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摘 要

类别特征推理的认知机制及脑机制

分类和推理是类别知识的两大重要功能，除了分类任务，类别特征推理任务也是类别知识的很重要的应用方面。分类任务是已知某项目具有的特征值，推测该项目所属类别的类别标签。而类别特征推理任务是已知某个项目所属的类别标签及部分特征值，推测该项目的未知特征值。以往的类别相关研究都局限于对分类任务的研究，而关于类别特征推理任务认知机制的研究还非常少，后者的研究表明，标签匹配类型、被推测项目的典型性程度及类别特征间的因果关系会影响类别特征推理任务。而关于类别特征推理任务脑机制的研究仅有一篇 fMRI 的研究，该研究发现，类别特征推理任务激活了前额叶，而分类任务激活颞叶，主要是梭状回。虽然，以往关于类别特征推理任务认知机制的研究发现一些因素会影响该任务，但是这些研究并没有探讨这些因素之间的相互作用。本研究在以往研究的基础上，旨在进一步探讨类别特征推理任务的认知机制及脑机制，对该任务认知机制的研究中，除了探讨影响该任务的影响因素之外，还探讨这些影响因素之间的相互作用，如类别标签匹配类型与典型性程度之间的交互作用问题以及（类别特征间存在因果关系前提下）关键前提与结论的关联方向与典型性程度之间的交互作用问题。在对该任务脑机制的研究中，首次采用高时间分辨率的 ERP 技术，利用任务—分段式实验设计，揭示了类别特征推理任务的时间进程及相关的 ERP 成分。

类别特征推理从宏观角度讲，包括类别学习和特征推理两个阶段，

影响类别特征推理的因素也主要来自两个方面，学习阶段的类别相关信息以及推理阶段被推理项目的属性特征信息，本研究中所有实验都采用学习——测试的二阶段实验范式，这样的研究范式更符合现实生活中的特征推理情境，所以，具有很好的生态学效度。实验一至实验四探讨类别特征推理任务的认知机制，实验五至实验七探讨类别特征推理任务的脑机制。研究一旨在探讨类别标签与类别特征推理的关系。实验一主要分析了标签类型、标签匹配类型及典型特征前提概率对类别特征推理的影响，本研究首次探讨典型特征前提概率对类别特征推理的影响，实验一结果表明三种因素都会影响类别特征推理任务，典型特征前提概率高的项目的特征推理分数显著高于典型特征前提概率低的项目，标签类型与标签匹配类型之间的交互作用显著，进一步分析发现，标签类型为类别标签时，标签匹配项目的特征推理分数显著高于标签不匹配项目，而标签类型为特征标签时，标签匹配项目上的特征推理分数与标签不匹配项目上的特征推理分数差异不显著，类别标签条件下的失匹配分数（标签匹配项目上的特征推理分数的平均数减去标签非匹配项目上的特征推理分数的平均数）显著高于特征标签条件，该结果说明类别标签与特征标签不同，类别标签在特征推理任务中起着非常重要的作用。实验二首次探讨了类别标签匹配类型与典型性程度对类别特征推理任务的共同影响，研究结果发现，与实验一结果相同，类别标签匹配类型会影响该任务，还发现典型程度也会影响类别特征推理任务，而且，这两个因素之间有明显的交互作用，高典型性条件下类别标签匹配类型对类别特征推理的影响要高于低典型性程度条件下类别标签匹配类型对类别特征推理的影响，而且，类别标签匹配条件下典型性程度对类别特征推理任务的影响要高于类别标签不匹配条件下典型性程度对类别特征推理任务的影响。研究二旨在分析特征间因果关系及典型性程度对类别特征推理的影响。实验三控制了测试项目的典型性程度，单独探讨类别特征间因果关系对类别特征推理任务的影响，实验中，因果关系组被试学习的类别各典型特征间具有复杂的因果关系结构，结果发现，因果关系组被试的特征推理分数受到典型特征间因果关系的影响，直接原因—结果推理项目的推理分数显著高于间接原因—结果及结果—结果推理项目的推理分数，而对于控制组（被试所学的类别各典型特征间无因果关系），被试在三类

