nature communications
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Article
文章

https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

Attribute latencies causally shape intertemporal decisions
属性潜伏期因果性地影响跨时间决策

Received: 5 August 2021
接收日期：2021年8月5日

Accepted: 5 March 2024
接受日期：2024年3月5日

Published online: 05 April 2024

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Intertemporal choices – decisions that play out over time – pervade our life. Thus, how people make intertemporal choices is a fundamental question. Here, we investigate the role of attribute latency (the time between when people start to process different attributes) in shaping intertemporal preferences using five experiments with choices between smaller-sooner and larger-later rewards. In the first experiment, we identify attribute latencies using mouse-trajectories and find that they predict individual differences in choices, response times, and changes across time constraints. In the other four experiments we test the causal link from attribute latencies to choice, staggering the display of the attributes. This changes attribute latencies and intertemporal preferences. Displaying the amount information first makes people more patient, while displaying time information first does the opposite. These findings highlight the importance of intra-choice dynamics in shaping intertemporal choices and suggest that manipulating attribute latency may be a useful technique for nudging.
跨期决策——即需要跨越时间跨度做出的选择——无处不在地影响着我们的生活。因此，人们如何进行跨期决策成为了一个根本性问题。本研究通过五项实验，探讨属性延迟（即人们开始处理不同属性的时间间隔）在塑造跨期偏好中的作用，实验设置包含“小奖励-快选择”和“大奖励-慢选择”两种选项。在首个实验中，我们通过追踪小鼠轨迹识别属性延迟，发现其能预测个体在选择偏好、反应时长及时间限制下的变化差异。在其余四项实验中，我们通过错序呈现属性信息来验证属性延迟与选择行为的因果关系。这种时间顺序的调整会改变属性延迟与跨期偏好的关联模式：先呈现数量信息会让人更耐心，而先呈现时间信息则会产生相反效果。这些发现凸显了选择过程中的动态变化对跨期决策的重要影响，并表明调整属性延迟可能是实施微调干预的有效手段。

Intertemporal choices that involve tradeoffs between outcomes available at different times are ubiquitous in our everyday life. These tradeoffs play an important role in many personal decisions and policy questions, such as saving, education, exercise, health care, nutrition, and so forth. Thus, understanding how people form intertemporal preferences and act on those preferences are fundamental issues in economics, psychology, and other social sciences, as well as to designing public policies or nudge interventions[1–9]. Economists typically analyze intertemporal choices and design public policies using utility models that assume discount rates on delayed rewards[10–14]. If we take these utility models as descriptions of how people actually decide, then we assume a static model of the decision process where the amount and time attributes are integrated within each option and the best option is selected, all instantaneously.
在日常生活中，人们常常需要在不同时期的收益之间做出权衡取舍。这种跨期决策在个人选择和政策制定中都至关重要，比如储蓄、教育、锻炼、医疗保健、营养摄入等。因此，理解人们如何形成跨期偏好并据此行动，不仅是经济学、心理学等社会科学的基础课题，更是制定公共政策或实施助推干预的关键[1-9]。经济学家通常采用效用模型来分析跨期决策并设计公共政策，这些模型假设延迟收益会受到折现率的影响[10-14]。若将这类效用模型视为真实决策过程的描述，我们实际上是在构建一个静态决策模型——其中选项的数量和时间属性被整合考量，而最佳选项的选择过程也被简化为瞬间完成。

On the other hand, there have been efforts to understand the dynamics of intertemporal choice, with both single- and dual-process models. In the dual-process studies, intertemporal choices are described as an interaction between automatic and deliberative processes. Some have argued that people automatically favor immediate rewards[15–19], while others have argued the opposite[20,21]. Time manipulations are often used to induce people to rely more on the intuitive process or the deliberative process when making decisions. For instance, past work has argued that time pressure encourages automatic responses, while time delay encourages more deliberative responses[22]. However, other work has instead argued that time pressure increases reliance on prior information (predispositions) while time delay increases the evaluation of the choice options[23]. More generally, it is not clear whether changes in choice behavior due to time constraints are the result of a shift between automatic and deliberative processes, or due to other components (e.g., processing biases or attentional priorities) of the choice process[24–26].
另一方面，学界已通过单过程模型和双过程模型对跨期选择的动态机制展开研究。在双过程模型中，跨期选择被描述为自动过程与深思熟虑过程的交互作用。有学者指出，人们会自动倾向于即时选择。关于时间压力对决策行为的影响，学界存在不同观点[15-19]。有研究认为时间压力会促使人们在决策时更多依赖直觉或深思熟虑的过程[20]，而另一些研究则持相反观点[21]。例如，早期研究表明时间压力会引发自动反应，而延迟时间则能促进更审慎的决策[22]。不过也有观点指出，时间压力会增强对既有信息（先验倾向）的依赖，而延迟时间则能促使更全面地评估选项[23]。总体而言，时间限制引发的决策行为变化究竟是源于自动与深思过程的切换，还是受决策过程其他因素（如处理偏差或注意力优先级）影响，目前尚未有定论[24-26]。

Single-process studies have attempted to examine the dynamics underlying intertemporal choice using sequential sampling models (SSMs), which account for both choice and response time (RT) data. These studies have argued that intertemporal choice involves attribute-wise processes in which amount and time are evaluated and compared separately[5,27–31]. Hence, this perspective sees intertemporal choices as resulting from the combination of amount comparisons and
单过程研究尝试通过序列抽样模型（SSMs）来探究跨期选择背后的动态机制，这类模型同时考虑了选择数据和反应时间（RT）数据。相关研究表明，跨期选择涉及属性层面的独立评估过程，其中金额和时间要素会被分别进行比较[5,27-31]。因此，这种观点认为跨期选择是金额比较与时间评估相结合的结果。

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https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

time comparisons. Moreover, using computational modeling, this line of studies has shown that people have predispositions and evaluation biases when making intertemporal decisions[24], and participants are heterogeneous in the relative speed of processing the amount and time attributes, where the difference between the onset times of the amount and time attributes is referred to as attribute latency[3,28,32].

时间比较研究。此外，通过计算建模方法，该研究领域揭示了人们在进行跨时间决策时存在固有倾向和评估偏差[24]。研究发现，参与者对数量属性和时间属性的处理速度存在个体差异，这种差异被定义为属性延迟（attribute latency）[3]，即两个属性的起始时间间隔[28 32]。

Prior work has analyzed attribute latencies using computational modeling based on choice and RT[3,28,32] but an alternative approach would be to directly measure participants' attribute latencies with mouse-trajectory data. Mouse-tracking—measuring the computer-mouse movements made by participants while making decisions—is a real-time technique to more directly tap into the processes underlying choices[33–37]. The rich temporal data offered by mouse-tracking allow us to test nuanced models regarding how decisions unfold[33]. Recent research has highlighted the usefulness of mouse trajectories in multi-attribute choice, in particular for inferring when attributes enter the decision process[38–44].

现有研究主要通过基于选择和反应时（RT）的计算建模来分析属性延迟现象[3]，[28 32]但另一种可行方法是直接利用鼠标轨迹数据测量受试者的属性延迟。鼠标追踪技术——即通过记录受试者在决策过程中计算机鼠标移动轨迹——是一种实时技术，能更直接地捕捉决策背后的神经机制[33]—[37]。鼠标追踪提供的丰富时间序列数据，使我们能够验证关于决策过程如何展开的精细模型[33]。最新研究表明，鼠标轨迹在多属性选择研究中具有重要价值，尤其有助于推断属性何时进入决策过程[38]—[44]。

In this work, we use five separate experiments to investigate the role that attribute latency plays in shaping intertemporal preferences and whether we can manipulate participants attribute latencies to

本研究通过五项独立实验，探究属性潜伏期在塑造跨期偏好中的作用，并验证是否可通过操控受试者的属性潜伏期来实现
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causally change their intertemporal choices. The first experiment (Study 1) combines mouse-tracking with a standard intertemporal choice paradigm where participants chose between smaller-sooner (SS) and larger-later (LL) monetary rewards with and without time constraints. We estimate participants' attribute latencies, i.e., the differences between the onset time of processing amount and time information (time-onset lag, TOL), using the mouse-trajectory data only. We find that the mouse-trajectory-derived time-onset lag (MTTOL) predicts individual differences in choices, RTs, and the behavioral changes across time constraints. We validate these results using an independent computational modeling analysis in which the attribute latency is estimated using choice and RT data. The mouse-trajectory data in Study 1 not only allows us to identify an independent measure of attribute latency, but also shows how the attribute latency changes across time constraints. We find that time constraints do not affect attribute latencies in the same way. Time pressure pushes

因果地改变他们的跨时间选择。第一个实验（研究1）结合了小鼠追踪与标准的跨时间选择范式，参与者在有无时间限制的情况下选择较小-更快（SS）和较大-更晚（LL）的金钱奖励。我们仅使用小鼠轨迹数据估计参与者的属性延迟，即处理金额和时间信息的起始时间差异（时间起始延迟，TOL）。我们发现，基于小鼠轨迹得出的时间起始延迟（MTTOL）可以预测个体在选择、反应时和时间限制下的行为变化上的差异。我们通过独立的计算模型分析验证了这些结果，其中属性延迟是通过选择和反应时数据估计的。研究1中的小鼠轨迹数据不仅使我们能够识别属性延迟的独立测量指标，还展示了属性延迟如何随时间限制而变化。我们发现时间限制对属性延迟的影响方式不同。时间压力推动

attribute latencies in opposite directions depending on whether they are positive or negative. This aligns with how behavior changes under time pressure, i.e., patient people become more patient under time pressure while impatient people become less patient under time pressure. Given the correlation between attribute latencies and behavior, we also test the causal pathway from attribute latencies to intertemporal choices using four experiments (Studies 2-5). Specifically, we manipulate attribute latencies by altering the onset of the amount and time information. We find that displaying the amount information first makes people process the amount information earlier than the time information, while displaying the time information first has the opposite effect. More importantly, this causally changes choices, i.e., people chose more patient (impatient) options when we display the amount (time) attribute first.

属性延迟时间会根据其正负属性呈现相反方向的变化趋势。这与时间压力下行为改变的规律相吻合——即耐心型人群在时间压力下会变得更加耐心，而急躁型人群则会变得不那么耐心。基于属性延迟与行为之间的相关性，我们通过四项实验（研究2-5）验证了从属性延迟到跨期选择的因果路径。具体而言，我们通过改变数量信息和时间信息的呈现顺序来操控属性延迟。研究发现，当先呈现数量信息时，人们会比先呈现时间信息时更早处理数量信息；而先呈现时间信息则会产生相反效果。更重要的是，这种因果关系会改变选择倾向——当先呈现数量（时间）属性时，人们更倾向于选择耐心型（急躁型）选项。

Results
结果

Intertemporal choice task
时间间隔选择任务

Study 1 consisted of 300 intertemporal choice trials (the same 300 trials were used in Studies 2–5) with and without time constraints. In each trial, participants decided between two options, one with a large reward but delivered at a later time (LL or patient option), the other with a small reward but delivered at a sooner time (SS or impatient option) (Fig. 1). That is, making decisions in each trial required deciding whether the additional money offered at the later date made it worth the extra delay.

