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Psychometric correlates of categorization: An exploratory study

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Recent studies have reported individual differences in the capacity to learn new categories; the differences had electrophysiological correlates. The objective of the present study was to test whether these differences reflected individual differences in cognitive traits. 15 participants (aged 20 to 30) who had participated in the prior category-learning studies agreed to take some tests of cognitive ability, including (1) the perceptual reasoning subtests of the Weschler Adult Intelligence Scale (WAIS-IV) and (2) the Doors & People test of visual memory. Prior category learning performance was found to be positively correlated with perceptual reasoning and with visual memory in partial correlations. These findings confirm that the differences in category learning may be linked at least in part to differences in cognitive abilities.

Keywords: intelligence, perceptual reasoning, visual memory, category learning, categorical perception

Des études récentes ont rapporté des différences individuelles dans la capacité à apprendre de nouvelles catégories. L'apprentissage des catégories possédait des corrélats électrophysiologiques. L'objectif de l'étude actuel était de tester si ces différences reflétaient des différences individuelles dans des traits. Quinze participants (entre 20 et 30 ans) qui avaient participé à des études précédentes d'apprentissage catégoriel ont accepté de participer aux sous-tests du raisonnement perceptuel du WAIS-IV et le Doors test du Doors & People test pour tester la mémoire visuelle. La performance dans la tâche d'apprentissage des catégories était corrélée positivement au raisonnement perceptuel et à la mémoire visuelle suite à des corrélations partielles. Ces résultats confirment que les différences dans l'apprentissage des catégories seraient liées, au moins en partie, à des différences cognitives.

Mots-clés : intelligence, raisonnement perceptuel, apprentissage des catégories, mémoire visuelle, perception catégorielle

Introduction

Sometimes stimuli from different categories look more different from one another than stimuli in the same category, even when the physical differences between them aren't greater than the difference observed between stimuli of the same category. This effect is called *Categorical Perception* (CP). In the case of color categories, 'Equal-sized frequency differences look much smaller and are harder to detect when they are within one color category than when they cross the boundary from one category to the other' (Harnad, 2017). Color categories are innate, but sometimes the CP effect can be caused by learning through trial and error to categorize stimuli (Goldstone & Hendrickson, 2009). In experiments on category learning, some participants succeed in learning the category and others do not. In this paper we ask 1) are there cognitive differences between the learners and non-learners; and 2) if so, what cognitive traits are linked to learning performance.

Intelligence

In category learning experiments, participants must learn to sort visual stimuli into one of two categories. This requires the ability to detect the visual features that distinguish the members (Pérez-Gay et al., 2017). The psychometric correlates of this ability may help us understand the factors underlying category learning and categorization. Potential measures are intelligence tests. Acton and Schroeder (2001) reported a positive correlation between general intelligence and sensory discrimination in several modalities (i.e., color & pitch discrimination), suggesting that discrimination and intellectual capabilities may be related to processing speed. Deary and al. (2004) found a positive correlation between several intelligence tasks and sensory discrimination tasks. They also found a correlation between the general intelligence factor and color discrimination, $r = .31$.

Prior reviews of sensory discrimination and intelligence test scores (Deary, 1994; 2001) describe a modest but consistent positive correlation between the two variables. A reanalysis (Fancher,1985b, cited in Deary 1994) finds a positive correlation close to 1.0 between the general intelligence factors and a general discrimination factor. The relationship is more apparent in more rigorous recent studies. Sample

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homogeneity was a methodological concern in earlier studies on intellectual capacities. Homogeneity must be considered; a correlation cannot be detected if there is little or no variation. Voelke and al. (2013) have proposed that the correlation between intelligence and sensory discrimination can in large part be explained by working memory. Working memory and sensory discrimination are shown to predict intelligence. However, sensory discrimination's predictive power was statistically dependent on working memory. The authors argue that working memory is solicited in both sensory discrimination tasks and intelligence tests as an explanation for the relationship.

