best fit by a

220 unidimensional response model than participants in the 2000 ms condition, $BF_{10} = 4.92$.

221 Hence reducing the stimulus presentation time increased unidimensional responding, even for

222 these integral stimuli. This result is predicted by Combination Theory, and disconfirms

223 Differentiation Theory.

224   One obvious criticism of this conclusion is that it is based on a post-hoc analysis which,

225 despite having precedents in the literature, was only engaged after our a priori analysis failed

226 to reveal conclusive results. For this reason, we conducted a direct replication.

₂₂₇ **Experiment 2**

₂₂₈ **Method**

₂₂₉   Fifty psychology students from XXX University participated for partial course credit;

₂₃₀ this sample size has sufficient (84%) power to detect the medium-to-large effect observed in

₂₃₁ the by-blocks analysis of the previous experiment (d = 0.83). The stimuli, apparatus, and

₂₃₂ procedure, were identical to the previous experiment.

Table 3

*Mean proportion of unidimensional (UD), overall similarity (OS), and identity (ID) blocks,
as a function of stimulus presentation time, in Experiment 2.*

Time	UD	OS	ID
100 ms	0.142	0.850	0.008
2000 ms	0.012	0.988	0.000

₂₃₃ **Results and discussion**

₂₃₄   One participant was excluded due to being best fit by a response-bias model. On 10%

₂₃₅ of blocks, models tied for first place; these blocks were removed from further analysis. Table

₂₃₆ 3 shows the key results, which are similar to the previous experiment. Crucially, shorter

₂₃₇ presentation times (compared to longer presentation times) once again increased the

₂₃₈ prevalence of unidimensional classification of these integral stimuli, $BF_{10} = 1047$. This

₂₃₉ Bayesian calculation makes use of a prior based on the size of the effect in the previous

₂₄₀ experiment. Specifically, following Dienes (2011), we used a normally-distributed prior of

₂₄₁ effect sizes, centered on the observed difference in the previous experiment, and with a

₂₄₂ standard deviation of half that observed difference. There is also Bayesian evidence for the

₂₄₃ effect of stimulus presentation time on unidimensional responding if one entirely ignores the

244 prior provided by the previous experiment and uses a non-directional test against a

245 non-informative prior, as performed in the previous experiment, $BF_{10} = 3.50$.

<div align="center">

Experiment 3

</div>

247   Our final experiment had two purposes. First, we wished to confirm that the stimuli as

248 presented in the first two experiments met a standard Garner definition of integrality, i.e. the

249 pairwise similarity ratings were better fit by a Euclidean than a city-block multidimensional

250 scaling (MDS) solution (Garner, 1976). Second, we wished to assess the closeness of the

251 resulting MDS solution to the solution provided by the Munsell colour codes attributed to

252 these stimuli. If differences were to be found, we would then use the MDS solution in a

253 re-analysis of the triad data that represents the stimuli in terms of a psychological, rather

254 than physical, stimulus space.

Method

256   **Participants, apparatus and stimuli.**   Twenty-four participants were tested in

257 this experiment; the sample size was determined by the number of course credits available at

258 the time of testing and is similar to past experiments Shin & Nosofsky (1992). PsychoPy

259 software (Pierce, 2007), version 1.83, was used to present the stimuli and to collect responses

260 via a standard PC keyboard and mouse. The stimuli were the same as in the two previous

261 experiments.

262   **Procedure.**   After some initial instructions explaining the task, the experiment

263 began. On each trial, two square stimuli were shown in the centre of the screen, arranged

264 horizontally, and placed 2cm apart as measured from their centres. Participants were asked

265 to rate the similarity of each pair of stimuli using a 1-9 scale. The scale was visually

266 presented on the screen, below the square stimuli, along with text specifying that "1 = not

267 very similar" and "9 = very similar". The number 5 was also indicated on the scale, but not

268 further labelled. A moveable rectangular slider was present on this scale. Initially placed

269 above the number 5, participants moved this slider to one of the nine available ratings using

²⁷⁰ the mouse and indicated their response with a mouse click. The screen cleared immediately

²⁷¹ after the participant's response, and the next trial began one second later.

²⁷² The experiment had two blocks of 56 trials. A block comprised two presentations of

²⁷³ each possible pair of the eight stimuli, with left-right position of the stimulus pair

²⁷⁴ counterbalanced across those two presentations. Trial ordering was randomized separately

²⁷⁵ for each block and participant.

²⁷⁶ Results and discussion

Table 4

Pairwise similarity ratings.

	1	2	3	4	5	6	7
2	4.32						
3	7.68	4.54					
4	5.03	7.12	6.38				
5	4.47	3.07	5.90	4.28			
6	3.78	3.33	4.79	4.65	6.60		
7	3.81	2.36	4.71	3.27	7.66	5.66	
8	3.57	2.97	3.92	3.95	5.61	7.34	5.33

²⁷⁷ The average pairwise similarity ratings for the eight stimuli are shown in Table 4.