研究1包含300次跨时段选择试验（研究2-5采用相同300次试验），设置有时间限制和无时间限制两种模式。每个试验中，受试者需在两种选项间做出抉择：一种是奖励丰厚但延迟发放（LL选项，即“耐心选项”），另一种是奖励较少但提前发放（SS选项，即“急躁选项”）（图1）。简而言之，每次决策都需要权衡延迟发放的额外奖金是否值得承受等待。

We divided the 300 trials into four blocks. The first and the last blocks were time-free blocks (with 100 trials in each). The other two blocks in between were time-pressure and time-delay blocks (with 50 trials in each). Participants had to make each decision within 2 s in the time-pressure block, and they had to make each decision after the decision problem had been displayed for 10 s in the time-delay block. In the two time-free blocks, participants could take as long as they wanted to make each decision. The order of time-pressure and time-delay blocks was counterbalanced across participants. The spatial positions of the LL and SS options were counterbalanced across trials for each participant.

我们将300次试验划分为四个区块。首尾两个区块为无时间限制区块（每组100次试验），中间两个区块分别为限时区块和延时区块（每组50次试验）。限时区块要求参与者在2秒内完成决策，延时区块则需在决策问题呈现10秒后作出选择。在两个无时间限制区块中，参与者可自由选择决策时长。限时区块与延时区块的顺序在不同参与者间进行了平衡设计，而LL和SS选项的空间位置在每位参与者的各次试验中也进行了平衡调整。

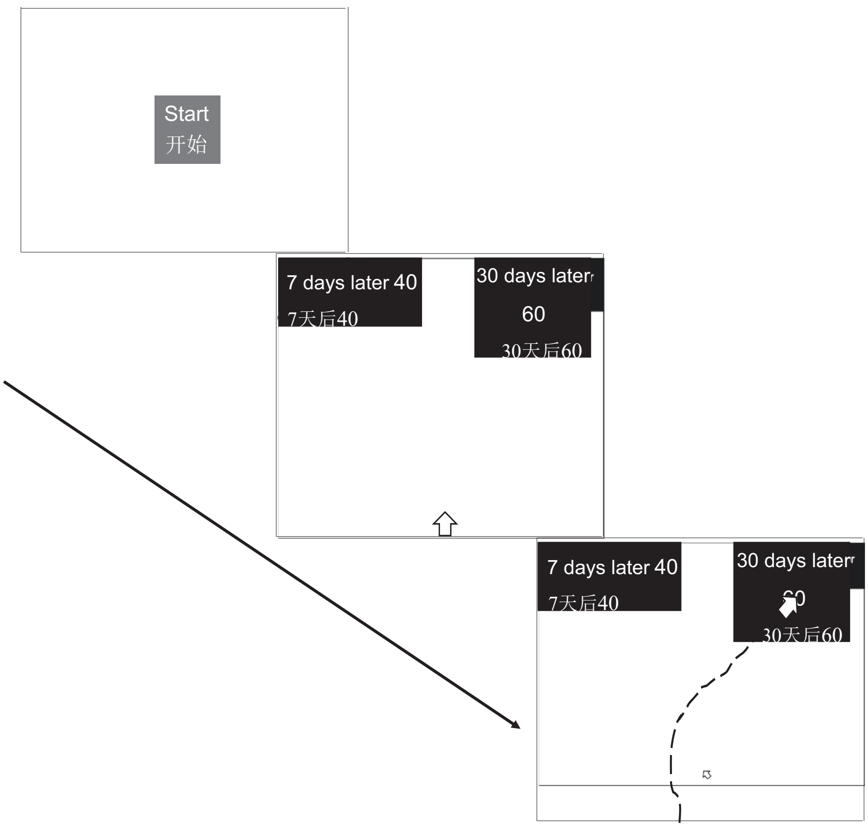

Fig. 1 | An example and the timeline of the intertemporal choice task in Study 1. At the beginning of each trial, participants clicked the "Start" button in the middle bottom of the screen, and then the decision problem appeared. In this example, the choice was between getting a reward of 40 in 7 days and getting a reward of 60 in 30 days. Participants made decisions by moving their mouse to their favored option and clicking the black area of that option. The text was enlarged for display purposes.

图1 | 研究1中跨期选择任务的示例及时间线。每次试验开始时，受试者点击屏幕底部中央的“开始”按钮，随后呈现决策问题。本示例中，受试者需在7天内获得40分的奖励与60分的奖励之间做出选择。30天。受试者通过将鼠标移动至其偏好的选项并点击该选项的黑色区域来做出决策。文本为便于显示而放大显示。

https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

The mean RTs were 2.121 (SD = 1.230), 1.263 (SD = 0.283), and 1.192 (SD = 0.868, after the 10 s enforced delay) seconds in the time-free, time-pressure and time-delay conditions respectively. In the time-free condition, the mean percentage of choosing LL options was 58.9% (SD = 21.3%). The mean percentages of choosing LL options were 65.5% (SD = 26.2%) and 53.9% (SD = 20.6%) in the time-pressure and delay conditions, respectively. That is, for our set of trials, participants generally chose the patient option, and they became more patient under time pressure and less patient under time delay, on average (two-sided sign rank tests, pressure vs. free: $V = 6526.5$, $p < 0.001$; free vs. delay: $V = 6222$, $p < 0.001$; pressure vs. delay: $V = 7116.5$, $p < 0.001$).

在无时间限制、时间压力和时间延迟三种条件下，受试者的平均反应时间分别为2.121秒（标准差 1.230），1.263 0.283）和1.192秒（标准差=0.868，经过10秒强制延迟后）。在无时间限制条件下，选择LL选项的平均百分比为58.9%（标准差=21.3%）。而在时间压力和延迟条件下，选择LL选项的平均百分比分别为65.5%（标准差=26.2%）和53.9%（标准差=20.6%）。这表明在本组试验中，受试者总体上更倾向于选择患者选项，且在时间压力下表现出更强的耐心，而在时间延迟下则显得不够耐心（双侧符号秩检验结果：压力组vs.自由组：V=6526.5，p<0.001；自由组vs.延迟组：V=6222，p<0.001；压力组vs.延迟组：V=7116.5，p<0.001）。

Attribute latency

属性延迟

Prior studies have shown that people start to process the amount and time attributes at different times when making intertemporal decisions[3,28]. Here we take the difference between the onset times of the amount and time attributes (i.e., time-onset lag, TOL) as the measure of the attribute latency. A positive TOL means that the participant starts to process the amount attribute earlier than the time attribute, while a negative TOL means that the participant starts to process the time attribute earlier than the amount attribute.

已有研究表明，在进行跨期决策时，人们处理数量属性和时间属性的起始时间存在差异[3 28]。本研究采用数量属性与时间属性起始时间的差值（即时间起始滞后量，TOL）作为属性延迟的衡量指标。正TOL值表示参与者处理数量属性的起始时间早于时间属性，而负TOL值则表明参与者处理时间属性的起始时间早于数量属性。

We first estimated the attribute latency (TOL) using mouse-trajectory data only (mouse-trajectory-derived TOL, MTTOL), for each participant in each time condition (see Methods for details). Figure 2a shows the distribution of the MTTOL in the time-free condition, and Supplementary Fig. 1 shows the distributions of the MTTOL in the time-pressure and delay conditions. The mean MTTOLs were 25.41 (SD = 41.44), 37.33 (SD = 46.44), 15.24 (SD = 31.19) in the time-free, time-pressure and time-delay conditions, respectively. That is, on average, participants processed the amount attribute earlier than the time attribute (two-sided Wilcoxon signed rank test, free: $V = 6609$, $p < 0.001$; pressure: $V = 6645.5$, $p < 0.001$; delay: $V = 5589$, $p < 0.001$), and they processed the amount attribute much earlier than the time attribute in the time-pressure condition compared to the other two conditions (pressure vs. free: $V = 9103.5$, $p = 0.044$; pressure vs. delay: $V = 11027$, $p < 0.001$, free vs. delay: $V = 9753.5$, $p = 0.002$).

我们首先使用mousetrajectory数据（小鼠轨迹衍生的TOL，MT-TOL）估计了每个时间条件中每个受试者的属性潜伏期（TOL）（详见方法部分）。图2 a 图1展示了无时间干扰条件下MTTOL的分布情况，补充图1则呈现了时间压力和延迟条件下MTTO的分布。在无时间干扰、时间压力和时间延迟三种条件下，平均MTTO值分别为25.41（标准差=41.44）、37.33（标准差=46.44）和15.24（标准差=31.19）。数据显示，受试者平均而言对数量属性的处理速度显著快于时间属性（双尾Wilcoxon符号秩检验：自由组V=6609，p<0.001；压力组V=6645.5，p<0.001；延迟组V=5589，p<0.001）。其中在时间压力条件下，受试者对数量属性的处理速度较其他两种条件更快（压力组与自由组对比：V=9103.5，p=0.044；压力组与延迟组对比：V=11027，p<0.001；自由组与延迟组对比：V=9753.5，p=0.002）。

To validate the mouse-tracking measure of attribute latency, we estimated a starting-time drift-diffusion model (stDDM, Supplementary Fig. 4)[3,28,32,45] at the participant level using the choice and RT data in the time-free condition (see Methods and Supplementary Note 2). The stDDM models the drift rate, which captures the rate of evidence accumulation in favor of one option over the other, as a linear function of the attribute differences and a constant. In particular, there is a delay before one of the attribute differences affects the drift rate. That is, the stDDM allows the amount and time attributes to enter into the evidence accumulation process at different times, and thus can decompose behavior into attribute latency (TOL), predisposition (starting point), evaluation bias (drift-rate constant), and subjective

为验证小鼠追踪实验中属性潜伏期的测量方法，我们采用无时间干扰条件下的选择数据和反应时数据（参见方法部分及补充说明2），在受试者层面构建了起始时间漂移扩散模型（stDDM，补充图4）[3 28 32 45]。该模型通过属性差异的线性函数和常数项来表征证据积累速率，即某一选项逐渐占据优势的速率。特别值得注意的是，当某个属性差异开始影响漂移速率时存在延迟效应。具体而言，stDDM允许数量属性和时间属性在证据积累过程中以不同时间节点参与，从而将行为分解为属性潜伏期（TOL）、倾向性（起始点）、评估偏差（漂移速率常数）及主观因素四个维度。