Psychometric intelligence is correlated not only with visual discrimination but with suppression mechanisms that underlie discrimination and hence categorization. Melnick et al. (2014) report a positive correlation between visual suppression capacity and performance on subtests of the Wechsler *Adult Intelligence Scale-III*. This suppression mechanism consists of inhibiting the processing of irrelevant stimuli during sensory discrimination. These irrelevant stimuli include large moving stimuli that appear to belong to the background. Suppression was measured by the difference in accuracy in discriminating between the large stimuli and smaller ones. This difference was called the *suppression index* (SI). A positive correlation between SI and intelligence was observed. The more intelligence increases, the fewer large stimuli are processed, and the faster smaller stimuli (i.e., more relevant to image recognition) are treated. The correlation was strong, r = .71, in study two, and in study 1, r = .64. For the Perceptual *Reasoning Index* (PRI), a subtest of the *WAIS-IV* that assesses visual-motor integration, spatial processing, and fluid reasoning (Wechsler et al., 2008), the correlation was of r =.47. This is relevant for two reasons. First, the PRI includes the *Block Design Task*. The *Block Design Task* measures sensorimotor coordination, more specifically visuomotor coordination. According to Harnad (2017), categories are grounded in our ability to detect invariant features from our sensorimotor interactions with our environment. This would imply that sensorimotor abilities measured in intelligence subtests may play a role in category learning. Second, selectively ignoring (i.e., hence, suppressing) non-relevant features is needed to categorize stimuli. By using a part of the PRI (i.e., the *Matrix Reasoning Task*), researchers have found a correlation between intelligence subtests and visual suppression and have proposed a physiological basis for this relationship (Cook et al., 2016). *Gamma-Aminobutyric acid* (GABA), a neurotransmitter, concentration in the occipital region was correlated with both visual suppression and intelligence test performance. In category learning studies, neurophysiological data were found to be correlated with differences between learners and non-learners and with individual learning performance in other contexts: Pérez-Gay and al. (2019) reported that patterns of *event-related potentials* (ERPs) in the occipital region distinguished learners from non-learners. An early N1 component is correlated with individual learning performance detectable in learners, but not in non-learners. The fact that a similar region of the brain is linked to both category learning and perceptual reasoning seems to support the claim that they are linked.

The correlation between visual suppression and psychometric intelligence seems to have been replicated in two studies. This is relevant to the current study as perceptual reasoning and visual suppression have also been linked to similar anatomic substrates and capacities thought to be necessary for acquiring categories.

Visual memory

Long-term memory also seems to have a relationship with categorization. Konkle and al. (2010a) suggest that long-term visual memory is involved in perceiving categories. Their task consisted of determining which stimuli had been in a previously presented set of images and which stimuli were new. Participants which stimuli had been in a previously presented set of images and which stimuli were new. Participants were less able to distinguish new items from old ones when they came from different categories than when they came from the same category. Ability to distinguish categories was also correlated with better memory for presented items (Konkle et al., 2010b). Conceptual distinctiveness was assessed by thein a previously presented set of images and which stimuli were new. Participants were less able to distinguish new items from old ones when they came from different categories than when they came from the same category. Ability to distinguish categories was also correlated with better memory for presented items (Konkle et al., 2010b). Conceptual distinctiveness was assessed by the number of subtypes a given category had.

Conceptually distinct categories were recalled with less interference. Additional evidence for a link between long-term visual memory and categorization exists in studies on episodic memory. Episodic memory relates to long-term memory for specific autobiographical moments (Conway, 2009). In a review, Ashby and O'Brien (2005) state several reasons to believe category learning may rely on episodic memory. For instance, in anterograde amnesiac patients whose episodic memory was not impaired, category learning performance was normal.

This suggests that categorization doesn't just help long-term memory, it benefits from it as well. The data outlined above lends support to the hypothesis that differences in performance between learners and non-learners are due to cognitive differences. Visual memory is a factor in the perception of categories and intelligence is correlated with processes (i.e., sensory discrimination and visual suppression) required for category learning.

Objectives

Our main objective is to assess the predictiveness of psychometric measures of perceptual reasoning and long-term visual memory in visual category learning and categorical perception. Our hypotheses are 1) A higher proportion of correct responses in the category learning task will be positively correlated with the score on perceptual reasoning tasks; 2) a higher proportion of correct responses in the category learning task will be positively correlated with the total score on the visual memory task; 3) learning speed, as measured by the number of completed trial before attaining learner status, will be positively correlated with the score on perceptual reasoning tasks; 4) CP size will be positively correlated with the score on the perceptual reasoning tasks; and 5) CP size will positively correlate with the performance on the visual memory task.