项目上的推理分数没有差异。实验四分析（类别特征间存在因果关系前提下）关键前提与结论的关联方向与典型性程度对类别特征推理任务的共同影响。因果关系组被试学习的类别各典型特征间具有共同原因的因果关系结构，结果发现，对于因果关系组被试，关键前提与结论的关联方向以及典型性程度这两个因素都会影响特征推理分数，而且，还发现这两个因素间的交互作用，进一步分析发现，在关键前提与结论正关联条件下典型性程度对类别特征推理任务的影响要高于关键前提与结论负关联条件下典型性程度对类别特征推理任务的影响，而且，典型性程度为高条件下关键前提与结论的关联方向对于类别特征推理任务的影响要高于典型性程度为低条件下关键前提与结论的关联方向对于类别特征推理任务的影响。研究三首次采用 ERP 技术分析类别特征推理任务的脑机制。实验五探讨类别归纳过程的神经机制。类别归纳是类别学习的重要过程，而类别学习又是类别特征推理任务的重要组成部分，实验五的结果发现有类别归纳条件与无类别归纳条件的分离表现在早期阶段（后部 N1 成分）以及晚期阶段（LPC 成分），而以往关于类别归纳的研究还没有发现这两种条件在早期阶段上的分离，LPC 是类别归纳的关键成分，它与类别归纳过程中的记忆更新过程有关。实验六揭示了与类别特征推理任务相关的 ERP 成分，研究发现，有类别特征推理条件与无类别特征推理条件的差异表现在早期成分 P2 以及晚期成分 P3 及 LPC 上，并且，在 P3 波幅上也体现了类别学习先后效应，P3 与特征推理任务的工作记忆负荷程度有关，而 LPC 则与特征推理任务中对无关类别信息的抑制过程有关。实验七探讨类别学习信息量程度是否影响类别特征推理的 ERP 成分，研究发现，类别学习信息量程度为高条件比类别学习信息量程度为中及低条件引发了更小的 P3 波幅，后两者间没有差异，而且，类别学习信息量程度为高条件引发的 LPC 波幅比类别学习信息量程度为中条件更低，类别学习信息量程度为中条件引发的 LPC 波幅又比类别学习信息量程度为低条件更低，与实验六结果一致，P3 波幅的大小体现了类别特征推理过程中的记忆负荷程度，而 LPC 波幅的大小则体现了类别特征推理过程中对无关类别信息的抑制程度。

本研究通过对类别特征推理任务认知机制及脑机制的分析，得出以下结论：

第一，典型特征前提概率、标签匹配类型、测试项目的典型性程度以及类别特征间的因果关系都会影响特征推理任务。

第二，类别标签匹配类型与测试项目的典型性程度之间存在交互效应，（类别特征间的因果关系存在前提下）关键前提与结论的关联方向与测试项目的典型性程度之间也存在交互效应。

第三，类别学习阶段，有类别归纳条件与无类别归纳条件的差异表现在早期的后部 N1 成分上以及晚期的 LPC 成分上。

第四，有类别特征推理条件比无类别特征推理条件引发的前部 P2 成分、P3b 成分以及 LPC 成分的波幅更小，而且，类别学习的先后也影响类别特征推理阶段引发的 P3b 波幅，属于先学习类别的测试项目引发的 P3b 波幅更小。

第五，类别学习信息量程度会影响类别特征推理阶段的 P3b 波幅以及 LPC 波幅，类别学习信息量程度为高条件引发的 P3b 波幅要低于类别学习信息量程度为中及低条件，而且，类别学习信息量程度为高条件引发的 LPC 波幅比类别学习信息量程度为中条件更低，而类别学习信息量程度为中条件引发的 LPC 波幅又比类别学习信息量程度为低条件更低。

本研究的重要发现在于，发现了典型特征前提概率对类别特征推理任务的影响；揭示了类别标签匹配类型与测试项目的典型性程度之间存在交互效应、（类别特征间的因果关系存在前提下）关键前提与结论的关联方向与测试项目的典型性程度之间的交互效应；发现了类别归纳的早期效应（体现在后部 N1 成分上）；首次采用 ERP 技术，揭示了与类别特征推理相关的成分：P3、LPC 成分；发现类别学习信息量程度在类别特征推理任务上的 ERP 效应。

本研究具有重要的理论意义和现实意义。在理论意义上，加深了对类别特征推理任务的理解，进一步完善了类别归纳及特征推理的相关理论，在研究方法上也有创新，尤其是在脑机制研究中，采用类别学习—特征推理的任务分段式设计，将复杂的类别特征推理过程简化，使得对于类别特征推理任务 ERP 成分的探讨成为可能。在现实意义上，由于类别特征推理是人类很重要的一项认知功能，所以，本研究对于更好地分析和理解人类行为、为认知功能失常的神经心理诊断方面都有一定的意义。