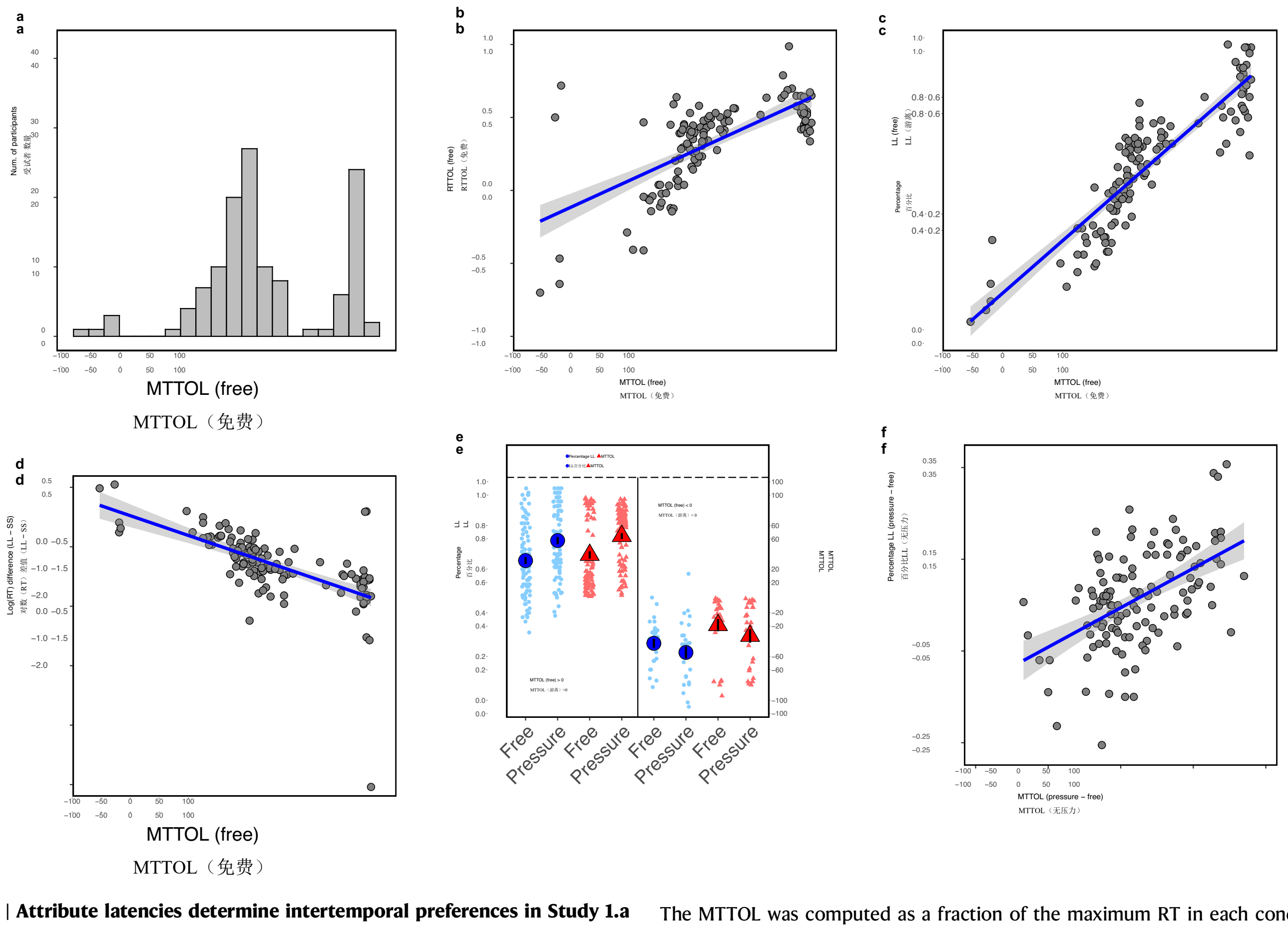

Fig. 2 | Attribute latencies determine intertemporal preferences in Study 1. a Distribution of the mouse-trajectory-derived time-onset lag (MTTOL) in the time-free condition. **b** Correlation between the response-time-derived time-onset lag (RTTOL) in the starting-time drift diffusion model (stDDM) and the MTTOL in the time-free condition. **c** Correlation between the MTTOL estimated using half of the time-free trials and the percentage of LL decisions in the other half of the time-free trials. **d** Correlation between the MTTOL and the log(RT) difference between LL and SS decisions in the time-free condition. **e** The MTTOL and the percentage of LL decisions across time-pressure and free conditions, separately for participants with positive and negative MTTOLs in the time-free condition. **f** Correlation between MTTOL change and behavioral change across time-pressure and free conditions. The MTTOL was computed as a fraction of the maximum RT in each condition, while the RTTOL was computed in seconds. The MTTOL in the time-free condition was estimated using half of the time-free trials, and the percentage of LL decisions in the time-free condition was computed using the other half of the time-free trials. Each dot in **b**–**d** and **f** represents one participant. The blue lines and grey shadings in **b**–**d** and **f** are the fitted linear regression lines and their standard errors. Each light blue dot (percentage of LL decision) or light red triangle (MTTOL) in **e** represents one participant. The deep blue dot and the deep red triangle in **e** represents the mean percentage of LL decisions and the mean MTTOL for a group of participants with positive or negative MTTOLs. The vertical bars in **e** represent standard errors of the mean clustered by participant.

图2 | 属性延迟决定研究1中的时间偏好。a 时间自由条件下小鼠轨迹衍生的时间起始延迟（MTTOL）的分布。b 起始时间漂移扩散模型（stDDM）中响应时间衍生的时间起始延迟（RTTOL）与时间自由条件下的 MTTOL 之间的相关性。c 使用一半时间自由试验估计的 MTTOL 与另一半时间自由试验中LL决策百分比之间的相关性。d MTTOL与时间自由条件下LL和SS决策的对数（RT）差异之间的相关性。e 时间压力和自由条件下 MTTOL 与LL决策百分比的分别对比，针对时间自由条件下具有正负MTTOL的参与者。f 时间压力和自由条件下 MTTOL 变化与行为变化之间的相关性。MTTOL 以最大反应时间的分数形式计算，而 RTTOL 以秒为单位计算。在无时间条件下，MTTOL 通过一半的无时间试验估算得出，而 LL 决策的百分比则通过另一半的无时间试验计算。图 b-d 和 f 中的每个点代表一个参与者。图 b-d 和 f 中的蓝色线条和灰色阴影是拟合的线性回归线及其标准误差。图 e 中的每个浅蓝色点（LL 决策百分比）或浅红色三角形（MTTOL）代表一个参与者。图 e 中的深蓝色点和深红色三角形分别代表具有正或负 MTTOLs 的一组参与者的 LL 决策平均百分比和平均 MTTOL 。图 e 中的垂直条表示按参与者聚类的均值标准误差。

https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

weights on each attribute in the evidence accumulation process (see Methods). The parameter recovery exercise revealed that earlier/later onset of evidence accumulation (TOL) can be distinguished from other components (e.g., predisposition, evaluation bias, and relative attribute weights, see Supplementary Note 2) of the process underlying intertemporal decisions.

证据积累过程中各属性的权重（参见方法部分）。参数恢复实验表明，证据积累的早期/晚期起始时间（TOL）可与其他构成要素（如易感性、评估偏倚及相对属性权重，参见补充说明2）区分开来，这些要素共同构成了跨期决策的基础过程。

We have to note that it is challenging to estimate the stDDM in the time-pressure and delay conditions, since it is not clear how the decision process was affected by the time constraints. For instance, time limits are usually modeled using collapsing boundaries[25,46]. However, whether boundaries collapse over time is still an active debate[47–52]. Thus, we cannot confidently estimate stDDM under time constraints and we only fit the stDDM to the data in the time-free condition.

需要指出的是，在时间压力和延迟条件下估算stDDM具有挑战性，因为目前尚不清楚时间限制如何影响决策过程。例如，时间限制通常通过边界坍缩模型进行建模[25 46]。然而，边界是否会随时间坍缩仍是一个活跃的学术争议[47-52]。因此，我们无法在时间限制条件下自信地估算stDDM，只能将stDDM模型拟合到无时间限制条件下的数据中。

The computational modeling results mirrored those from the mouse-trajectory analysis. On average, participants processed the amount attribute earlier than the time attribute (Mean = 0.330 s, SD = 0.288 s, two-sided Wilcox signed rank test, $V = 7380$, $p < 0.001$). In more detail, the TOLs in the stDDM (response-time-derived time-onset lag, RTTOL) were correlated with the MTTOLs across participants (Fig. 2b, two-sided Pearson correlation test, $r(124) = 0.676$, $p < 0.001$, $t = 10.221$, 95% CI = [0.569, 0.761]). The sign of the RTTOL was the same as the sign of the MTTOL for 117 out of 126 participants. For the 26 participants whose MTTOL was negative, 18 of them had a negative RTTOL (two-sided Binomial test, $p = 0.076$), and for the 99 participants whose MTTOL was positive, all of them had a positive RTTOL. This lends credence to the estimation of attribute latency based on the mouse-trajectory data.

计算建模的结果与小鼠轨迹分析的结果相吻合。平均而言，参与者处理数量属性的时间早于时间属性（均值=0.330秒，标准差=0.288秒，双侧Wilcoxon符号秩检验，V=7380，p<0.001）。更详细地说，stDDM中的TOLs（反应时间衍生的起始时间延迟，RTTOL）与MTTOLs在参与者间存在相关性（图2b，双侧Pearson相关检验，r（124）=0.676，p<0.001，t=10.221,95%CI=[0.569,0.761]）。在126名参与者中，117名的RTTOL符号与MTTOL符号相同。对于26名MTTOL为负的参与者，其中18名的RTTOL也为负（双侧二项式检验，p=0.076），而对于99名MTTOL为正的参与者，所有人的RTTOL均为正。这为基于小鼠轨迹数据的属性潜伏期估计提供了支持。

Additionally, we estimated four other versions of the DDM (see Supplementary Note 2). The cross-validation analysis revealed that the stDDM and the standard DDM had better out-of-sample predictive performance than the other three models, while the stDDM had higher predictive performance than the standard DDM (though non-significantly). Thus, going forward we focus on comparisons between the stDDM and the standard DDM.

此外，我们还估算了DDM的另外四个版本（见补充说明2）。交叉验证分析显示，stDDM和标准DDM在样本外预测性能优于其他三个模型，而stDDM的预测性能也高于标准DDM（尽管差异不显著）。因此，接下来我们将重点关注stDDM与标准DDM之间的比较。

Attribute latency explains individual differences in choices and response times

属性延迟揭示了个体在选择与反应时间上的差异

Next, we tested whether between-participant differences in MTTOL could explain variation in choice behavior and RTs. Prior studies have shown that attribute-wise models can sometimes better describe participants' intertemporal choices than option-wise models[27,28,31], while others argue that option-wise utility models work better[1,53–55]. Therefore, we opted not to fit a utility model here but used a model-free measure instead. Specifically, we computed the percentage of LL decisions for each participant and took this percentage as a measure of their intertemporal preferences (i.e., patience).

接下来，我们测试了参与者间在MTTOL（效用-损失函数）上的差异是否能解释选择行为和反应时间的差异。已有研究表明，属性层面的模型有时比选项层面的模型更能准确描述参与者的时间偏好选择[27 28 31]，而另一些研究则认为选项层面的效用模型效果更佳[1,53-55]。因此，我们选择不采用效用模型，转而使用无模型测量方法。具体而言，我们计算了每位参与者做出长期利弊权衡（LL）决策的百分比，并以此作为衡量其时间偏好（即耐心水平）的指标。

Figure 2c shows that the MTTOL identified using half of the time-free trials was correlated with the likelihood of choosing LL options in the other half of the time-free trials (two-sided Pearson correlation test, $r(124) = 0.895$, $p < 0.001$, $t = 22.395$, 95% CI = [0.854, 0.925]; also see Supplementary Fig. 6a). Moreover, MTTOLs were correlated with the percentage of LL decisions in the time-pressure and delay conditions (Supplementary Fig. 2, pressure: $r(124) = 0.920$, $p < 0.001$, $t = 26.194$, 95% CI = [0.888, 0.943]; delay: $r(124) = 0.839$, $p < 0.001$, $t = 17.199$, 95% CI = [0.779, 0.884]). That is, the attribute latency under time pressure and delay can also predict participants' choice behavior.

