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NEUROPSYCHOLOGY | SHORT COMMUNICATION

End-state comfort effects in adults with intellectual disabilities: A pilot study

Yukino Kikuchi^{1*+}, Shogo Hirata^{2*+*} and Hideyuki Okuzumi³

Abstract: This study investigated the end-state comfort (ESC) effect in adults with intellectual disabilities (ID). The ESC effect represents a tendency to maximize comfortable hand and arm postures at the end of an object manipulation task. Participants were 22 adults with non-specific ID. The ESC effect was assessed using a simple object manipulation task. Difficulties were found with manifestation of the ESC effect in adults with non-specific ID. Only four participants displayed the ESC effect. The participants' intellectual function was correlated with expression of the ESC effect. These results were assessed in terms of competition between a goal-directed system and habitual systems in adults with ID.

Subjects: Neuropsychology; Cognitive Psychology; Developmental Psychology

Keywords: end-state comfort (ESC) effect; intellectual disability; motor planning; tool use

1. Introduction

Tool use is a necessary activity of everyday human life. In recent years, the end-state comfort (ESC) effect has been reported as a probable basis for tool use (Comalli et al., 2016). This effect, initially reported by Rosenbaum et al. (1990), is a tendency to maximize comfortable hand and arm postures at the end of an object manipulation task (Adalbjornsson et al., 2008; Rosenbaum, 2017). For instance, a typical adult will grasp an object with an initial grasp posture that can produce a comfortable and controllable position at the end of the movement (Rosenbaum, 2017). The ESC effect provides an efficiency constraint on the vast degrees of freedom of human action (Rosenbaum et al., 1996). Many researchers have examined the nature of this effect in typical

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PUBLIC INTEREST STATEMENT

Intellectual disability (ID) refers to an intellectual or adaptive difficulty with onset occurring before 18 years of age. Persons with ID are well known to have poor tool use skills. The end-state comfort (ESC) effect, a tendency to maximize comfortable hand and arm postures at the end of object manipulation tasks, is probably a basis for tool use. This report describes the first investigation of the ESC effect in adults with non-specific ID. Results indicate difficulties with manifestation of the ESC effect in adults with ID.

adults, children, and older adults using various tasks such as the Bar Transport Task, Handle Rotation task, and Overturned Glass task.

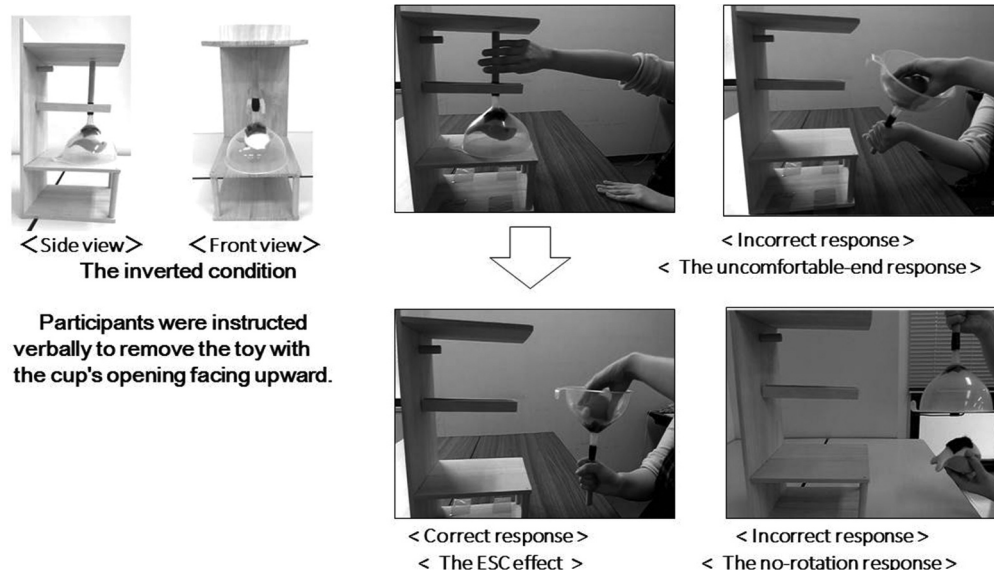
Rosenbaum et al. (1990) reported the ESC effect for typical adults such as university students and staff. Later studies also revealed that typical adolescents over age ten consistently show the ESC effect (Rosenbaum, 2017). Wunsch et al. (2013) provided a sophisticated review of the ESC effect in typical children. Wunsch et al. (2017) reported a decline of this anticipatory motor planning skill near the end of life (i.e., 71–80 years old). Rosenbaum et al. (1990), in their first report of the ESC effect, emphasized the importance of the motor system's cognitive properties for planful behaviors. Stöckel and Hughes (2016) asserted that the expression of the ESC effect is related to a participant's intellectual function, especially cognitive planning, in typical children aged 5–6 years.

