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Three-year-olds' Ability to Reason using Disjunctive Syllogism

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Abstract

Logical reasoning is fundamental for human cognition, yet its developmental origins remain unknown. In two experiments, we investigated whether 3-year-old children can reason using disjunctive syllogism. Children (N = 73) participated in a gumball game where they helped an experimenter obtain a desired gumball. To succeed, they needed to use disjunctive syllogism to determine which of two gumball machines *must* or *might* produce the desired gumball. Results provide evidence of reasoning using disjunctive syllogism in 3-year-olds.

Keywords: logical reasoning; disjunctive syllogism; cognitive development

Introduction

Logical reasoning is a fundamental cognitive ability that enables human learners to draw valid conclusions from premises. It plays a critical role in decision-making and problem-solving and is considered a hallmark of abstract and combinatorial thought (Carruthers, 2002; Quilty-Dunn et al., 2023). Given its significance in human reasoning, philosophers and cognitive scientists have long debated its origins.

A form of logical inference widely studied in developmental psychology in recent years is disjunctive syllogism, which follows the structure: A OR B, NOT A, THEREFORE B. Reasoning through disjunctive syllogism requires integrating multiple cognitive processes: first, the ability to represent two mutually exclusive possibilities; second, understanding logical negation (NOT A); third, the ability to use negation to eliminate one of the two possibilities (e.g., eliminate A), and deduce a valid conclusion (THEREFORE B). The last few years have seen a surge in empirical studies on logic in development, focusing on disjunctive syllogism and its components.

Thinking about Alternative Possibilities

The ontogeny of the ability to reason about alternative possibilities has been highly debated. Initially, it was believed that children under 3 years cannot reason about alternative possibilities (Leahy, 2023; Leahy & Carey, 2020; Leahy et al., 2022; Mody & Carey, 2016; Redshaw & Suddendorf, 2016). Recently, however, studies using new and simpler methods have found that 3-year-old children can consider incompatible alternative possibilities (Alderete & Xu, 2023; Andreuccioli et al., 2024; Turan-Küçük & Kibbe, 2024, 2025). These conflicting findings also generated discussions about why children failed some tasks but succeeded in others (Phillips & Kratzer, 2024; Turan-Küçük et al., under review).

In language, some have suggested that children younger than 3 produce words to express possibilities (e.g., maybe, can) (e.g., Cournane, 2021; Dieuleveut et al., 2019; Van Dooren et al., 2017). However, production itself does not mean the child possesses the conceptual understanding of those words (Leahy & Žalnieriunas, 2022).

Negation

Understanding negation begins relatively early in development. In English, children produce "no" with the primary function of rejection by 17 months (Fenson et al., 2007; Frank et al., 2017), and "not" around 24-30 months for denial (e.g., "It's not a ball, it's a monkey") (Pea, 1982). By around 24-27 months, children can use negative clues in search tasks (e.g., "it's not in the bucket") (Feiman et al., 2017), and they can use verbal and physical gestures (e.g., hearing "no", or observing a head shake) to find a reward hidden amongst two objects (Austin et al., 2014). By 30-42 months, children begin to produce negative words with logical categories such as normative and inferential negation (e.g., "he can't go on the boat", or "I did not break it") (Choi, 1988). Thus, by around 3 years, children use negation in their language production.

Disjunctive Syllogism

Can children combine these two concepts – alternative possibilities and negation - to draw a deductive conclusion, reasoning in the structure of A OR B, NOT A, THEREFORE B?

So far, the evidence has been mixed. Studies using looking-time and eye-tracking methods suggest that infants as young as 10 months can infer outcomes using disjunctive syllogism (Bohus et al., 2023; Cesana-Arlotti et al., 2018, 2020, 2022). However, alternative interpretations suggest that infants may rely on working memory models rather than logical reasoning (Feiman et al., 2022; Jasbi et al., 2019).

Using eye-tracking, Cesana-Arlotti & Halberda (2024) found evidence for disjunction in toddlers aged 2;3-3;2. Their main measurement of disjunction was double-checking. For example, when presented with a familiar object (e.g., a ball) and an unfamiliar object (dax), and told to "look at the dax", toddlers whose eyes were fixed on the dax looked to the ball and then back at the dax, a behavior providing evidence of disjunction (e.g., the child thinks "that is not the dax (referring to the ball), therefore this (the dax) must be the dax"). This double-checking pattern was found to be domain general, appearing in their word learning, social learning, and explicit negation tasks.