图2c显示，使用半数无时间限制试验识别出的MTTOL与另一半试验中选择LL选项的可能性存在相关性（双侧皮尔逊相关检验，r（124）=0.895，p<0.001，t=22.395,95%CI=[0.854,0.925]；另见补充图6a）。此外，MTTOLs与时间压力和延迟条件下的LL决策百分比相关（补充图2，压力条件：r（124）=0.920，p<0.001，t=26.194,95%CI=[0.888,0.943]；延迟条件：r（124）=0.839，p<0.001，t=17.199,95%CI=[0.779,0.884]）。这表明，时间压力和延迟条件下的属性反应时间也能预测受试者的选择行为。

The OLS regressions in Supplementary Table 3 show that the MTTOL

OLS回归分析结果如补充表3所示，MTTOL为

added additional power in explaining participants' choice behavior in the time-free condition. Except the RTTOL, all the other parameters in stDDM explained 86.8% of the variance of participants' choice behavior (model 2). Adding the MTTOL (model 3) significantly increased R^2R2 from 0.868 to 0.920 (models 2 vs 3, two-sided partial-F test, F-value = 78.184, $p < 0.001$). Moreover, the R^2 of the regression on standard DDM parameters (0.938) is less than that of the regression on

在解释无时间条件下的参与者选择行为时，增加了额外的效力。除了RTTOL之外，stDDM中的所有其他参数解释了参与者选择行为的86.8%（模型2）。加入MTTOL（模型3）显著提高了R^2R2值，从0.868增加到0.920（模型2与3对比，双侧部分F检验，F值=78.184，p＜0.001）。此外，标准DDM参数回归的R^2值（0.938）低于标准参数回归的R^2值。

stDDM parameters (0.945; models 1 vs. 4, two-sided partial-F test, F-value = 15.613, $p < 0.001$).

stDDM参数（0.945；模型1与模型4对比，双侧部分F检验，F值=15.613，p＜0.001）。

With respect to RT, we expected MTTOL to be negatively correlated with the RT difference between LL and SS decisions in the time-free condition. The reason is that, on average, participants who process the amount information earlier (later) than the time information are quicker (slower) in making LL decisions than SS decisions. Figure 2d shows that the MTTOL was correlated with the RT difference between LL and SS decisions (two-sided Pearson correlation test, $r(123) = -0.635$, $p < 0.001$, $t = -9.120$, 95% CI = [−0.729, −0.517]; also see Supplementary Fig. 6b). The regressions in Supplementary Table 4 show that, except RTTOL, all the other parameters in stDDM explained 48.6% of the variance of the RT differences (model 2). Adding the MTTOL (model 3) significantly increased R^2 from 0.486 to 0.533 (models 2 vs. 3, two-sided partial-F test, F-value = 12.910, $p < 0.001$). The R^2 of the regression on the standard DDM parameters (0.553) is less than that of the stDDM parameters (0.573; models 1 vs. 4, two-sided partial-F test, F-value = 6.656, $p = 0.011$). Therefore, taking attribute latency into account adds power in explaining RT differences.

关于反应时间，我们预期在无时间条件下，MTTOL与LL和SS决策之间的反应时间差异呈负相关。原因是，平均而言，参与者在处理数量信息比时间信息更早（更晚）时，做出LL决策的速度（速度）比SS决策更快（更慢）。图2 d显示，MTTOL与LL和SS决策之间的反应时间差异相关（双侧皮尔逊相关检验，r（123）= -0.635，p＜0.001，t = -9.120,95% CI = [-0.729，-0.517]；另见补充图6b）。补充表4中的回归分析显示，除了RTTOL之外，stDDM中的所有其他参数解释了反应时间差异的48.6%（模型2）。加入MTTOL（模型3）显著增加了R ^{2}从0.486增至0.533（模型2对比3，双侧部分F检验，F值 = 12.910，p＜0.001）。标准DDM参数回归的R值（0.553）小于stDDM参数的R值（0.573；模型1对比4，双侧部分F检验，F-value=6.656，p=0.011）。因此，考虑属性潜伏期增加了解释反应时间差异的能力。

Attribute latency predicts behavioral changes across time constraints

属性延迟预测时间限制下的行为变化

Supplementary Fig. 7 shows an S-shaped pattern of the choice behavior across time constraints, especially in the cases of time-pressure versus free (Supplementary Fig. 7a) and time-pressure versus delay (Supplementary Fig. 7c) conditions. Participants with a high percentage of LL decisions in the time-free condition (i.e., patient participants) chose more LL options under time pressure and chose fewer LL options under time delay, while participants with a low percentage of LL decisions (i.e., impatient participants) did the opposite. That is, time constraints did not affect participants choice behavior in the same

补充图7展示了不同时间限制条件下选择行为呈现的S型模式，尤其在时间压力与自由（补充图7a）及时间压力与延迟（补充图7c）条件下的对比。在无时间限制条件下LL决策占比较高的参与者（即耐心型参与者）表现出时间压力下选择更多LL选项、而时间延迟下选择更少LL选项的特征；而LL决策占比较低的参与者（即急躁型参与者）则呈现相反趋势。这表明时间限制并未以相同方式影响参与者的决策行为。

way, and the effects depended on the level of participants' patience. In particular, the behavioral changes across time-pressure and delay conditions were correlated with the percentage of LL decisions in the time-free condition (Supplementary Fig. 7d, two-sided Pearson correlation test, $r(124) = 0.367$, $p < 0.001$, $t = 4.390$, 95% CI = [0.205, 0.509]). Participants who were more patient in the time-free condition became more patient when going from time delay to time pressure.

实验结果表明，行为变化的幅度与受试者耐心程度密切相关。具体而言，时间压力与延迟条件下的行为变化，与无时间限制条件下的LL决策比例呈显著相关性（补充图7d，双侧Pearson相关检验，r（124）= 0.367，p<0.001，t=4.390,95%置信区间=[0.205,0.509]）。在无时间限制条件下表现出较高耐心的受试者，从时间延迟条件转为时间压力条件时，其耐心程度进一步提升。

Recent studies have shown that behavioral changes across time-pressure and delay conditions can be predicted by the pre-decisional bias (captured by the starting-point parameter in the DDM), the evaluation bias (captured by the drift-rate constant), or the attentional priorities on different attributes (captured by the subjective weights)[23–25]. Here we investigate whether attribute latency can predict behavioral changes across time constraints. Supplementary Fig. 8c shows that the MTTOL in the time-free condition was correlated with the behavioral changes across time-pressure and delay conditions (two-sided Pearson correlation test, $r(124) = 0.329$, $p < 0.001$, $t = 3.885$, 95% CI = [0.164, 0.477]). The OLS regressions in Supplementary Table 5 show that taking attribute latency into account can better explain the directions and magnitudes of behavioral changes across time conditions (see Supplementary Note 4 for more details).

最近的研究表明，行为变化在时间压力和延迟条件下的预测可以通过决策前偏见（由DDM中的起始点参数捕捉）、评估偏见（由漂移率常数捕捉）或不同属性的注意力优先级（由主观权重捕捉）来实现[23-25]。本文探讨属性潜伏期是否可以预测时间约束下的行为变化。补充图8c显示，无时间条件下的MTTOL与时间压力和延迟条件下的行为变化相关（双侧皮尔逊相关检验，r（124）= 0.329，p＜0.001，t = 3.885,95% CI = [0.164,0.477]）。补充表5中的OLS回归分析显示，考虑属性潜伏期可以更好地解释时间条件下行为变化的方向和幅度（更多细节见补充说明4）。

Attribute latency changes are in line with the behavioral changes across time constraints

属性延迟变化与时间限制下的行为变化一致

In the time-delay condition, participants could only start to move the mouse after the options had been displayed for 10 s. Moreover, participants' decisions were fastest (on average, after the 10 s enforced delay) in the time-delay condition (mean = 1.192 s). Thus, it is clear that participants began to make their choices before moving the mouse. Therefore, here we only analyze how the MTTOL changed across time-free and pressure conditions.

在时间延迟条件下，参与者只有在选项显示10秒后才能开始移动鼠标。此外，参与者在时间延迟条件下的决策速度最快（平均在10秒强制延迟后），平均时间为1.192秒。因此，很明显，参与者在移动鼠标之前就开始做出选择。因此，我们在这里仅分析MTTOL在无时间限制和压力条件下的变化。

Participants whose MTTOL was positive in the time-free condition processed the amount attribute much earlier than the time attribute under time pressure (Fig. 2e, two-sided Wilcoxon signed rank test,

在无时间压力条件下MTTOL呈阳性的受试者，在时间压力下对数量属性的处理远早于时间属性（图2 e，双侧Wilcoxon符号秩检验）。

https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

$V = 1148$, $p < 0.001$), while participants whose MTTOL was negative processed the time attribute earlier than the amount attribute under time pressure (Fig. 2e, $V = 231.5$, $p = 0.065$). This shows a similar S-shaped pattern as the behavioral change across time-pressure and free conditions (Supplementary Fig. 9). That is, time pressure sped up the processing of one attribute over the other. More importantly, the MTTOL changes were aligned with the behavioral changes for the two groups of participants (Fig. 2e). Compared to the time-free condition, participants with positive MTTOLs chose more LL options (two-sided Wilcoxon signed rank test, $V = 4481.5$, $p < 0.001$), while participants with negative MTTOLs chose fewer LL options ($V = 89$, $p = 0.027$) in the time-pressure condition. The MTTOL change was correlated with the behavioral change across participants (Fig. 2f, two-sided Pearson correlation test, $r(124) = 0.515$, $p < 0.001$, $t = 6.693$, 95% CI = [0.374, 0.633]).

V=1148，p<0.001），而 MTTOL 为负的参与者在时间压力下会优先处理时间属性而非数量属性（图2 e，V=231.5，p=0.065）。这显示出与时间压力条件和自由条件下的行为变化相似的S型模式（补充图9）。也就是说，时间压力会加速对某一属性的处理速度。更重要的是，两组参与者的 MTTOL 变化与行为变化保持一致（图2 e）。与无时间压力条件相比，具有正向MTTOLs的参与者在时间压力条件下选择了更多LL选项（双侧Wilcoxon符号秩检验，V=4481.5，p<0.001），而具有负向MTTOLs的参与者则选择了更少的LL选项（V=89，p=0.027）。MTTOL 的变化与参与者的行为变化显著相关性（图2 f，双侧Pearson 相关检验，r（124）=0.515，p<0.001，t=6.693,95%CI=[0.374, 0.633]）。

We also tested whether MTTOL mediated the effect of time constraint on the choice behavior. Both time condition and MTTOL entered into a linear regression model predicting choice behavior. The mediation analysis revealed that the effect of time constraint was significantly reduced (from $\beta = 0.065$, $p = 0.032$ to $\beta = 0.006$, $p = 0.632$), and that MTTOL was a significant predictor of choice behavior ($\beta = 0.005$, $p < 0.001$). Using a bootstrapping method (with 10, 000 iterations), we tested the significance of the indirect effect of time constraint on choice behavior through MTTOL. The 95% confidence interval for the indirect effect did not include zero (0.003, 0.110), indicating significant mediation (Supplementary Fig. 10).