Studies have indicated lessened ESC effects in atypical populations such as people with cerebral palsy and autism spectrum disorders (ASD). For example, Steenbergen and colleagues found adolescents with hemiplegic cerebral palsy did not show the ESC effect consistently in their spastic hands (Steenbergen et al., 2000, 2004; Mutsaerts et al., 2006). Reportedly, participants with ASD do not consistently show ESC effects (Hughes, 1996; Scharoun & Bryden, 2016). However, Van Swieten et al. (2010) reported that participants with ASD have intact motor planning ability, which produces the ESC effect. An apparent shortcoming of earlier studies of the ESC effect in atypical populations is that the role of the participants' intellectual function on the ESC effect was not discussed. In studies of ESC effects of participants with CP, the range of participants' intelligence quotients (IQs) was not reported (i.e., Steenbergen et al., 2004); alternatively, it was apparently too broad (i.e., Steenbergen et al., 2000; Mutsaerts et al., 2006). In the study by Steenbergen et al. (2000), the participants' verbal IQs were 56–101. The non-verbal IQs were 54–102. In the study conducted by Mutsaerts et al. (2006), the participants' IQs were 52–111. An IQ of less than 70 would be of the intellectual disability range (American Psychiatric Association, 2013). It is not easy to reject the possibility that participants' intellectual disabilities prevent the ESC effects of participants with CP. Regarding studies of participants with ASD, children participating in a study by Hughes (1996) had mild intellectual disabilities and autism, but their IQs were not reported. The range of participants' IQs was not reported by Scharoun and Bryden (2016). By Van Swieten et al. (2010), it was reported that participants with ASD had normal verbal IQ. It is reasonable to infer that differences in participants' respective intellectual functions have led to inconsistent findings of the ESC effect of participants with ASD. Lack of detailed analyses between motor control and severities of intellectual disabilities was a critical methodological shortcoming presented by motor control studies of atypical populations (Hirata et al., 2014).

Investigations of adults with intellectual disabilities might provide a promising route to resolving this difficulty. Intellectual disability (ID) refers to an intellectual and adaptive difficulty with onset occurring before age 18 (American Psychiatric Association, 2013). IDs are often divided into two groups: one demonstrating a clear biological or organic cause for the disability (e.g., Down syndrome or William syndrome) and the other demonstrating no such organic cause. The latter group is designated as non-specific ID. Henry (2012) pointed the importance of research with persons with non-specific-ID because it enables us to isolate ID effects on psychological processes. If a participant's intellectual functions play a fundamentally important role in producing the ESC effect, then adults with non-specific ID are presumed not to show this effect because their chronological ages are adequate to produce the ESC effect. No study has investigated the ESC effect on adults with non-specific ID. This study investigated this point specifically. Studies of this type can be expected to increase our understanding of the characteristics of the ESC effect.

The motor planning task developed by Wunsch et al. (2015) was used for this study. Participants were asked to reach for a plastic cup that had a stem. The cup was suspended vertically in an apparatus, either upright or in an inverted orientation (Figure 1). After removing the cup from the instrument by grasping its stem, participants had to retrieve a small toy from inside of the cup. When the cup was suspended in an inverted orientation, evidence for the ESC effect was achieved by initially gripping the stem using a thumb-down grip posture. This simple structure is apparently

Figure 1. Motor planning task.



adequate for adoption by adults with ID. Wunsch et al. (2015) reported that typical children of about ten years old tended to exhibit this grip selection. Younger children of five years old, however, do not show this grip selection. Surprisingly, behavioral characteristics were not investigated thoroughly when the participant showed no ESC effect in this motor planning task. Such error-response analyses are apparently useful to elucidate the motor control system features of adults with ID. The present study also investigated this point.

We examined a group of non-specific ID including people of various ages and IQ ranges. This group was examined because, given the lack of earlier studies of the ESC effect in adults with non-specific ID, we were unable to refer to a consensus about what factors are related to the presence of ESC effects. Therefore, explorative studies must be conducted with the aim of investigating the factors determining ESC effects of adults with non-specific ID. This approach was followed in earlier motor control studies of participants with ID (i.e., Haishi et al., 2011; Hirata et al., 2013).

In sum, this study was conducted to investigate whether adults with non-specific ID show the ESC effect for the motor planning task. Earlier studies indicated the possible importance of intellectual function to produce the ESC effect (Rosenbaum et al., 1990; Stöckel & Hughes, 2016). We hypothesized that adults with non-specific ID show no ESC effect. When a participant showed no ESC effect with the motor planning task, error-response analyses were conducted.