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Despite the reported successes in infants and toddlers, findings with preschoolers have been mixed, using the cups task (Mody & Carey, 2016; Gautam et al., 2021). Three-year-old children succeed in the Mody & Carey (2016) version of the 4-cups task, but it has been questioned whether the results are evidence of disjunctive syllogism (Leahy & Carey, 2020). Gautam et al. (2021) eliminated occlusion and used a Piagetian invisible displacement method, and found success in 2.5-year-olds. However, methodological differences, such as grouping the cups by color, therefore increasing the salience of the critical pair of cups, might provide an alternative interpretation.

To date, the research on disjunctive syllogism in young children is mixed, leaving open the question of whether other methods might reveal a clearer picture of the developmental trajectory of reasoning using disjunctive syllogism.

In the present study, we ask whether 3-year-old children can reason using disjunctive syllogism. To test this, we adapt a task in which children successfully reasoned about alternative possibilities (Alderete & Xu, 2023) and modify it into a disjunctive syllogism task (Figure 1). Success in our study requires that children reason through disjunctive syllogism to infer which of two gumball machines *must* or *might* produce a desired gumball.

Experiment 1

Experiment 1 was approved by the UC Berkeley Institutional Review Board.

Participants. The final sample comprised 24 three-year-old children (Mean age = 3.5, Range = 3.03–3.99, SD = .29, 12 Female). The sample size was determined based on prior studies investigating logical reasoning in three-year-olds (e.g., Mody & Carey, 2016;Leahy et al., 2022). Fourteen additional participants were excluded for the following reasons: 3 failed the demonstration trial, 4 failed the two-machines trial, 2 failed the occlusion trial, 2 failed the disjunction trial (see below for description of the trial types), 1 did not complete the experiment, 1 was excluded due to experimenter error, and 1 for having a color bias. Participants were tested online over Zoom, except for one participant who was tested at a science museum. Participants received a $5.00 Amazon gift card or a small prize as compensation for their participation.

Materials. Materials included animated images of gumballs and gumball machines, created using Microsoft PowerPoint. All stimuli were presented on a laptop. Data was analyzed on R using packages such as TidyVerse, lme4, rstatix, emmeans, and dplyr.

Design. Experiment 1 used a within-subject repeated measure design. Children were assigned to one of eight counterbalanced orders (A-H), which controlled the following features of the study: The color of the gumball (orange or purple) that exited the machine in the disjunction training trial, the side of the blue machine during test trials (left or right), the order in which the experimenter pressed each machine during test trials, alternating between (left, right, right, left, right, left) or (right, left, left, right, left, right).

To ensure that children understand the various components of the task, we provided extensive training before the test trials. The study included five phases: demonstration trials, two-machines training trial, occlusion training trial, disjunction training trial, and test trials.

Procedure. Children were seated in front of a computer screen, either next to their parents or on their parent's lap. Parents were instructed not to provide hints or interfere with the study. Children were told that they would play a fun game to help the experimenter collect gumballs from gumball machines. Prior to the study, children were asked to name the colors of different stars to ensure they could correctly identify different colors.

Demonstration Trials. The purpose of the demonstration trials was to show children how the gumball machine works and to teach them that when the experimenter presses the handle of a gumball machine, *only one gumball* comes out. In the first trial, children were shown a red gumball machine containing eight pink gumballs. The experimenter pressed the handle of the gumball machine, and a pink gumball exited the machine. To ensure that children understood how the gumball machine worked, they saw a second trial with a red gumball machine containing eight blue gumballs. In this trial, the experimenter asked the child, "When I press this red handle [gesturing to the handle of the gumball machine], what color gumball will I get?" After the child stated the color of the gumball, the experimenter pressed the handle, and a blue gumball exited the machine.