Methods

Participants

A sample of 15 university students (i.e., 13 females and 2 males; age 20 to 30) who had participated in prior studies on visual categorical perception and category learning were recruited for the present study. Participants were equally distributed amongst learners, non- learners, and borderlines (i.e., participants who attained learner status but could not maintain it). None of the participants suffered from neuropsychological disorders. All participants gave their written consent before participating in the study. An ethical committee provided a certificate of ethical approbation which allowed for the current study's testing to take place. Scores for all measures were converted to *z*-scores to look for outliers (i.e., three standard deviations beyond the mean); no outliers were found. Each participant was paid a sum of 15 dollars.

Procedure

Data from two components were combined for this study: 1) the category learning and data from prior category learning, and ABX discrimination experiments that had been conducted by other researchers in our lab from an anterior study; and 2) the direct assessment of the perceptual reasoning subtests of the *WAIS-IV* and the *Doors & People Test* to a sample of participants from the anterior study and analysing the results in relation to their prior learning performance.

To measure perceptual reasoning, we derived scores from individual subtests that constitute the PRI (i.e., *Block Design*, *Picture Completion*, Visual *Puzzles*, and *Matrix Reasoning*). For subtests with a time limit, participants were asked to answer items as quickly as they could. In *Block Design*, participants must replicate images using white and red cubes. As the task progresses, participants are given more complex structures that require using more cubes. In *Matrix Reasoning*, the participants must select an image that completes a pattern of presented images. In the *Visual Puzzle Task*, participants must identify three images that can be grouped to match a target image. In the *Picture Completion Task*, participants are instructed to find which elements of a picture are missing. Which construct was measured by each subtest is shown in Table 1.

To measure long-term visual memory, we used the *Doors* subtest of the *Doors & People Test*. Participants were asked to sit in front of a monitor and shown 12 images of doors (i.e., per set). The task consisted of two sets. Set B was harder than set A. After seeing each set, participants were shown a screen with four doors (i.e., three novel doors and one door from the set they had just been). Participants were then asked to indicate which door was previously presented. Both the total score and the scores for each individual set were computed for each participant. Each set started with two practice items.

Table 1

Psychometric measures and their measured constructs according to the WAIS-IV Technical and Interpretative Manual (4th ed.)

Measures	Constructs
Block Design (*WAIS-IV*)	Conceptual reasoning, visuospatial abilities, and visuomotor coordination
Matrix Reasoning (*WAIS-IV*)	Perceptual organization, classification, and simultaneous processing
Visual Puzzles (*WAIS-IV*)	Visuospatial aptitudes
Picture Completion (*WAIS-IV*)	Visual perception of details
Doors Test (*Doors & People Test*)	Long-term visual memory

The variables related to categorization were the category learning scores on the last 100 trials and the differences between the ABX discriminability scores (i.e., within and between categories) before and after the category learning (cf. description below). A *positive* difference in discriminability between objects in different categories was the CP variable 'between-category separation'. A *negative* difference in discriminability between objects in the same category was the CP variable 'within-category compression'. The number of trials it took to attain and maintain the learning criterion (i.e., 80%) was also computed as a measure of the speed of learning.

Prior learning experiments

Participants sat in front of a computer screen with a keyboard and a mouse. Experimenters placed a cap with electrodes on the participants' heads to gather electroencephalogram (EEG) data. The task started with a set of practice trials, followed by an ABX discrimination task to assess the degree of CP. The ABX task consists of showing the participant two different texture stimuli, type A or B, one after the other, followed by a third, X, which is either identical to A or to B (i.e., hence the sequence is either ABA or ABB). The participant has to indicate whether X was A or B. Sometimes A and B are from different categories and sometimes from the same category, but the participant has not yet learned the categories at this stage. The ABX task always consisted of 48 trials.