2. Methods

Participants

We recruited volunteers from users of two private institutions for adults with ID. Patients were excluded if they had severe sensory or motor impairment. Participants with specific etiologies of ID were also excluded. Twenty-one adults (13 men, 8 women) with non-specific ID participated. The following personal data were collected from their proxies. Participants were free from severe sensory and motor impairments such as blindness, low vision, deafness, and cerebral palsy. They had no other developmental disability such as Down syndrome or autism. Medical doctors confirmed these conditions. Their mean chronological age (CA) was 39.4 ± 8.7 years (range: 24–54). Furthermore, their intelligence quotient (standardized score) was 31.7 ± 16.1 (range: 11–68). Their participant IQ was measured using the Tanaka-Binet Intelligence Scale, which is a standardized and commonly used

test in Japan. The Tanaka–Binet scale is suitable for assessing the intelligence of persons with ID because it is applicable to a broader range of IQ than the Wechsler test is.

For this study, the authors also evaluated two aspects of intellectual abilities: verbal and nonverbal. According to the test manual, the Picture Vocabulary Test—Revised (PVTR; Ueno et al., 2008) was applied to assess the verbal ability of participants with ID. The norm attached to the test manual was used when raw scores were converted to a PVTR score, which has a range of 0–89.

The Raven Color Progressive Matrices (RCPM; Sugishita & Yamazaki, 1993) were used to assess the nonverbal ability of participants with ID. Raw scores were analyzed as an RCPM score, which has a range of 0–35. According to the test manual, a raw score of less than 10 points can be interpreted as being from a participant who did not understand the task rules. A raw score below 10 points was assigned 0 in this study. Their PVTR scores were 32.6 ± 27.9 (range: 0–86). Furthermore, their RCPM scores were 10.4 ± 9.6 (range: 0–35).

Apparatus

The apparatus was modeled on that used by Wunsch et al. (2015) (Figure 1). Participants were presented with a large plastic cup with a wooden stem. The 15-cm-diameter cup was 10 cm deep. The stem was a 16-cm-long wooden cylinder that was 1.5 cm thick. A soft miniature toy was affixed with cellophane tape to the bottom of the cup's interior.

During the testing phase, the cup was suspended from a wooden apparatus that allowed participants to remove it by taking hold of the stem. The cup and the apparatus were placed on a 70-cm-high table within arm's reach of all participants. Participants were seated in front of the apparatus. The distance between the participant and the apparatus was adjusted for ease of grasping the plastic cup. A high-speed video camera (120 frames per second, EX100-Pro; Casio Computer Co. Ltd.) was placed beside the table, recording the apparatus and participants' movement from the side.

Procedure

Ethical approval for the study was obtained from the Research Ethics Board of Tokyo Gakugei University. Consent for each participant's participation in the study was obtained from a proxy. Informed assent was obtained from each participant. Participants were under no obligation to take part in the tests.

First, a participant's preferred hand was ascertained. We confirmed the participant's response to the question of which is the dominant hand and observed the hand that was chosen for using a pen. These two points were the same for all participants. According to Wunsch et al. (2015), all participants were familiarized with the cup outside of the apparatus before the start of measurements. The cup with the stem was placed on top of the table. Participants were asked to retrieve a small toy from inside of the cup. After repeating the task several times, the test progressed to measurement of the ESC effect.

For measurement of the ESC effect, the experimenter suspended the cup with the stem vertically on the apparatus. Furthermore, participants were instructed verbally to remove the toy with the cup's open end facing upward. Participants were asked to grasp the cup's stem using a power grip and the preferred hand, but they were not instructed in how to grasp the stem (i.e., thumb-up or thumb-down grip). The experimenter also showed the power grip with a gesture.

The measurement consisted of eight trials: four with the cup in an upright orientation (upright condition) and four in an inverted orientation (inverted condition). The cup's orientation was changed every two tests. The starting orientation was counterbalanced across participants. Before every trial, the experimenter instructed the participant to extract the toy using one hand. If the participant

violated a rule in any trial (e.g., a participant removed the toy with the cup's opening facing downward, the participant changed the hand during a trial; then the participant used both hands), then the experimenter again instructed the participant verbally before the next trial began. During the experiment, the experimenter never grasped the cup by its stem, thereby avoiding observational learning effects that might occur with the participant. About ten minutes were necessary to complete this motor planning task. After a short rest, the RCPM and the PVTR were conducted.