Two-machines training trial. After the demonstration trials, children completed a two-machines training trial. This training trial had two goals. The first goal was to train children to choose between two gumball machines, rather than just state the gumball color that will exit a machine. The second goal was to train children to assist the experimenter in obtaining the desired gumball by indicating which gumball machine handle she should press. Children were presented with two gumball machines: a blue machine containing two pink gumballs, and a green machine containing two black gumballs. The experimenter asked the child, "I really want a *pink* gumball, which handle should I press to get a *pink* gumball, the blue handle or the green handle?". Children responded either verbally or by pointing.

Occlusion training trial. After the two-machine training trial, children completed an occlusion training trial. Because the gumballs in the gumball machines are occluded during the test trials, this trial was designed to ensure that children could remember the color of the gumballs in each machine when they are no longer visible.

In this trial, children were shown two gumball machines: a blue machine with two purple gumballs and a green machine with two red gumballs. The experimenter first guided the child through identifying the colors of the machines and the gumballs inside. Then she said, “Watch closely, because two clouds are about to come.” Then, two gray opaque clouds appeared on the screen, covering the tops of the gumball machines and occluding the gumballs from view. The experimenter then asked, “I really want a red gumball. Which handle should I press to get a red gumball, the blue handle or the green handle?” Children responded either verbally or by pointing.

Disjunction training trial. After the occlusion training trial, children completed a disjunction training trial. This trial aimed to determine whether children could remember the gumballs in the machine and accurately predict the color of the next gumball to exit the machine after one had already been dispensed.

In this trial, children were presented with a single red gumball machine containing an orange and a purple gumball. The experimenter said, “Here we have a red gumball machine with a purple gumball and an orange gumball in it. Let’s see what color I get when I press the handle!” The experimenter pressed the handle, and a gray cloud occluded the top of the gumball machine, making the remaining gumball no longer visible. Then, an orange [or purple] gumball exited the machine and landed next to it. The experimenter then asked, “Look, [child’s name], I got an orange gumball. Now, [child’s name], if I press the handle again, what color gumball will come out?”

Half of the children saw the orange gumball exit the machine first, while the other half saw the purple gumball exit first. For all training trials (demonstration, two-machines, occlusion, and disjunction), if a child failed the trial, they were given a repeated trial with gumballs of different colors. If the child failed the repeated trial, they were excluded from the final sample.

Test Trials. Each child completed six test trials. The color of the gumballs in the machines varied across the test trials. Before the test trials began, children were told that they would help the experimenter collect gumballs from gumball machines.

In each trial, children were presented with two gumball machines, for example, a blue and a green machine each containing a black and a pink gumball. The experimenter said, “I really want a pink gumball. I am going to press the handle of the gumball machine. Let’s watch.” The experimenter then pressed the handle of one of the gumball machines, for instance, the green machine. Two clouds appeared and covered the tops of the machines so that the gumballs inside were no longer visible. A black gumball exited the green machine, prompting the experimenter to say, “Oh, I did not get a pink gumball. Okay, [child’s name], I need your help. I only have one more chance to get a pink gumball. Which handle should I press to be sure I get a pink gumball, the blue handle or the green handle?”

Children responded either verbally or by pointing. No feedback was provided during the test trials. Once the child made their selection, the experimenter said, “Thank you. Let’s do another one.” and proceeded to the next trial. At the end of the six trials, children were shown a basket filled with different colored gumballs and were told they did a great job.

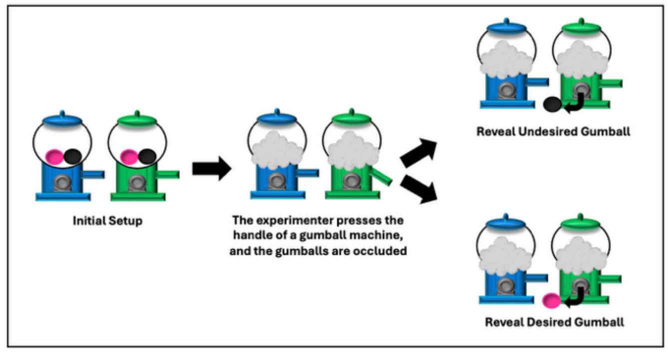

Figure 1: Test Trials for the two trial types: Reveal Undesired Gumball and Reveal Desired Gumball (Experiment 2 only).

Results

Test Trials. Chance was established at 50%, as there were two gumball machines children could choose from. On average, participants selected the correct gumball machine 77% of the time, significantly above chance, as indicated by a Wilcoxon test ($V = 231$, $p < .001$, r = .74). Thus, children successfully identified the gumball machine that must produce the experimenter’s desired gumball.