我们还测试了 MTTOL 是否介导了时间限制对选择行为的影响。时间和 MTTOL 都进入了预测选择行为的线性回归模型中。中介分析显示，时间限制的影响显著减弱（从 β =0.065，p =0.032降至 β =0.006，p =0.632），且 MTTOL 是选择行为的重要预测因子（β =0.005，p < 0.001）。通过自助法（10,000次迭代），我们检验了时间限制通过 MTTOL 对选择行为间接影响的显著性。间接效应的95%置信区间不包含零（0.003,0.110），表明存在显著的中介作用（补充图10）。

Manipulating intertemporal choice behavior via attribute latency
通过属性潜伏期操纵跨时间选择行为

The results above show that attribute latency (TOL) is malleable. To test the causal link from attribute latencies to intertemporal choices, we ran four experiments (Studies 2–5) with two different manipulations and with/out mouse-tracking. Studies 2 and 3 are purely behavioral studies. In these two studies, we manipulated the order in which we displayed the amount and time information and tested whether this altered the likelihood that participants made a patient choice. Compared to Study 1, we changed the time-pressure and time-delay blocks into amount-first and time-first blocks in Study 2. In the amount-first block, the amount attribute for each option was first displayed for 3 s, followed by the time attribute (along with the amount information). In the time-first block, the time attribute for each option was first displayed for 3 s, followed by the amount attribute (along with the time information). Participants were free to make decisions at any time. In Study 3, we first displayed one attribute for 1.5 s, before the other attribute appeared. Moreover, participants could not make decisions in the first 1.5 s in Study 3. Otherwise, the two studies (2 and 3) were identical. Studies 4 and 5 were replications of Studies 2 and 3 respectively, with mouse-tracking.

上述结果表明属性延迟（TOL）具有可塑性。为验证属性延迟与跨时间选择之间的因果关系，我们开展了四项实验（研究2-5），分别采用两种不同操作方式，并设置是否使用鼠标追踪的对照组。研究2和3为纯行为学实验。在这两项研究中，我们通过改变金额信息与时间信息的呈现顺序，测试这种调整是否会影响受试者做出患者选择的可能性。相较于研究1，我们在研究2中将时间压力与时间延迟模块调整为金额优先与时间优先模块。在金额优先模块中，每个选项的金额属性首先显示3秒，随后呈现时间属性（同时显示金额信息）。在时间优先模块中，每个选项的时间属性首先显示3秒，随后呈现金额属性（同时显示时间信息）。受试者可随时做出决策。研究3中，我们先显示一个属性1.5秒，再呈现另一个属性。此外，研究3中受试者在前1.5秒内无法做出决策。除此之外，两项研究（2和3）的实验设计完全一致。研究4和研究5分别是研究2和研究3的重复实验，采用小鼠追踪法。

The central idea here is that displaying one attribute first may induce participants to start processing this attribute first. We expected that, compared to the control condition, the TOL would increase in the amount-first condition and decrease in the time-first condition. Based on the results of Study 1, this would make participants more patient (choose LL options more) in the amount-first condition and less patient (choose LL options less) in the time-first condition.

此处的核心观点是，首先呈现某一属性可能会诱导受试者优先处理该属性。我们预期，与对照组相比，数量优先条件下的时间偏好水平（TOL）会升高，而时间优先条件下的TOL会降低。根据研究1的结果，这将使受试者在数量优先条件下表现出更高的耐心（选择LL选项更多），而在时间优先条件下表现出更低的耐心（选择LL选项更少）。

In line with our predictions, participants chose more LL options in the amount-first condition (Study 2: mean = 0.630, SD = 0.285; Study 3: mean = 0.570; SD = 0.274; Study 4: mean = 0.666, SD = 0.255; Study 5: mean = 0.639, SD = 0.224) than the control condition (Study 2: mean = 0.578, SD = 0.258; Study 3: mean = 0.528; SD = 0.249; Study 4: mean =

与我们的预测一致，参与者在数量优先条件下选择更多LL选项（研究2：均值=0.630，标准差=0.285；研究3：均值=0.570，标准差=0.274；研究4：均值=0.666，标准差=0.255；研究5：均值=0.639，标准差=0.224）比对照条件（研究2：均值=0.578，标准差=0.258；研究3：均值=0.528，标准差=0.249；研究4：均值=

0.593, SD = 0.273; Study 5: mean = 0.592, SD = 0.215; two-sided Wilcoxon signed rank tests, Study 2: $V = 151$, $p < 0.001$; Study 3: $V = 222.5$, $p = 0.007$; Study 4: $V = 180$, $p < 0.001$; Study 5: $V = 345.5$, $p < 0.001$), and chose fewer LL options in the time-first condition (Study 2: mean = 0.527, SD = 0.270, $V = 206.5$, $p < 0.001$; Study 3: mean = 0.481, SD =

0.593，标准差=0.273；研究5：均值=0.592，标准差=0.215；双侧Wilcoxon符号秩检验，研究2：变异系数(V)=151，p<0.001；研究3：V= 222.5，p=0.007； 研究4：V=180，p<0.001； 研究5：V=345.5，p <0.001），且在时间优先条件下选择的LL选项更少（研究2：均值= 0.527，标准差=0.270，V=206.5，p<0.001；研究3：均值=0.481，标准差=

0.245, $V = 159.5$, $p < 0.001$; Study 4: mean = 0.548, SD = 0.290, $V = 365$, $p < 0.001$; Study 5: mean = 0.548, SD = 0.223, $V = 393$, $p < 0.001$; Fig. 3a–e; Supplementary Figs. 11–14).

0.245，V=159.5，p < 0.001；研究4：均值=0.548，SD=0.290，V=365，p < 0.001；研究5：均值=0.548，SD=0.223，V=393，p < 0.001；图3 a-e；补充图11-14）。

However, there are potentially many reasons why our manipulation might have changed participants' behavior. To verify that our manipulation affected attribute latency, and thus choice, we turn to Studies 4 and 5 and compare the MTTOL across conditions. Figure 3c, d show that, compared to the control condition, the attribute latency (MTTOL) increased in the amount-first condition and decreased in the time-first condition (two-sided Wilcoxon signed rank tests, Study 4: amount-first vs. control, $V = 143$, $p < 0.001$; control vs. time-first, $V = 1492.5$, $p < 0.001$; Study 5: amount-first vs. control, $V = 257.5$, $p < 0.001$; control vs. time-first, $V = 1425$, $p = 0.004$; see Supplementary Figs. 15 and 16 for details, and see Supplementary Figs. 17 and 18 for the correlations between MTTOL and the percentage of LL decisions within each condition). That is, compared to the control condition, displaying the amount information first induced participants to process the amount attribute earlier than the time attribute, while displaying the time information first induced participants to process the time attribute earlier than the amount attribute. The exogenous manipulation indeed altered participants attribute laten-

然而，我们的干预措施可能改变受试者行为的原因可能有很多。为了验证这种干预是否影响了属性延迟（进而影响选择行为），我们参考了研究4和研究5的数据，并对比了不同条件下的 MTTOL 值。图3 c、d显示，与对照组相比，数量优先条件下的属性延迟（MTTOL）有所增加，而时间优先条件下的属性延迟则有所减少（双侧Wilcoxon符号秩检验结果：研究4中数量优先组对比对照组，V=143，p<0.001；对照组对比时间优先组，V=1492.5，p<0.001；研究5中数量优先组对比对照组，V=257.5，p<0.001；对照组对比时间优先组，V=1425，p=0.004；具体细节参见补充图15和16，各条件下的MTTOL与LL决策百分比相关性数据见补充图17和18）。也就是说，与对照组相比，先呈现数量信息会促使受试者更早处理数量属性，而先呈现时间信息则会促使受试者更早处理时间属性。外源性干预确实改变了受试者的属性延迟

cies in the expected way.
以预期方式发生。

Moreover, Fig. 3c, d show that the behavioral change was in line with the MTTOL change across manipulation conditions (see Supplementary Figs. 13–16 for more details). The MTTOL change was correlated with the behavioral change across manipulation conditions in Study 5 (two-sided Spearman correlation tests, Fig. 3g: amount-first vs. time-first, $\rho = 0.525$, $p < 0.001$, $S = 22772$; Supplementary Fig. 20a: amount-first vs. control, $\rho = 0.494$, $p < 0.001$, $S = 24264$; Supplementary Fig. 20b: control vs. time-first, $\rho = 0.330$, $p = 0.007$, $S = 32080$). In Study 4, the MTTOL change was correlated with the behavioral change across amount-first and control conditions (Supplementary Fig. 19a, $\rho = 0.382$, $p = 0.001$, $S = 33851$) and across control and time-first conditions (Supplementary Fig. 19b, $\rho = 0.406$, $p < 0.001$, $S = 27169$), but not across amount-first and time-first conditions (Fig. 3f, $\rho = 0.174$, $p = 0.165$, $S = 37792$).

此外，图3 c、d 显示行为变化与操作条件下的 MTTOL 变化一致（更多细节见补充图 13-16）。在研究 5 中，MTTOL 的变化与操作条件下的行为变化相关（双侧斯皮尔曼相关检验，图3 g：数量优先与时间优先，ρ = 0.525，p < 0.001，S = 22772；补充图 20a：数量优先与对照组，ρ = 0.494，p < 0.001，S = 24264；补充图 20b：对照组与时间优先，ρ = 0.330，p = 0.007，S = 32080）。在研究 4 中，MTTOL 的变化与数量优先和对照组条件下的行为变化相关（补充图 19a，ρ = 0.382，p = 0.001，S = 33851），以及对照组与时间优先条件下的行为变化相关（补充图 19b，ρ = 0.406，p < 0.001，S = 27169），但与数量优先和时间优先条件下的行为变化无关（图3 f，ρ = 0.174，p = 0.165，S = 37792）。

A mediation analysis based on bootstrapping (with 10,000 iterations) revealed that the 95% confidence interval for the indirect effect of manipulation on choice behavior through MTTOL did not include zero (Study 4: (0.058, 0.140), Study 5: (0.014, 0.090)). This indicates that the effect of manipulation on choice behavior was mediated via MTTOL (see Supplementary Figs. 21 and 22 for details).