Following the ABX task, participants did trial and error category learning with corrective feedback (i.e., 400 trials). The textures, presented one at a time, could be either "Kalamites" or "Lakamites." Participants had to respond on each trial by pressing 'K' for 'Kalamite' or 'L' for 'Lakamite'. Then there was feedback indicating whether their response had been correct or incorrect. After the 400 training trials, the ABX task is repeated. Figure 1 shows the category learning task. Figure 2 shows the ABX discrimination task.

Psychometric testing session

The session would start with *WAIS-IV* subtests to assess the PRI. The tests are always presented in the same order: first *Block Design*, then Matrix *Reasoning*, *Visual Puzzle*, *Picture Completion*, and *Doors*. Two participants completed the *Doors Test* at home after being given instructions to complete it on their own and to avoid distractions.

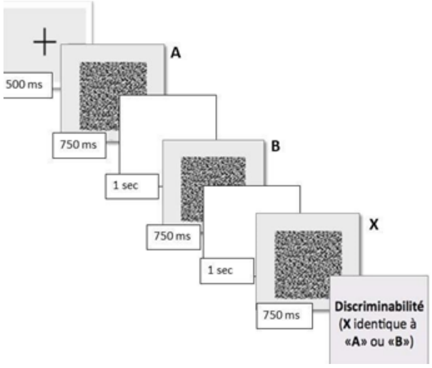
Analysis

The first 2 hypothesis were tested by looking at the correlations that PRI scores and *Door Test* scores have with the proportion of correct responses in the last 100 trials of the category learning task. The third hypothesis was tested by correlating PRI with the number of trials before attaining learner status. The fourth and fifth hypotheses will be tested looking at the correlations PRI scores and *Door Test* scores have with separation and compression. To assess whether the relationships between intelligence and long-term memory were independent of one another, partial correlations were used. *Doors* score was controlled in the correlation between PRI and the proportion of correct responses. PRI score was controlled in the correlation between *Doors* and the proportion of correct responses. Scores for all measures were converted to *z*-scores to look for outliers (i.e., 3 standard deviations beyond the mean); no outliers were found.

Results

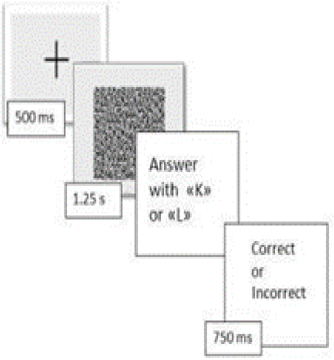
Values were distributed normally (i.e., kurtosis and skewness between 2 and -2), except for separation (cf. Table 2). Separation had a kurtosis above 5 meaning it wasn't normally distributed and couldn't be used in further analysis. Our sample was small, making it difficult to obtain statistically significant results. Overall effect sizes were moderate.

Figure 1
ABX discrimination task



Sets of 3 pictures are presented to participants .After each set, the participant must determine if the third picture is identical to the first (**press 1** on the keyboard) or the second (**press 2** on the keyboard).

Figure 2
Learning through trial and error of binary category



The participants try to learn a category through trial and error with a corrective feedback.

Table 2

Descriptive statistics

	n	Min	Max	Mean	Std. deviation	Variance	Skewness	SE	Kurtosis	SE
Perceptual reasoning index	15	66	125	102.67	15.57	242.52	-0.82	0.58	0.61	1.12
Bloc Design task	15	3	14	9.60	3.46	11.97	-0.47	0.58	-0.78	1.12
Matrix Reasoning task	15	5	18	12.33	3.18	10.10	-0.60	0.58	0.84	1.12
Picture Completion task	15	1	13	8.73	3.26	10.64	-0.95	0.58	0.84	1.12
Visual Puzzles task	15	3	12	9.07	2.71	7.35	-0.95	0.58	0.24	1.12
Category Learning task score (4th part)	15	0.41	0.96	0.72	0.15	0.02	-0.15	0.58	-0.23	1.12
Degree of Separation	15	-3.88	1,49	-0.53	1.21	1.47	-1.58	0.62	5.30	1.19
Degree of Compression	13	-1	1.43	0.21	0.80	0.64	-0.03	0.62	-1.32	1.19
Doors (set A)	13	0	13	6.38	4.75	22.59	0.08	0.62	-1.00	1.19
Doors (set B)	13	0	11	2.54	3.48	12.10	1.58	0.62	1.98	1.19
Doors (total score)	13	0	6	3.54	2.03	4.10	-0.74	0.62	-0.74	1.19
Valid *n* (listwise)	11									

Note. Min = minimum; Max = maximum; SE = standard error.