Next, a Generalized Linear Mixed Effects Model (GLMM) was fit to predict the probability of a correct response from the fixed effects of order (orders A–H as described in the design section of the Methods), gender (male vs. female), age (as a continuous variable), and trial number (trials 1–6), with a random effect of participant ID. Age and trial number were z-transformed to improve model fit.

There was no significant main effect of order (all $p > .05$), gender ($\beta = 0.24$, $SE = 0.75$, $z = 0.33$, $p = 0.74$), or age ($\beta = –0.07$, $SE = 0.38$, $z = -0.18$, $p = 0.85$). There was a significant main effect of trial number ($\beta = –0.51$, SE = 0.23, z = -2.18, p = 0.02), with performance decreasing in the later trials.

Discussion

The data from Experiment 1 support the hypothesis that 3-year-old children can reason using disjunctive syllogism, demonstrating a capacity for logical reasoning. Children successfully inferred that if an undesired gumball exited the machine when the experimenter pressed the handle, that machine must produce a desired gumball color on the next handle press, whereas the other machine might only possibly produce a desired gumball color.

Experiment 2 aimed to replicate and extend the findings of Experiment 1, by introducing two types of test trials. Half of the children were assigned to the Reveal Undesired Gumball trial type, which directly replicated Experiment 1. In this trial type, the experimenter received an undesired gumball when she first pressed the handle of a machine.

To further investigate whether 3-year-olds can reason deductively, the other half of the children were assigned to the Reveal Desired Gumball trial type. This trial type was nearly identical to the Reveal Undesired Gumball one, except that when the experimenter pressed the handle of the gumball machine, she received her desired gumball color. Children were then asked which handle she should press to get *another* desired gumball. In contrast to the Reveal Undesired Gumball trial type, here the correct response is to choose the other machine, as it is the only machine that might produce a desired gumball on the next handle press.

This new trial type was designed to ensure that children can flexibly apply their deductive reasoning abilities across different scenarios. In the Reveal Undesired Gumball trial type, the final inference requires distinguishing between what is possible and what is necessary (i.e., one gumball machine must produce a desired gumball on the next handle press, while the other only might produce it). In contrast, the Reveal Desired Gumball trial type requires children to distinguish between what is possible and what is impossible (i.e., one gumball machine might produce a desired gumball, while the other cannot).

Additionally, the Reveal Desired Gumball trial type serves as a control for Experiment 1. Success in this trial type would rule out the possibility that children succeeded in Experiment 1 by relying on a low-level heuristic, such as selecting the gumball machine where a gumball had previously exited or choosing the same machine the experimenter had chosen. If children were using such a strategy in Experiment 1, they would fail in the Reveal Desired Gumball trial type because they would incorrectly select the machine the experimenter had previously selected. Thus, success would provide further evidence that children are reasoning about the contents of the gumball machines when deciding which handle the experimenter should press next.

Experiment 2

Experiment 2 was pre-registered on as-predicted.org (https://aspredicted.org/v8ks-3tw9.pdf) and was approved by the UC Berkeley Institutional Review Board.

Participants. The final sample included 49 three-year-olds (Mean age = 3.5 years, Range = 3.01–3.99, SD = .32, 29 female). The initial goal was to collect data from 48 children (24 per condition); however, a scheduling error led to an additional participant being included in the Reveal Undesired Gumball condition. Eighteen additional participants were excluded for the following reasons: 3 failed the demonstration trial, 2 failed the two-machines training trials, 3 failed the occlusion training trial, and 10 failed the disjunction training trial (see below). The 49 non-excluded participants were tested in various locations: 31 were tested at a local science museum, 4 were tested at a local park, and 14 were tested over Zoom. Participants received a $5.00 Amazon gift card or a small prize for their participation.

Materials. Materials included animated images of gumballs and gumball machines. Animations were created using Microsoft PowerPoint. Data was analyzed on R using packages such as TidyVerse, lme4, rstatix, emmeans, and dplyr.