基于自助法（10,000次迭代）的中介分析显示，通过 MTTOL 间接影响选择行为的95%置信区间不包含零（研究4：（0.058,0.140），研究5：（0.014,0.090））。这表明操纵对选择行为的影响是通过 MTTOL 介导的（详见补充图21和22）。

The likely reason for the non-significant correlation between MTTOL change and behavioral change across amount-first and time-first conditions in Study 4 is that participants could choose before seeing the second attribute (i.e., before 3 s was up); this occurred in 45.3% of trials in the amount-first condition and in 17.2% of trials in the time-first condition. The IQR method eliminated most of the trials that were shorter than 3 s in the time-first condition, but not in the amount-first condition (see Methods for details). Supplementary Note 6 shows that the correlations between MTTOL change and behavioral change across time-first and amount-first conditions are significant if we exclude trials shorter than 3 s (Supplementary Fig. 23c), or if we keep trials shorter than 3 s and only exclude trials with extremely long RTs (Supplementary Fig. 24c). Thus, we are reasonably confident that the relationships between MTTOL change and behavioral change that we found in Study 5 (which sidesteps these issues), are also present in Study 4.

研究4中，数量优先和时间优先条件下 MTTOL 变化与行为变化之间未显著相关的原因可能是参与者可以在看到第二个属性之前（即在3秒结束前）做出选择；这种情况在数量优先条件下发生在45.3%的试验中，在时间优先条件下则发生在17.2%的试验中。IQR 方法消除了时间优先条件下大多数短于3秒的试验，但在数量优先条件下则没有（详见方法部分）。补充说明6显示，如果我们排除短于3秒的试验（补充图23 c），或者保留短于3秒的试验但仅排除反应时间极长的试验（补充图24 c），那么时间优先和数量优先条件下的 MTTOL 变化与行为变化之间的相关性是显著的。因此，我们有理由相信，在研究5中发现的 MTTOL 变化与行为变化之间的关系（该研究避开了这些问题）在研究4中同样存在。

In summary, these results show that manipulating the order of displaying information alters participants' attribute latencies and affects their choices. This confirms the causal role of attribute latency in shaping intertemporal decisions.

综上所述，这些结果表明，操纵信息呈现顺序会改变受试者的属性潜伏期并影响其选择。这证实了属性潜伏期在塑造跨期决策中的因果作用。

Discussion
讨论

This paper describes the results of five separate studies designed to investigate the role of attribute latencies in determining intertemporal

本文阐述了五项独立研究的结果，旨在探讨属性潜伏期在决定跨时间效应中的作用。

https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

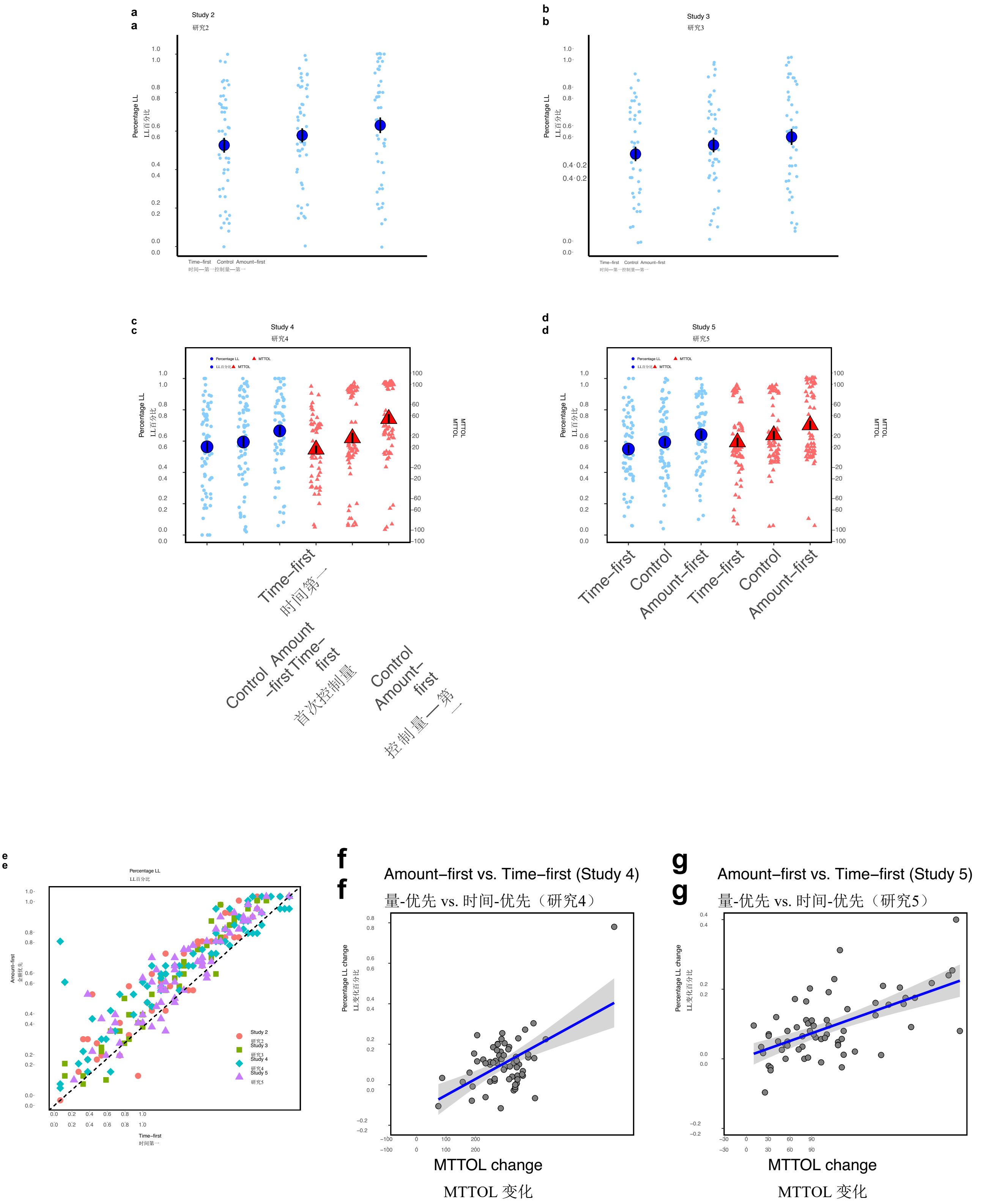

Fig. 3 | Attribute latencies causally shape intertemporal choices in Studies 2–5. **a**, **b** The percentage of LL decisions across manipulation conditions in Studies 2 and 3; **c**, **d** The percentage of LL decisions (blue dots) and the mouse-trajectory-derived time-onset lag (MTTOL, red triangles) across manipulation conditions in Studies 4 and 5; **e** the percentage of LL decisions across time-first and amount-first conditions for each participant in Studies 2–5. **f**, **g** Correlation between the MTTOL change and the behavioral change across time-first and amount-first conditions in Studies 4 and

图3 | 属性延迟因果地影响了研究2-5中的跨时间选择。a，b 在研究2和3中，不同操作条件下LL决策的百分比；c，d 在研究4和5中，不同操作条件下LL决策（蓝色点）和小鼠轨迹衍生的时间起始延迟（MTTOL，红色三角）的百分比；e 在研究2-5中，每位参与者在时间优先和数量优先条件下的LL决策百分比。f，g 在研究4中，MTTOL 变化与时间优先和数量优先条件下的行为变化之间的相关性。

5. Each light blue dot or light red triangle in **a**–**d** represents one participant. The deep blue dot in **a**–**d** represents the mean percentage of LL decisions and the deep red triangle in **c**, **d** represents the mean MTTOL. The vertical bars in **a**–**d** represent the standard errors of the mean clustered by participant. Each data point in

5. 图a-d中的每个浅蓝色圆点或浅红色三角形代表一个参与者。图a-d中的深蓝色圆点代表LL决策的平均百分比，图c、d中的深红色三角形代表平均 MTTOL 。图a-d中的垂直条表示按参与者聚类的均值标准误差。每个数据点在

e–**g** represents one participant. The black dashed line in **e** is the identity line. The blue solid lines and gray shadings in **f**, **g** are the fitted linear regression lines and their standard errors.

e-g表示一名受试者。图e中的黑色虚线为身份线。图f、g中的蓝色实线及灰色阴影线为拟合的线性回归线及其标准误差。

choices. We estimated attribute latencies using mouse-trajectory data and found that most (but not all) people process amount information before time information. These attribute latencies predicted individual differences in intertemporal choices, RTs, and behavioral changes across time constraints. We validated these results using an independent computational modeling analysis where the attribute latency was identified based on choice and RT data. Moreover, the behavioral changes under time constraints were in line with the attribute latency changes across participants. Then we tested whether exogenously manipulating the order of displaying amount and time information would influence attribute latency and causally change intertemporal preferences. Consistent with this hypothesis, our results revealed that

在选择实验中，我们通过分析小鼠运动轨迹数据估算属性反应时，发现多数（但非全部）受试者会优先处理数量信息而非时间信息。这些属性反应时预测了个体在跨时间选择、反应时（RT）及不同时间限制下的行为变化差异。我们通过独立的计算建模分析验证了这些结果，其中属性反应时是根据选择数据和反应时数据确定的。此外，受试者在时间限制下的行为变化与参与者间的属性反应时变化趋势一致。随后我们测试了外源性改变数量信息与时间信息呈现顺序是否会影响属性反应时并因果改变跨时间偏好。与这一假设一致，我们的研究结果表明

manipulating the display order of the amount and time information altered the attribute latency and changed preferences. In particular, displaying amount before time makes people more patient, while displaying time before amount makes people less patient.

操纵金额和时间信息的显示顺序会改变属性延迟并改变偏好。 特别是，先显示金额再显示时间会使人更耐心，而先显示时间再显示金额会使人更不耐烦。

These results deepen our understanding of the nature of intertemporal decisions. The focus on intertemporal decisions is typically on just the choice itself, rather than the process underlying decisions. Researchers often treat observed differences in intertemporal choices as fixed differences in underlying parameters (e.g., discount rate) of the utility-based choice models. In contrast, we have shown that intrachoice dynamics, i.e., attribute latency, can explain individual differences in intertemporal choices and RTs. Because attribute latencies

这些研究结果深化了我们对跨期决策本质的理解。以往对跨期决策的研究往往仅关注选择本身，而忽视了决策背后的过程机制。研究者通常将观察到的跨期选择差异视为效用型选择模型中基础参数（如贴现率）的固定差异。与之形成对比的是，我们发现选择过程中的动态变化——即属性反应时——能够解释个体在跨期选择和反应时间上的差异。由于属性反应时

https://doi.org/10.1038/s41467-024-46657-2
https://doi.org/10.1038/s41467-024-46657-2

can depend on how choices are presented, this indicates that intertemporal preferences are not purely outcome-based.
这表明跨期偏好并非完全基于结果，而是取决于选择的呈现方式。

We have shown that time pressure and delay have opposite effects on participants' intertemporal preferences. The behavioral changes across time constraints cannot be parsimoniously explained by static utility models because those models do not account for the dynamics of the choice process. On the other hand, attribute latencies yield accurate predictions about the effects of time constraints on the direction and magnitude of behavioral changes.