Abstract

The Cognitive and Neural Mechanism of Category-based Feature Inference

Research Field: Cognitive Development
Specialty: Developmental and Educational Psychology
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Categorization and inference are two important functions of category knowledge, besides categorization, category-based feature inference is an important application of category information. In categorization task, the feature values of the test item is known and the subjects need to infer the label of the category which the item belongs to, while in category-based feature inference task, the category label of the test item and parts of its feature values are known, and the subjects need to infer the unknown feature value(s) of the test item. Previous studies on category mainly limited to the categorization tasks, while studies on cognitive mechanism of the category-based feature inference tasks were very small in number, and the studies on the latter suggested that factors such as matching type of label, typical level and causal relations between category features affected category-based feature inference tasks. And so far, there is only one study to explore the neural mechanism of category-based feature inference tasks with fMRI, which found that the PFC (prefrontal cortex) was activated in category-based feature inference task, and the temporal lobe, especially fusiform gyrus, was activated in the categorization

task. Though previous studies on the cognitive mechanism found that some factors had effect on category-based feature inference task, but they did not explore the interactions between these factors. And the purpose of this study is to probe further the cognitive and neural mechanism of category-based feature inference task on the basis of previous studies. On probing the cognitive basis of category-based feature inference task, we explore not only the factors which affect the task but also the interactions between these factors. On probing the neural basis of the task, we use ERP for the first time to explore the time course and the ERP components relative to category-based feature inference task with task-segmentation manipulation.

From a macroscopical view, category-based feature inference task included two stages, category learning and feature inference, and the factors which affect category-based feature inference task come mainly from two sides, relative category information in learning phase and attributes information of test items in feature inference phase, and accordingly, all experiments in this study utilize learning-testing two phase paradigm, which more fits the feature inference task in natural life, so this study have better ecological validity. Experiment one to four probe the cognitive basis of category-based feature inference task, and experiment five to seven explore the neural basis of category-based feature inference task. The purpose of study one is to discover the relation between category label and category-based feature inference task. In experiment one, we explore how label type, matching type of label and basal probability of typical features affect category-based feature inference task, and this study probe the effect of basal probability of typical features on category-based feature inference task for the first time, and the results of experiment one suggest that all the three factors mentioned above affect category-based feature inference task, and the inference scores for the test items with high basal probability of typical features are higher than the one with low basal probability of typical features, and the interactions between label type and matching type of label are significant, because when label type is category label, the inference scores for the test items with matching label were significant higher than the one with non-matching label, while when label type is feature label, the inference scores for the test items with matching label were

not different from the one with non-matching label, further more, the non-matching score (difference score that the mean inference score for the test items with matching label minus the one with non-matching label) in the category label condition is significant higher than the one in the feature label condition, so these results suggest that being different from feature label, category label exert very important role in category-based feature inference tasks. In experiment two, we explore the common effects of matching type of category label and typical level on category-based feature inference tasks, the results suggest that, in accordance with the results from experiment one, matching type of category label affect category-based feature inference tasks, and typical level affect this task too, further more, the interaction between these two factors is significant, that is, the effect of matching type of category label on category-based feature inference task in high typical level condition is stronger than the one in low typical level condition, additionally, the effect of typical level on category-based feature inference task in matching category label condition is stronger than the on in non-matching category label condition. The purpose of study two is to probe how causal relation between category features and typical level affect category-based feature inference task. In experiment three, controlling the typical level of test items, we only probe the effect of causal relation between category features on category-based feature inference task, there are complex casual relations between the typical features of the category learned by subjects in casual relation group, the results suggest that casual relations between typical features affect inference score in casual relation group, that is, the inference score for test items with direct cause-result inference is significant higher than the one with indirect cause-result inference and the one with result-result inference, and there is no difference between the latter two, however there are no casual relations between the typical features of the category learned by subjects in control group and there are no difference in inference scores of the three types of items mentioned above. In experiment four, we study the common effect of the orientation of the relation between key premise and result and typical level on category-based feature inference task when there are casual relations between typical features of the learned category, there are casual relations (called