²⁷⁸ Two-dimensional, non-metric multidimensional scaling (Kruskal, 1964) was applied to these

²⁷⁹ data, using the `isoMDS` function of the R package `MASS` (Ripley, 2023). The stress of the

²⁸⁰ Euclidean solution (0.04) was lower than the city-block solution (3.19), implying that these

²⁸¹ stimuli are better considered as integral than separable by Garner's operational definition.

²⁸² Figure 2 shows the Euclidean MDS solution, scaled and Procrustean rotated for best fit

²⁸³ to the co-ordinates of the stimuli in the Munsell colour system; these rigid transformations

284 do not affect the distance relationships in a Euclidean MDS solution. The `procrustes`

285 function of the R package `vegan` (Oksanen et al., 2022) was used for this part of the analysis.

286 Following standard practice, we assumed that, in the Munsell system, two units of chroma

287 are psychologically equivalent to one unit of brightness (Nickerson, 1936; Nosofsky, 1987;
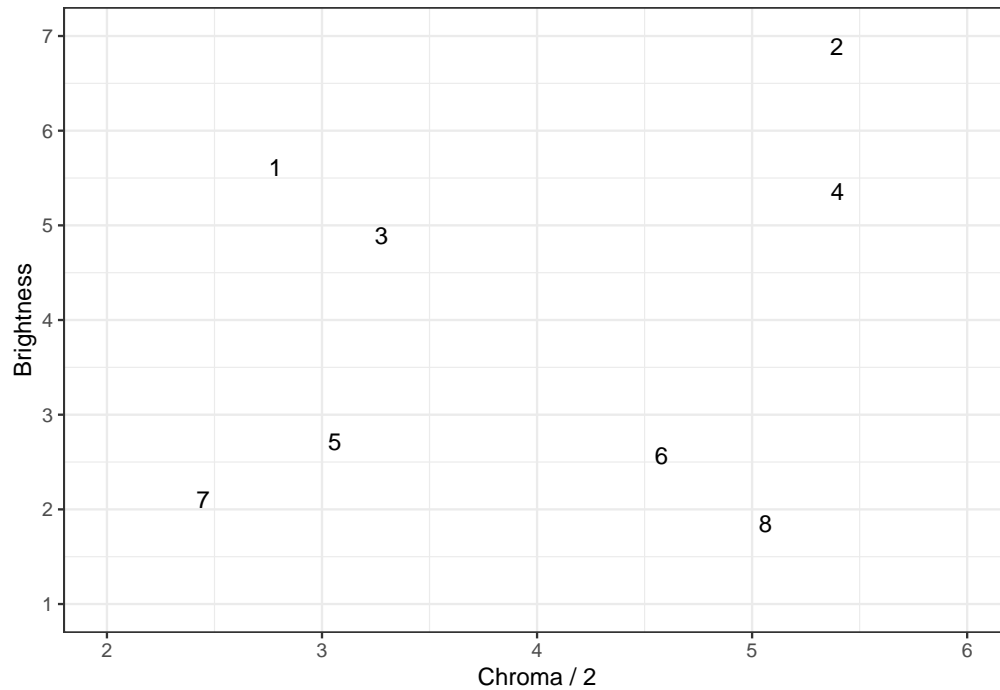
288 Shepard, 1958).

Figure 2. Multidimensional scaling solution

289   Inspection of Figure 2 indicates that, for six of the eight stimuli, the MDS solution

290 shows similarity relations comparable to those in the Munsell co-ordinates. The exceptions

291 are stimuli 2 and 4, which would appear to have been perceived as somewhat brighter and

292 more saturated than their Munsell co-ordinates would indicate. This may have been a

293 function of our use of commodity hardware for screen display.

294   Given these moderate discrepancies between the Munsell co-ordinates and the

295 multidimensional scaling solution, we re-analyzed the data from the previous two

296 experiments, combining the two datasets and using the MDS co-ordinates as the inputs to

297 our response models, rather than the Munsell co-ordinates.

Table 5

Mean proportion of unidimensional (UD), overall similarity (OS), and identity (ID) blocks,
as a function of stimulus presentation time.

Time	UD	OS	ID
100 ms	0.319	0.681	0
2000 ms	0.086	0.914	0

298   Two participants were excluded due to being best fit by a response-bias model. On

299 25% of blocks, models tied for first place; these blocks were removed from further analysis.

300 Table 5 shows the results of our re-analysis. Using the MDS co-ordinates for these stimuli

301 approximately doubled the magnitude of the effect observed with the Munsell co-ordinates;

302 unidimensional responding rose from 9% at 2000 ms to 32% at 100 ms. Bayesian analysis,

303 employing a non-informative prior, provides very strong support for an effect of stimulus

304 presentation time on the prevalence of unidimensional responding, $BF = 892$. Hence, overall,

305 the three experiments presented in the current paper provide strong evidence for the effect

306 predicted by Combination Theory, and disconfirm Differentiation Theory.