我们已证实时间压力与延迟对受试者的时间偏好具有相反效应。由于静态效用模型未能解释选择过程的动态性，因此无法简洁地说明时间约束下的行为变化。另一方面，属性潜伏期能准确预测时间约束对行为变化方向及幅度的影响。

Although dual-process theories are usually introduced to explain behavioral changes under time constraints, we offer an alternative explanation for such changes. Our results indicate that the attribute latency within a single evidence accumulation process might be a better explanation for the effects of time pressure on behavior. Prior work has also identified predispositions (i.e. starting-point biases) as an important factor in predicting the effects of time pressure[23]. Predispositions and attribute latencies both capture similar things, namely differences between the fastest and slowest decisions. Here (and elsewhere) there is evidence for both factors impacting choices[3,24,25,32]. In our study the stDDM did not significantly improve on the standard DDM in out-of-sample predictions. This is likely due to the high degree of mimicry between attribute latencies and predispositions. However, these two constructs are theoretically different and possible to distinguish in behavior. Predispositions occur prior to processing any information from the current choice problem and thus do not depend on trial-level variables. Attribute latencies capture a tendency to consider one attribute sooner than the other, and so their effects depend on trial-level attribute values[45]. It is still a debated issue how much the effects of time constraints on choices are due to predispositions[23], attentional priorities[25,56], or attribute latencies[45]. Future work will need to carefully disentangle these components of the decision process.

尽管双重处理理论通常被用来解释时间压力下的行为变化，但我们提出了另一种解释框架。研究结果表明，单个证据积累过程中的属性延迟可能更符合时间压力对行为影响的解释机制。先前研究也指出，先天倾向（即起始点偏差）是预测时间压力效应的重要因素[23]。先天倾向与属性延迟都捕捉到相似的特征——即最快决策与最慢决策之间的差异。现有证据表明，这两个因素都会影响选择行为[3 24 25 32]。在本研究中，标准双决策模型（stDDM）在样本外预测上的表现并未显著优于标准双决策模型（DDMin）。这很可能源于属性延迟与先天倾向的高度相似性。不过，这两个概念在理论上存在本质区别，且可通过行为观察进行区分。先天倾向在处理当前选择问题中的任何信息之前就已存在，因此不依赖于试验层面的变量。属性潜伏期反映了人们倾向于优先考虑某一属性而非另一属性的倾向，因此其效应取决于试验层面的属性值[45]。关于时间限制对选择的影响究竟有多大程度上源于先天倾向[23]、注意力优先级[25 56]或属性潜伏期[45]，目前仍存在争议。未来的研究需要仔细区分决策过程中的这些不同组成部分。

Different from Fisher[26] which finds that manipulating exposure to the amount versus time information alters people's patience while the order of displaying the two types of information has no significant effects on people's choice behavior, the current study shows that simply manipulating the order of displaying information alters participants' attribute latencies and affects their choices. The reason that there was no order effect in Fisher[26] could be that this effect was dominated by the strong exposure manipulation.

与费希尔[26]的研究不同——他发现改变暴露量与时间信息的呈现顺序会影响人们的耐心水平，而两种信息的展示顺序对选择行为没有显著影响——本研究发现，仅通过改变信息展示顺序就能改变受试者的属性反应时，并影响其选择行为。费希尔研究中未观察到顺序效应的原因[26]，可能是由于这种效应被强烈的暴露量操控所主导。

The current study is also related to the research on order effects during information searching and choice tasks in marketing[57–59], which are referred to as primacy and recency effects[60]. Studies in psychology and economics have explained these effects as decision-makers choosing the item they pay more attention to, and therefore choices can be manipulated via information search[61–64]. Here we reveal an underlying mechanism, attribute latency, that determines information processing order and can also be manipulated to influence choice behavior.

本研究还与市场营销领域关于信息搜索和选择任务中顺序效应的研究密切相关[57–59]，这些效应在心理学中被称为首因效应和近因效应[60]。心理学和经济学研究将这些效应解释为决策者倾向于选择他们更关注的项目，因此可以通过信息搜索来操纵选择行为[61–64]。我们在此揭示了一个潜在机制——属性延迟，它决定了信息处理的顺序，同时也可通过操纵该机制来影响选择行为。

Many previous studies have neglected the role of individual differences and missed opportunities to link variability in the process to variability in behavior (Stillman et al.[36]) The current study seeks to address this issue by incorporating evidence related to heterogeneity across participants, linking aspects of the process-tracing data and model parameters to response latencies and choices. Future studies

以往诸多研究忽视了个体差异的作用，错失了将过程变异性与行为变异性相关联的研究机遇（Stillman等[36]）。本研究通过整合参与者间异质性相关证据，将过程追踪数据与模型参数的特征与反应时长及选择行为相关联，旨在解决这一问题。未来研究

can examine how the manipulation interacts with people s prior inclination to process attributes with different latencies. It would also be interesting to link the attribute latency with the actual timing with which the information is acquired using other process-tracing data, e.g., eye-tracking.

可探究这种操作如何与人们先前对不同延迟属性的加工倾向产生交互作用。此外，若能结合其他过程追踪数据（如眼动追踪）将属性延迟与信息实际获取时间相关联，也将具有重要意义。

An important goal of this literature is the design of policies or interventions to ameliorate negative real-world outcomes. Knowing whether changes in attribute latencies causally influence intertemporal choices is useful because nudging might be easier than changing more hard-wired preference parameters[65]. Though intertemporal choice is

该领域的核心目标之一，是制定政策或干预措施来改善现实中的负面结果。了解属性延迟变化是否会对跨期决策产生因果影响具有重要价值，因为相较于调整那些根深蒂固的偏好参数，实施引导性干预可能更为可行[65]。尽管跨期决策

not solely determined by the attribute latency, the current paper suggests that simply manipulating the attribute latency has substantial impacts on intertemporal choices. In particular, we show that manipulating the display order of the time and amount attributes is an effective way to manipulate participants' intertemporal choices[66]. Moreover, policies of waiting periods (time delay) have been applied in real life to prompt a shift towards more deliberative thinking and lead to less myopic decisions[16,67,68]. Our results indicate that we should be careful when using such interventions since they might only be effective for some people, and push other people in the opposite direction.

本研究指出，时间选择不仅受属性延迟时间的影响，单纯调整属性延迟时间对跨期决策具有显著作用。具体而言，我们发现通过改变时间与金额属性的呈现顺序，能有效影响参与者的跨期决策[66]。值得注意的是，现实生活中已普遍采用等待期（时间延迟）策略，这种做法既能促使人们进行更审慎的思考，又能减少短视决策[16 67 68]。但研究结果表明，使用此类干预措施需谨慎，因其可能仅对部分人群有效，而对另一些人则会产生相反效果。

Methods
方法

Participants
参与者

The Institutional Review Board of the Neuromanagement Lab at Zhejiang University approved the experiment (Studies 1–5). 126 university students (70 females, mean age = 22.7 years, SD = 2.4 years) participated in Study 1 from June 2019 to June 2020 (interrupted by COVID-19), 49 students (29 females, mean age = 22.9 years, SD = 2.7 years) participated in Study 2 in April 2021, 43 students (22 females, mean age = 23.3 years, SD = 2.6 years) participated in Study 3 in May 2021, 69 students (43 females, mean age = 22.56 years, SD = 2.6 years) participated in Study 4 in January 2022, and 66 students (46 females, mean age = 21.62 years, SD = 2.1 years) participated in Study 5 in March 2022 at the Neuromanagement Lab, Zhejiang University. Informed consent was obtained from all participants before the experiment.

浙江大学神经管理实验室机构审查委员会批准了本实验（研究1-5）。2019年6月至2020年6月期间（因新冠疫情中断），共有126名大学生（70名女性，平均年龄22.7岁，标准差2.4岁）参与研究1；2021年4月，49名学生（29名女性，平均年龄22.9岁，标准差2.7岁）参与研究2；2021年5月，43名学生（22名女性，平均年龄23.3岁，标准差2.6岁）参与研究3；2022年1月，69名学生（43名女性，平均年龄22.56岁，标准差2.6岁）参与研究4；2022年3月，66名学生（46名女性，平均年龄21.62岁，标准差2.1岁）参与研究5。所有参与者在实验前均签署了知情同意书。

Experimental design and procedure
实验设计与操作

Studies 1–5 used the same 300 trials. In these 300 trials, the payment times in the SS and LL options included today, 7 days, 30 days, 60 days, and 180 days. The reward amount in SS and LL options varied from 10 to 99 units. We provided participants with instructions before each block/condition. They could only start the experiment when they correctly answered the comprehension questions after reading the instructions. In Study 1, we tracked the mouse-trajectories of each decision using MouseTracker[37] with a temporal resolution of 70 Hz. Participants were instructed to start moving the mouse as soon as the two options were displayed, and if they did not start to move the mouse in 750 ms, they were given a reminder message following that trial. In Studies 2 and 3 we programmed the experiment using Python and did not record the mouse-trajectories. The experiments in Studies 4 and 5 were also programed using Python and participants' mouse-trajectories were recorded with a temporal resolution of 70 Hz. At the end of the experiment in each study, one trial was randomly selected for each participant and we transferred money to the participant via Alipay based on his/her decision on the date in the selected trial. On average, participants earned 56.5 RMB in Study 1, 55.4 RMB in Study 2, 61.0 RMB in Study 3, 63.3 RMB in Study 4, and 60.0 RMB in Study 5 (including the show-up fee of 15 RMB).

研究1-5采用了相同的300次试验。在这300次试验中，SS和LL选项的支付时间包括今日、7天、30天、60天和180天。SS和LL选项的奖励金额从10到99个单位不等。我们在每个实验区块/条件开始前向参与者提供了操作说明。参与者只有在阅读说明并正确回答理解题后才能开始实验。在研究1中，我们使用时间分辨率为70赫兹的MouseTracker追踪每次决策的小鼠轨迹。参与者被要求在两个选项显示后立即开始移动鼠标，若在750毫秒内未开始移动鼠标，则会在该次试验后收到提醒信息。研究2和3采用Python编程进行实验，未记录小鼠轨迹。研究4和5同样使用Python编程，但以70赫兹的时间分辨率记录了参与者的鼠标轨迹。在每项研究的实验结束时，随机选取每位受试者在所选试验中的一个试验日期，并根据其在该日期的决策通过支付宝向其转账。平均而言，受试者在研究1中获得56.5元人民币，在研究2中获得55.4元人民币，在研究3中获得61.0元人民币，在研究4中获得63.3元人民币，在研究5中获得60.0元人民币（含15元人民币的出勤费）。

Estimation of the mouse-trajectory-derived time-onset lag (MTTOL)
小鼠轨迹衍生的起效滞后时间（MTTOL）的估计

We normalized the coordinates of the center of the start box to (0,0), and the center of the left and right options to (−1,1) and (1,1), respectively. Prior studies have often normalized the mouse trajectories into 100 intervals before performing analysis[38,44]. This might distort onset times because a unit of MTTOL in trials with longer durations is longer in absolute time than a unit of MTTOL in trials with shorter durations. Therefore, we extended the mouse-position at the last time point of each trial out to the maximum RT in each time condition[45]. Before doing this, we excluded trials with extremely long or short RTs using the IQR method (see Supplementary Fig. 3 for the correlations between the MTTOL based on the extended mouse-trajectory data and the MTTOL based on the raw mouse-trajectory data). That is, we eliminated trials where RTs were above the 0.75