Table 3

Bivariate correlations

	PRI	PCT	BD	MRT	VP	CATL	Comp.	Sep.	*Doors* (Total)	*Doors* (set B)	*Doors* (set A)
PRI	1	.12	.92**	.93**	.67**	.49	-.42	.02	-.05	-.22	.11
PCT	.12	1	.10	.16	-.14	.43	-.13	.44	-.09	-.15	.03
BD	.92**	.10	1	.81**	.45	.49	-.46	.08	-.06	-.26	.05
MRT	.93**	.16	.81**	1	.61*	.41	-.20	-.03	-.10	-.11	-.01
VP	.67**	-.14	.45	.61*	1	.05	-.08	-.57	-.10	-.16	.15
CATL	.49	.43	.49	.41	.05	1	-.75**	.47	.48	-.20	.55
Comp	-.42	-.13	-.46	-.20	-.08	-.75**	1	-.50	-.11	.62	-.56
Sep	.02	.44	.08	-.03	-.57	.47	-.50	1	.24	-.30	.33
Doors (total score)	-.05	-.09	-.06	-.10	-.10	.48	-.11	.24	1	.22	.74**
Doors (set B)	-.22	-.15	-.26	-.11	-.16	-.20	.62	-.30	.22	1	-.45
Doors (set A)	.11	.03	.05	-.01	.15	.55	-.56	.33	.74**	-.45	1

Notes. BD = *Bloc Design Task*; CATL = *Category Learning Task* (4th part); Comp. = compression; MRT = *Matrix Reasoning Task*; PCT = *Picture Completion Task*; PRI = Perceptual Reasoning Index; Sep. = Separation; VP = *Visual Puzzles Task*; *$p < .05$; **$p < .01$.

Table 4

Partial Correlations between category and PRI subtests

Control variable			CATL	PRI	BD	MRT	PCT	VP
Doors (total score)	CATL	Corrélation	1	.65*	0.62*	.59*	.58*	.17
		Significance (bilateral)		.02	.03	.05	.05	.60
		df	0	10	10	10	10	10

Note. BD = *Block Design*; CATL = *Category Learning Task* (4th part); MRT = *Matrix Reasoning Task*; PCT = *Picture Completion Task*, PRI = Perceptual Reasoning Index; VP = *Visual Puzzles;* *$p < .05$.

Table 5
Partial correlations between scores on the Doors test and Category learning

			CATL	*Doors* (Total)	*Doors* (set B)	*Doors* (set A)
PRI	CATL	Correlation	1	.60*	-.1	.58*
		Signification (bilateral)		.04	.76	.05
		df	0	10	10	10

Note. CATL = *Category Learning Task* (4th part); PRI = Perceptual Reasoning Index; **p* < .05.

Bivariate correlations failed to reach statistical significance (cf. Table 3). However, significant associations were obtained when looking at the performance on the last learning block and the total score on Doors, $r = .602$, $p = .038$, as well as for Set A, $r = .584$, $p = .046$, after controlling for the PRI. After controlling for the total score of the *Doors* test, the PRI showed a positive correlation, $r = .646$, $p = .023$, with the last learning block as did most individual subtests: the *Bloc Design*, $r = .624$, $p = .03$, the *Matrix*, $r = .59$, $p = .045$, and *Picture Completion*, $r = .58$, $p = .05$ (cf. Table 5).

Discussion

The goal of this study was to find which cognitive capacities are associated with success in category learning. Partial correlations support our prediction, in part, of a positive correlation between learning and two constructs: long-term visual memory and perceptual reasoning. This may suggest that factors contributing to long-term visual memory perceptual reasoning (i.e., visuospatial ability, conceptual reasoning, and especially visuomotor construction) play a role in category learning ability. Due to the correlational nature of our study, it is impossible to demonstrate that the perceptual reasoning abilities measured by the PRI play a causal role in category learning. It may be that categorization plays a causal role in perceptual reasoning abilities. If categorization is grounded in detecting invariant features of our sensorimotor interactions with the environment (Harnad, 2017), this may help in the *Block Design Task* performance which employs visuomotor aptitudes and has the second strongest correlation after the PRI, when we controlled for the *Doors* 'score. It could also be that perceptual reasoning and the discrimination ability used in the categorization task both depend on processing speed; Acton and Schroder (2001) and Deary (1994, 2001) have suggested this.