Data analysis

Video data were used for examination of correct and incorrect responses. A correct response was defined by initial grasps that led to a comfortable thumb-up posture at the end of the movement. For example, participants must choose the thumb-up grip in the upright condition. Alternatively, participants must select the thumb-down grip in the inverted condition. The numbers of correct responses in the two conditions were subsequently used as data for analyses.

We classified incorrect responses in the inverted condition. Then reactions of three types were identified (Figure 1). We refer to these as (a) uncomfortable-end response, (b) both hand use response, and (c) no-rotation response. In the *uncomfortable-end response*, a participant grasped the cup with the stem using the thumb-up grip in the inverted condition. The participant then rotated the hand clockwise or counter-clockwise and removed the toy with the cup's opening facing upward. This response led to an extremely uncomfortable ending posture. In *both hand use response*, a participant grasped the cup with the stem using the thumb-up grip with their preferred hand and rotated the hand slightly clockwise or counter-clockwise. The participant then grasped the cup with the other hand and removed the toy using the preferred hand. This response was defined as the incorrect response because the use of both hands in this experiment was prohibited. In the *no-rotation response*, participants grasped the cup with the stem using the thumb-up grip. They then removed the toy without the cup's opening facing upward. This response was defined as the incorrect response because the participant must remove the toy with the cup's opening facing upward.

3. Results

All participants made an initial grasp by their dominant hand in each trial. Table 1 shows the distributions of correct responses in each condition. Each participant showed more than three

Figure 2. Scatter plot of the inverted condition.

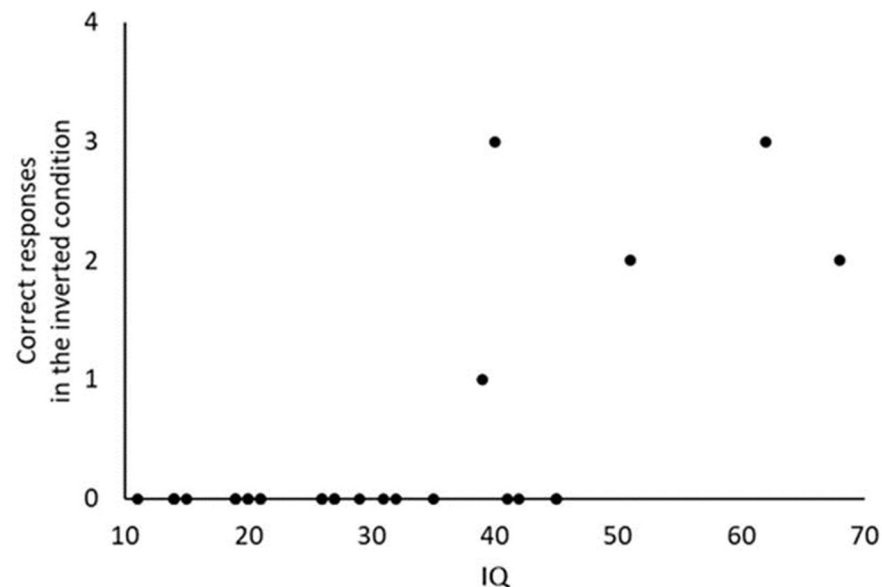


Table 1. Numbers of participants exhibiting correct responses in respective conditions

		Correct responses in inverted condition					Total
		Zero	One	Two	Three	Four	
Correct responses	Zero	0	0	0	0	0	0
in upright condition	One	0	0	0	0	0	0
	Two	0	0	0	0	0	0
	Three	2	1	0	0	0	3
	Four	15	0	2	1	0	18
	Total	17	1	2	1	0	

correct responses under the upright condition. By contrast, many participants showed no correct response under the inverted condition. Wilcoxon’s signed-rank test revealed that a significant difference was found between the median (Me) of correct responses under the upright condition (Me = 4) and the inverted condition (Me = 0. $V = 231, p < .001$).

Next, we calculated Spearman’s rank correlations between the participant’s attributes (age, gender: men were assigned 1; women assigned zero, IQ, the PVTR score, and the RCPM score) and the correct responses in each condition. Table 2 presents the results. A Bonferroni-adjusted significance level was used. Regarding rank correlations, the correct responses in the inverted condition were significantly and positively correlated with the participant’s intellectual indexes such as IQ, the PVTR score, and the RCPM score. Lower correct responses in the inverted condition were associated with lower participant intellectual indexes. Figure 2 depicts a scatter plot of the relation between a participant’s IQ and the correct responses in the inverted condition. Poisson regression analyses were conducted to clarify the role of participants’ IQ on the ESC effect. The number of correct responses in the inverted condition was used as the dependent variable. The independent variables were participants’ CA (age) and IQ. Results indicate that the number of correct responses was predicted significantly by the participant IQ (coefficient of determination (R^2) = .762, $p < .01$; standardized regression coefficient = .833, $p < .01$). Participant CA does not contribute significantly to the dependent variable (standardized regression coefficient = .147, $p > .01$).