307   Further inspection of Figure 2 reveals that no stimulus is identically placed on either

308 dimension (this is true even for stimuli 2 and 4 on the chroma dimension). As a consequence,

309 the Identity response model can never predict participants' responses, leading to reported

310 zero prevalence of Identity responding in Table 5. It would in principle be possible to

311 generalize the Identity response model such that it could deal with near-identity (such as

312 stimuli 2 and 4 on chroma) effectively, and the work of L. B. Smith (1989) suggests a way in

313 which this could be done. However, given the very low prevalence of ID classification

314 observed for these stimuli in our earlier analysis, where the use of Munsell co-ordinates

315 would have made such responding detectable if it had occurred, such a generalization of the

316 Identity model would be unlikely to change the conclusions of the current work.

General Discussion

317   As stimulus presentation time increases, the prevalence of single-dimension

318 classification of multi-attribute stimuli increases (Wills et al., 2015). This phenomenon is

319 well established for separable stimuli (e.g. squares varying in size and brightness), but the

320 current experiments are the first demonstration for integral stimuli (specifically, for squares

321 varying in saturation and brightness). Intuitively, this effect of stimulus presentation time on

322 integral stimuli may seem surprising. After all, under unspeeded conditions, it is well

323 established that selectively attending to integral stimulus dimensions requires effort (Garner,

324 1976). Such observations have led some to conclude that cognition begins with an

325 undifferentiated stimulus whole, which is analyzed into its components only with effort

326 (Lockhead, 1972 et seq.); a view subsequently described as Differentiation Theory (Wills et

327 al., 2015). However, our results support an approximately opposite account - cognition

328 begins with stimulus attributes, which are combined if time and mental resources allow

329 (Neisser, 1967 et seq.); an account subsequently described as Combination Theory (Wills et

330 al., 2015). Once attributes are combined, selective attention is somewhat effortful, and that

331 effort is greater for integral than for separable stimuli. Under a Combination Theory account

332 synthesis, rather than analysis, is the more appropriate chemical metaphor. Integral stimuli,

333 rather than being slowly analyzed, are quickly synthesized.

334

335   Although the current experiments concern the presentation of simple stimuli in the

336 laboratory, the distinction between Differentiation and Combination Theory is of broader

337 relevance. The terms 'analytic' and 'nonanalytic' (or 'holistic') are broadly applied in

338 psychology as theories of modes of thought. Such terms seem to assume the correctness of

339 Differentiation Theory (otherwise terms such as 'synthetic' would be more appropriate).

340 Given that Differentiation Theory seems to be largely the wrong theory for the classification

341 of simple stimuli, an investigation of the extent to which the predictions of Differentiation

342 Theory are correct across psychology more generally seems worthy of further examination.

343 For example, a form of Differentiation Theory seems to underlie the proposal that the

344 training of radiologists could be improved by distracting them with a secondary task

345 (Filoteo, Lauritzen, & Maddox, 2010), while Combination Theory predicts that this is likely

346 to be harmful (Newell, Moore, Wills, & Milton, 2013). A second example - one of the key

347 ways WEIRD (Western Educated Industrialized Rich and Democratic) populations are

348 described as differing from some other cultures is in the unusual extent to which WEIRD

349 thought is characteristically 'analytic' rather than 'holisitic' (Henrich, Heine, & Norenzayan,

350 2010). Such a description presupposes a form of Differentiation Theory.

351   Returning to the experiments reported in the current paper, the same-lab replication of

352 our results reduces the chances that we are reporting a false positive, but replication by an

353 independent lab would further increase confidence, and we are keen to support such efforts.

354 Our materials and analysis methods are publicly available. One crucial aspect for successful

355 replication of our results is the well-controlled presentation of precisely-defined stimuli; the

356 logic of the experiment requires, for example, that the location of stimuli in physical stimulus

357 space (Figure 1) corresponds reasonably closely to their position in psychological stimulus

358 space. Investigations of our own stimuli (reported in Experiment 3) support the conclusion

359 that, in our case, the correspondence was sufficiently close that our conclusions remain valid

360 (in fact, use of a psychological stimulus space strengthens the support for our conclusions).

361 Nonetheless, future investigators may wish to take further steps towards tight stimulus

362 control (for example, the use of more specialist hardware for stimulus presentation). Future

363 research might also consider extending to other integral stimulus sets, with pure tones

364 differing in pitch and loudness probably the other most-validated integral set to date (Grau

365 & Kemler Nelson, 1988). Finally, it would be interesting to see which formal process models

366 of classification can accommodate the current results. EGCM (Lamberts, 1995) seems a

367 likely candidate, as does any other model that explicitly combines stimulus dimensions over

368 time (Cohen & Nosofsky, 2003). In contrast, theories such as COVIS (Ashby, Alfonso-Reese,

369 Waldron, et al., 1998), in which responding on the basis of a single dimension is a function of

the effortful use of the rule-based system, seem conceptually closer to Differentiation Theory, and hence may require some modification in order to accommodate the present results.

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