Our second hypothesis was partially supported. After controlling for PRI, however, correlations for set A and the total Doors tests score became statistically significant. This may be evidence for Konkle and al.'s (2010a) suggestion that long-term memory benefits from the ability to perceive categories. Alternatively, long-term memory may be important in category learning: a better capacity to memorize the features of category members may be useful. This is supported by the fact category learning capabilities were normal in amnesic patients with no impairments in episodic memory (Ashby & O'Brien, 2005). However, the idea of long-term memory as a distinct factor from PRI is reinforced by their different neurological substrates. The left parietal cortex is implicated in perceptual reasoning (Glascher et al., 2009) whereas the hippocampus and medial temporal are implicated in episodic memory (Tulving, 2002). The difference in correlation the Door Test performance and PRI have with category learning may be a result of the underlying physiological processes being dissimilar. The lack of significant results in set B may be a result of the low amount of variance relative to set A in the scores the participants had on this part of the task (cf. Table 2).

In conclusion, the findings suggest that intelligence, and more precisely perceptual reasoning, either share a common basis with categorization abilities or facilitates it. They also suggest that long-term visual memory may facilitate visual categorization performance. Partial correlations suggest that the relationship between Doors performance and category learning is independent of perceptual reasoning and that the correlation with perceptual reasoning is independent of the *Doors* test, but is strongest with the *Block Design*. This study provides evidence for the link between intelligence and sensory discrimination, and the role of visual memory in category learning. It also confirms the sensorimotor nature of category learning.

Limitations

We failed to control for the visual acuity of participants. It would have been worthwhile to use a test for uncorrected myopia using a distance chart, for example. Our small sample limits the statistical significance and generalizability of our findings. The sample was even smaller for the Doors test because two participants did not take part in it (i.e., due to technical problems). Information on the validity and reliability of the *Doors* test is also limited. Because our study is correlational, we can only speculate about causality. Additionally, the fact that our participants were students aged between 20 and 30 with no history of neuropsychological impairment restrains our ability to generalize our results to a clinical population, such as Alzheimers patients. Furthermore, the greater amount of semantic knowledge of common everyday objects required in tasks such as the Doors test compared to the WAIS-IV tasks may affect the performance of individuals in certain cultures and people suffering from disorders like semantic dementia, for instance.

Categorization abilities may also help in reasoning or visual memory. Another methodological problem was that participants' keyboards in the original experimental study would occasionally disconnect from the computer, so some timeouts were wrongly recorded. Timeouts were hence excluded in the final scores for the categorization tasks.

Further research should increase the sample size and control for uncorrected visual problems. The current study only used measures of long-term memory. In the future, other forms of memory such as working memory should be examined. As it was mentioned before, previous studies have found that working memory has been shown to correlate with both discrimination ability and intelligence measures (Voelke et al., 2013). It may also be beneficial to use another test of long-term visual memory. There is little information in the literature on the reliability and validity of the Doors and People test. The lack of psychometric data on the Doors tests makes it difficult to determine how predictive it is of performance in other tasks of long-term memory, and how well its different parts and items measure the same construct. This makes it difficult to explain the difference in results in sets A and B, for instance, and how much each set is reliable and valid in the assessment of the underlying memory construct.

Conclusion

In conclusion, the findings suggest that intelligence, more precisely perceptual reasoning, either shares a common basis with categorization abilities or facilitates it. They also suggest that long-term visual memory may facilitate visual categorization performance. Partial correlations suggest that the relationship between *Doors* performance and category learning is independent of perceptual reasoning and that the correlation with perceptual reasoning is mainly due to the capacities measured by *Block Design* such as visuomotor coordination, conceptual reasoning, and visuospatial abilities. Visuospatial aptitudes may also play a role in the CP separation/compression effect.

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