common-cause casual relation) between the typical features of the category learned by subjects in casual relation group, the results from this group suggest that both the orientation of the relation between key premise and result and typical level affect the category-based feature inference task, further more, there are significant interactions between these two factors, because, the effect of typical level on category-based feature inference task in the condition of positive relation between key premise and result is stronger than the one in the condition of negative relation between key premise and result, what's more, the effect of the orientation of the relation between key premise and result on category-based feature inference task in high typical level condition is stronger than the one in low typical level condition. Study three explore the neural mechanism of category-based feature inference task with ERP for the first time. In experiment five, we probe the neural mechanism of category induction process. Category induction is an important process for category learning which is an important part of category-based feature inference task, the results from experiment five discovery that the ERP divergence between category induction and non-induction occurred at both early stage (posterior N1 component) and late stage (LPC component), while previous studies on category induction have not discovery the ERP divergence between the two conditions occurred at early stage, LPC is the key component of category induction and relates to memory updating process. In experiment six, we discovery the ERP component relative to category-based feature inference process, the results suggest that the ERP waves elicit by category-based feature inference condition and non-inference condition differ on P2, P3 and LPC, additionally, the order for category learning also exerts effects on P3b amplitudes in category-based feature inference condition, we conclude that P3 component relates to working memory load level and LPC relates to prohibiting process for task-irrelevant category information in category-based feature inference task. In experiment seven, we study the effect of the level of category learning information amounts on ERP components relative to category-based feature inference task, and the results show that P3 amplitudes elicited by high level category learning information amounts condition is significantly smaller than the one elicited by middle and low level category learning information amounts condition, while

there is no difference between the latter two conditions, further more, LPC amplitudes elicited by high level category learning information amounts condition is significantly smaller than the one elicited by middle level category learning information amounts condition, and LPC amplitudes elicited by middle level category learning information amounts condition is significantly smaller than the one elicited by low level category learning information amounts condition, in accordance with the result from experiment six, P3 amplitudes manifest the working memory load level in category-based feature inference task, while LPC amplitudes reflect the prohibition level for task irrelevant category information in the task.

This study explores the cognitive and neural mechanism of category-based feature inference task, and the results are as follows:

Firstly, basal probability of typical features, matching type of label, typical level of test items and causal relation between category typical features have effect on category-based future inference task.

Secondly, there are interactions between matching type of category label and typical level of test items, as while as between the orientation of the relation between key premise and result and typical level when there are casual relations between typical features of category.

Thirdly, in category leaning phase, the ERP divergence between category induction and non-induction occurred at both early stage (posterior N1 component) and late stage (LPC component).

Fourthly, category-based feature inference condition elicits smaller anterior P2, P3b and LPC amplitudes than non-inference condition, what' s more, the order for category learning also exerts effects on P3b amplitudes in category-based feature inference condition, and the items belonging to the category learned first elicit smaller P3b amplitudes than the one belonging to the category learned after.

Lastly, the level of category learning information amounts affect the amplitudes of P3 and LPC in feature inference stage, in that, P3 amplitudes elicited by high level category learning information amounts condition is significantly smaller than the one elicited by middle and low level category learning information amounts conditions, additionally, LPC amplitudes elicited

by high level category learning information amounts condition is significantly smaller than the one elicited by middle level category learning information amounts condition, and LPC amplitudes elicited by middle level category learning information amounts condition is significantly smaller than the one elicited by low level category learning information amounts condition.

The important discovery of this study lies in that we find that basal probability of typical features influences the category-based feature inference task, and there are interactions between matching type of category label and typical level of test items, as while as between the orientation of the relation between key premise and result and typical level when there are casual relations between typical features of category, and we discover that the early effect of category induction occurring at posterior N1 component, and this study for the first time explore the ERP component relative to feature inference, that is, P3 and LPC, and we find the ERP effect of the level of category learning information amounts on category-based feature inference task.

This research has important theoretic and practical significance. For the theoretic significance, this study deepen the comprehension for category-based feature inference task, and improve further the theory relative to category induction and category-based feature inference task, and there are innovations in research method, especially in the study on the neural mechanism of category-based feature inference task, we use task segmentation manipulation to simplify the complex cognitive process, and accordingly, we have the probability to explore the ERP component relative to category-based feature inference task. For the practical significance, because category-based feature inference is an important cognitive function for human being, this research has significance to a certain degree for better analyzing and understanding behaviors of human beings and offer neural-psychological diagnostic project for the cognitive function abnormality.

Keywords: category-based feature inference, category induction, event-related potential (ERP), P3, late positive component (LPC)

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