Design. Experiment 2 used a between-subject, repeated-measures design. Children were randomly assigned to one of two trial types: the Reveal Desired Gumball or the Reveal Undesired Gumball trial type. Within each trial type, children were assigned to one of eight counterbalanced orders (A -H). These counterbalancing orders controlled the following features of the study: the color of the gumball (orange or purple) that exited the machine during the disjunction training trial, the position of the blue machine during test trials (left or right), and the sequence in which the experimenter pressed each machine on each trial, alternating between (left, right, right, left, right) and (right, left, left, right, left).

Procedure. Children were seated in front of a computer screen next to their parents or on their parent's lap. They were told that they would be playing a fun game where they would help the experimenter collect gumballs from gumball machines.

Training. The training trials were the same as in Experiment 1, which consisted of the demonstration trials, two-machines trial, occlusion trial, and disjunction trial.

Test Trials. Each child completed six test trials. In each trial, children were presented with two gumball machines, for example, a blue and a green machine, each containing a black and a pink gumball (Figure 1). The experimenter said to the child, "I really want a [pink] gumball. I am going to press the handle of the gumball machine. Let's watch." The experimenter then pressed the handle of, for example, the green machine, and two clouds appeared, covering the tops of the gumball machines so the gumballs were no longer visible.

After the experimenter pressed the handle of a machine, the two conditions diverged. In the Reveal Undesired Gumball trial type, an undesired (e.g., black) gumball exited the machine that the experimenter pressed. The experimenter said to the child, "Oh, I did not get a [pink] gumball. Okay, [child's name], I need your help. I only have one more chance to get a pink gumball. Which handle should I press to be sure I get a [pink] gumball, the blue handle or the green handle?"

In the Reveal Desired Gumball trial type, when the experimenter pressed the handle of the gumball machine, the desired gumball (e.g., pink) exited the machine. The experimenter said to the child, "Oh, I did get a pink gumball. Okay, [child's name], I need your help. I want to get another pink gumball. Which handle should I press to get another pink gumball: the blue handle or the green handle?"

For both trials, children responded verbally or by pointing. No feedback was provided during the test trials. Once the child made their selection, the experimenter said, "Thank you. Let's do another one." and moved on to the next trial. The color of the gumballs in the machines varied across trials.

Results

Test Trials. Chance was established at 50% as children had to choose between two gumball machines. Across both trial types (Reveal Desired Gumball and Reveal Undesired Gumball), participants selected the correct gumball machine 74% of the time, significantly above chance, as indicated by a Wilcoxon test ($V = 776$, $p < .001$, $r = .61$).

Next, a GLMM was fit to predict participants' responses from the fixed effects of order (A–H), age (included as a continuous variable), trial number (1-6), gender (male vs female), and trial type (Reveal Desired Gumball vs. Reveal Undesired Gumball), with a random effect of participant ID. Age and trial number were z-transformed to improve model fit.

The analysis revealed no significant main effect of order (all $p > .05$), age ($\beta = .33$, $SE = 0.98$, $z = 0.344$, $p = 0.73$), or trial number ($\beta = -0.26$, $SE = 0.16$, $z = -1.58$, $p = 0.11$) on participants' responses. There was, however, a significant effect of gender ($\beta = 3.94$, $SE = 1.80$, $z = 2.81$, $p = 0.02$), with males demonstrating higher odds of a correct response on a given trial. More importantly, a significant main effect of trial type was observed ($\beta = -2.00$, $SE = 0.59$, $z = -3.37$, $p < .01$), with the Reveal Undesired Gumball trial type predicting lower performance compared to the Reveal Desired Gumball trial type.

Given the significant effect of trial type on participants' responses, we analyzed the two trial types separately. First, we examined children's performance on the Reveal Desired Gumball trial type. Participants' average performance was 89%, which was significantly above chance (50%), as indicated by a Wilcoxon test ($V = 253$, $p < .001$, $r = .88$). Next, we examined participants' performance in the Reveal Undesired Gumball trial type. Participants' average performance was 62%, which was marginally different from chance as indicated by a Wilcoxon test ($V = 144$, $p = .06$, $r = .32$).

Finally, to increase power, we pooled the data from all the Reveal Undesired Gumball trials across both experiments to assess overall performance. The average performance was 69%, which was significantly above chance (50%), as indicated by a Wilcoxon test ($V = 726$, $p < .001$, $r = .52$)(Figure 2).