我们将起始框中心的坐标归一化为（0,0），左右选项中心的坐标分别归一化为（-1,1）和（1,1）。先前的研究常在分析前将小鼠轨迹归一化为100个区间[38]，[44]。这可能会扭曲起始时间，因为在持续时间较长的试验中，MTTOL 的单位在绝对时间上比持续时间较短的试验中的 MTTOL 单位更长。因此，我们将每个试验最后一个时间点的小鼠位置扩展到每个时间条件下的最大反应时[45]。在此之前，我们使用 IQR 方法排除了反应时极长或极短的试验（有关基于扩展小鼠轨迹数据的 MTTOL 与基于原始小鼠轨迹数据的 MTTOL 之间的相关性，请参见补充图3）。即，我们剔除了反应时超过0.75秒的试验。

https://doi.org/10.1038/s41467-024-46657-2
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quartile by more than 1.5 times the interquartile range, or below the 0.25 quantile by more than 1.5 times the interquartile range in each time condition. In Study 1, 6.2%, 0.02% and 7.8% of the trials were excluded from the time-free, time-pressure, and time-delay conditions, respectively. In Study 4 (5), 6.9% (6.5%), 1.0% (7.0%) and 22.2% (6.7%) of the trials were excluded from the control, amount-first, and time-first conditions, respectively. The reason that 22.2% of the trials were excluded from the time-first condition in Study 4 was that there were many trials faster than 3 s that were eliminated (see Supplementary Note 6). After this adjustment, all the mouse-trajectories in each condition had the same duration, i.e., the maximum RT of that condition. Then we equally split each extended trajectory into 100 intervals starting at $t = 1$ and ending at $t = 101$. For each time t, we calculated the angle between the current cursor position and the start position (0, 0). Thus, an angle of $45^\circ / -45^\circ$ indicates direct movement toward the right/left option, and an angle of 0° indicates direct movement upwards.

在每个时间条件下，若轨迹长度超出四分位距1.5倍以上，或低于0.25四分位距1.5倍以上，则被排除。在研究1中，无时间限制、时间压力和时间延迟条件下分别有6.2%、0.02%和7.8%的试验被剔除。研究4(5)中，对照组、数量优先组和时间优先组分别有6.9%（6.5%）、1.0%（7.0%）和 22.2%(6.7%）的试验被排除。研究4中时间优先组排除22.2%试验的原因是存在大量超过3秒的快速试验被剔除（详见补充说明6）。调整后，各组小鼠轨迹时长统一为该组最大反应时间。随后将每个扩展轨迹从t=1开始至t=101均匀分割为100个区间。针对每个时间点t，计算当前光标位置与起始点（0,0）之间的夹角：当角度为45°°时表示直接向右/左选项移动，角度为0°则表示直接向上移动。

To identify the onset time that the participant started to consider and process each attribute, we estimated linear regressions at the participant level for how the trajectory angle at each time point t was affected by the time ($\mathrm{DiffTime} = \mathrm{Time}_{\mathrm{right}} - \mathrm{Time}_{\mathrm{left}}$) and the amount differences ($\mathrm{DiffAmount} = \mathrm{Amount}_{\mathrm{right}} - \mathrm{Amount}_{\mathrm{left}}$) between the two options. The regression for participant i at time point t in each condition is:

为确定受试者开始考虑和处理每个属性的起始时间，我们对每个受试者进行了线性回归分析，以评估轨迹角度在每个时间点t如何受到时间（差值时间=$\mathrm{Time}_{\mathrm{right}} - \mathrm{Time}_{\mathrm{left}}$）和两个选项之间的数量差异（$\mathrm{Amount}_{\mathrm{right}} - \mathrm{Amount}_{\mathrm{left}}$）的影响。每个条件下受试者i在时间点t的回归方程为：

$$\mathrm{Angle}_{itj} = \gamma_{itc} + \gamma_{itT} \times \mathrm{DiffTime}_j + \gamma_{itA} \times \mathrm{DiffAmount}_j \tag{1}$$

$$\mathrm{Angle}_{itj} = \gamma_{itc} + \gamma_{itT} \times \mathrm{DiffTime}_j + \gamma_{itA} \times \mathrm{DiffAmount}_j$$
（1）

where γ_{itc} is the constant, γ_{itT} is the coefficient for the time difference, γ_{itA} is the coefficient for the amount difference, and j is the index of trials (observations). Consistent with Sullivan et al.[38] and Lim et al.[44], we carried out a one-tailed test of the hypothesis that the estimated regression coefficient of interest was significantly positive at the 5% level at time t. Using this procedure, we identified the earliest time t at which the test was satisfied and remained significant until the end of the trial. We defined the difference between the onset times of the amount and time attributes as the attribute latency, i.e., mousetrajectory-derived time-onset lag (MTTOL).

其中 γ_{itc}为常数，γ_{itT}为时间差异系数，γ_{itA}为数量差异系数，j为试验（观测）索引。与Sullivan等人[38]和Lim等人[44]的研究方法一致，我们采用单尾检验法验证在时间t时目标回归系数是否在5%显著性水平上显著正向。通过该方法，我们确定了最早满足检验条件且持续显著至试验结束的时间t。我们将数量属性与时间属性的起始时间差定义为属性潜伏期，即基于鼠类运动轨迹推导的时间起始滞后量（MTTOL）。

Estimation of the starting-time drift diffusion model (stDDM)
起始时间漂移扩散模型（stDDM）的估计

We estimated the stDDM using the toolbox in Maier et al.[3]. The stDDM (Supplementary Fig. 4) allows one attribute to start affecting the drift rate later than the other. Specifically, if the amount attribute enters into the process first, the update equation of the relative evidence is:

我们采用Maier等人开发的工具箱来估算stDDM模型[3]。该模型（补充图4）允许某一属性对漂移速率的影响时间晚于另一属性。具体而言，若数量属性最先参与计算过程，则相对证据的更新方程为：

$$R_{t+1} = R_t + \left(\omega_c + \left(t > \left|\frac{\mathrm{TOL}}{\mathrm{d}t}\right|\right) * \omega_T * \mathrm{DiffTime} + \omega_A * \mathrm{DiffAmount}\right) * \mathrm{d}t + \varepsilon \tag{2}$$

$$R_{t+1} = R_t + \left(\omega_c + \left(t > \left|\frac{\mathrm{TOL}}{\mathrm{d}t}\right|\right)\right) * \omega_T * \text{差异时间} + \omega A * \text{差异量} * \mathrm{d}t + \varepsilon$$ （2）

If the time attribute enters into the process first, the update equation of the relative evidence is:

若时间属性最先进入流程，则相对证据的更新方程为：

$$R_{t+1} = R_t + \left(\omega_c + \omega_T * \mathrm{DiffTime} + \left(t > \left|\frac{\mathrm{TOL}}{\mathrm{d}t}\right|\right) * \omega_A * \mathrm{DiffAmount}\right) * \mathrm{d}t + \varepsilon \tag{3}$$

$$R_{t+1} = R_t + \left(\omega_c + \omega_T * \mathrm{DiffTime} + \left(t > \left|\frac{\mathrm{TOL}}{\mathrm{d}t}\right| * \omega A * \text{差异量} * \mathrm{d}t + \varepsilon\right.\right.$$ （3）

where TOL (time-onset lag) is the onset time that the amount attribute begins to affect the decision process minus the onset time that the time attribute begins to affect it, and ε represents the amount of zero-mean Gaussian noise. In addition to these drift-rate parameters, the stDDM includes three additional parameters for: (1) Boundary separation (a), (2) non-decision time (t_0), and (3) starting point (z). Without loss of generality, we fixed the noise parameter (ε) to 1 in the estimation. In the estimation, we coded the decision of choosing the SS option as 1 and the decision of choosing the LL option as 0. That is, a starting point greater than 0.5 represents a predisposition towards the SS option, and a starting point less than 0.5 represents a predisposition towards the LL option.

其中TOL（起始滞后时间）表示数量属性开始影响决策过程的时间减去时间属性开始产生影响的时间，ε代表零均值高斯噪声的强度。除了这些漂移率参数外，stDDM模型还包含三个附加参数：(1)边界分离(a)、(2)非决策时间（t_0）、(3)起始点(z)。在估算过程中，我们固定噪声参数（ε）为1。具体编码规则是：选择SS选项的决策记为1，选择LL选项的决策记为0。也就是说，起始点超过0.5表示存在偏向性倾向。若选择SS选项，当初始值大于0.5时，表明该选项更倾向于LL选项。

Reporting summary
报告摘要

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

有关研究设计的更多信息，请参阅本文所附的《自然》期刊投资组合报告摘要。

Data availability
数据可用性

The data generated in this study have been deposited to the Open Science Framework (https://doi.org/10.17605/OSF.IO/CY4GR).

本研究产生的数据已存入开放科学框架（https://doi.org/10.17605/OSF.IO/CY4GR）。

Code availability
代码可用性

The code for the analyses presented in this article have been deposited to the Open Science Framework (https://doi.org/10.17605/OSF.IO/CY4GR).

本文所分析的代码已存入开放科学框架（https://doi.org/10.17605/OSF .IO/CY4GR）。

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Acknowledgements

致谢

We thank Todd Hare for sharing their toolbox for model estimation, and Wenjia Joyce Zhao for helpful comments. F.C. gratefully acknowledges support from the National Natural Science Foundation of China (Grant Nos. 72322009, 72173113, 71803174) and Zhejiang Provincial Philosophy and Social Sciences Planning Project (23SYS04ZD). J. Z. gratefully acknowledges support from the National Natural Science Foundation of China (Grant No. 72002195) and the Humanities and Social Sciences Research Fund supported by the Ministry of Education of China (Grant No.20YJC630228). L.W. gratefully acknowledges support from the Ministry of Science and Technology [STI 2030—Major Projects 2021ZD0200409] and the National Natural Science Foundation of China (Grant Nos. 72371226, 71871199). I.K. gratefully acknowledges support from NSF Grant 2148982.

我们感谢托德·黑尔分享其模型估算工具箱，并感谢赵文佳·乔伊斯提供的宝贵建议。F.C.衷心感谢中国国家自然科学基金（项目编号：72322009、72173113、71803174）和浙江省哲学社会科学规划项目（23SYS04ZD）的支持。J.Z.衷心感谢中国国家自然科学基金（项目编号：72002195）和中国教育部人文社会科学研究基金（项目编号：20YJC630228）的支持。L.W.衷心感谢科技部[STI 2030—重大项目 2021ZD0200409]和中国国家自然科学基金（项目编号：72371226、71871199）的支持。I.K.衷心感谢美国国家科学基金会（NSF）项目2148982的支持。

Author contributions

作者贡献

F. C., J.Z., L.W., and I. K. designed research; F.C. and J.Z. performed research; F.C. and J.Z. analyzed data; and F.C. and I.K. wrote the paper.

F.C.、J.Z.、L.W.和I.K.负责研究设计；F.C.与J.Z.执行研究；F.C.与J.Z.进行数据分析；F.C.与I.K.撰写论文。

Competing interests

利益冲突

The authors declare no competing interests.

作者声明无利益冲突。

Additional information

补充信息

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41467-024-46657-2.

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Peer review information *Nature Communications* thanks the anonymous reviewers for their contribution to the peer review of this work.

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