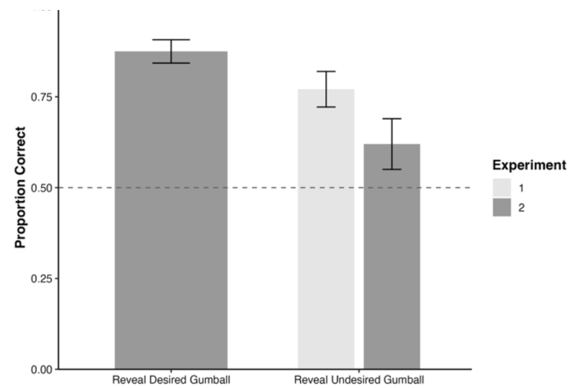

Figure 2: Participants' Performance for the two trial types

Discussion

The data from Experiment 2 provide further support for the hypothesis that the 3-year-old children can reason using disjunctive syllogism. Across both Experiments, children succeed in the Reveal Undesired Gumball trial type. Children were able to infer that if an undesired gumball exited one machine, then that machine must produce the desired gumball on the next handle press, while the other machine only might possibly produce a desired gumball. Additionally, we found differences in performance across the two trial types, which we will discuss in the general discussion.

General Discussion

Results from the current study provide further evidence that 3-year-olds can reason using disjunctive syllogism, suggesting that this ability is present in the early preschool years. Our study included two trial types that complement one another and tested children's ability to flexibly apply their reasoning across different contexts.

Across both Experiments, children performed above chance in the Reveal Undesired gumball trial type, suggesting they can use disjunctive syllogism to deduce that one machine must produce a desired gumball while the other might. Success in the Reveal Desired Gumball trial type shows that children can reason disjunctively to infer that one machine cannot produce a desired gumball while the other might. Furthermore, the latter trial type eliminated the possibility that performance in the Reveal Undesired Gumball trial type was driven by a low-level heuristic, such as selecting the handle the experimenter pressed first or the machine from which the first gumball exited.

Why were children better in the Reveal desired gumball trial type? One possible explanation is that children may find it easier to compare impossibilities and possibilities (i.e., 0% vs. 50%) rather than necessities and possibilities (i.e., 100% vs. 50%). When comparing an impossibility to a possibility, only one option can yield a desired outcome, making the choice of the impossible option irrational. In contrast, when comparing a possibility to a necessity, both options can produce a desired outcome. Therefore, selecting the suboptimal option is less irrational because one could achieve the desired outcome from both alternatives. A recent study by Stahl and Feigenson (Stahl & Feigenson, 2024) provides corroborating evidence that impossibility may be conceptualized qualitatively differently from improbabilities by 2- and 3-year-olds.

One limitation of our study is the exclusion rate. In both experiments, about 37% of the children were excluded due to failing training trials that required them to make decisions under occlusion. The presence of occlusion in our task may have increased working memory demands, adding to the difficulty of the task. High exclusion rates were also present in the study by Cesana-Arlotti & Halberda (2024), where for various reasons, almost half of the participants were excluded from the final sample. Similarly, critics of the cup-tasks have noted its complex design, adding additional task demands for children at this age (e.g., physical reasoning, working memory) (Turan-Küçük et al., under review). These issues shed light on the difficulty of developing tasks that measure disjunctive syllogism. Future research may investigate simpler methods to measure preschoolers' ability to reason using disjunctive syllogism.

How should our results be interpreted in relation to the existing literature on the development of disjunctive syllogism? We see this as converging evidence to the work in infants and toddlers (e.g., Bohus et al., 2023; Cesana-Arlotti et al., 2018, 2020, 2022; Cesana-Arlotti & Halberda, 2024). Additionally, our study presents a novel paradigm, distinct from the 4-cups task, for which it has been debated whether results can be interpreted as evidence of disjunctive syllogism (Leahy & Carey, 2020).

In conclusion, our findings suggest an ability to reason using disjunctive syllogism in 3-year-olds. While the previous literature suggests they can reason about alternative possibilities and understand negation, the integration of the two to draw a sound conclusion may also be achieved by children at this age. Future studies may devise simpler methods to further investigate preschoolers' logical reasoning abilities.

Acknowledgments

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