Table 3 shows the numbers of incorrect responses across trials. This table also revealed the numbers of correct responses in the inverted condition, i.e., the end-state comfort effect. It must be emphasized that each participant showed no end-state comfort effect at trial 1. The number of

Table 2. Spearman’s rank correlations between measures

	Correct responses	
	Upright condition	Inverted condition
Gender	.24	-.33
Age	.01	.14
IQ	.16	.61*
RCPM	.02	.64*
PVTR	-.07	.67*

NOTE: Significance cutoffs are based on adjusted p values. For this set of results, the Bonferroni-adjusted P -value cutoff was .005 (0.05/10).

* Correlations significant at this level.

Table 3. Numbers of participants exhibiting various responses across trials

	Trial 1	Trial 2	Trial 3	Trial 4
End-state comfort	0	2	2	4
Uncomfortable end	7	8	9	7
Both hands	4	3	5	6
No rotation	10	8	5	4

this effect increased slightly from trial 1 through trial 4. Furthermore, the number of no-rotation responses decreased from trial 1 through trial 4. Chi-square tests revealed that the number of no-rotation responses was significantly larger than that of correct responses (end-state comfort) at trial 1 ($\chi^2(3) = 10.42, p < .01$). No significant results were obtained for other trials. Spearman's rank correlation between the participant attributes (age, gender, IQ, the PVTR, and the RCPM score) and the number of each incorrect response was not significant.

4. Discussion

This report is the first of an investigation of the ESC effect in adults with non-specific ID. Results indicate that adults with ID showed difficulty in choosing the thumb-down grip in the inverted orientation condition. Wunsch et al. (2015) reported that 87% of the adults (26.8 years) clearly showed ESC effects in a task similar to that used for this study. They defined manifestation of the ESC effect as at least three of the four correct responses in the inverted condition. Only one person examined for this study meets this definition. These tendencies suggest apparent difficulty with the manifestation of the ESC effect in adults with non-specific ID. According to our hypothesis, these results revealed that intellectual functions play a fundamentally important role in the ESC effect. In future research in this area, especially studies of atypical populations, due attention must be devoted to participants' intellectual functions and the severity of intellectual disability.

Only four participants chose the thumb-down grip in this study. These participants' IQs were high among the participants with ID in this study (Figure 2). The high correlation coefficient between a participant's IQ and the correct response in an inverted condition is based on these characteristics of the distribution. The Poisson regression analyses confirmed this relation. In this study, a participant's verbal ability and non-verbal ability were correlated strongly with manifestation of the ESC effect. Stöckel and Hughes (2016) revealed expression of the ESC effect as related to the participant's executive function, especially cognitive planning, in typical children aged 5–6 years. The relation between their intellectual capacity and executive function in people with non-specific ID has not been well investigated. As one might expect, the link between executive function and a participant's verbal ability and non-verbal ability in adults with ID is not clear. The RCPM score, however, is reportedly useful as an index of fluid intelligence, which is closely related to executive function (Brydges et al., 2012). Moreover, inner verbal activity, i.e., inner speech, serves a fundamentally important role in executive function (Alderson-Day & Fernyhough, 2015). Consequently, it was reasonable to find that verbal ability and non-verbal ability are strongly associated with manifestation of ESC effects in adults with non-specific ID.

Results also demonstrated that adults with non-specific ID chose an inappropriate grip at the beginning of the inverted condition, sometimes leading to an uncomfortable thumb-down end position. In earlier studies (Wunsch et al., 2015), typical children aged 3–6 years showed no ESC effect in the same task to this study. No detailed description has been given of the incorrect responses. As described in the *Introduction*, the ESC effect originally proposed a tendency to maximize comfortable hand and arm postures at the end of object manipulation tasks. Consequently, tacit agreement exists that responses with non-ESC effects were uncomfortable hand and arm postures at the end of object manipulation tasks. However, that finding did not hold for adults with ID. Error-response analyses were conducted for this study. We observed both hand

use response and no-rotation response in addition to uncomfortable-end response. Similar results were also reported for typical children in another task used to evaluate the ESC effect (Adalbjornsson et al., 2008; Comalli et al., 2016). Differences of incorrect responses between adults with ID and typical children in the task of the present study must be investigated.

Stöckel and Hughes (2015) postulated that manifestation of the ESC effect is based on the two competitive systems of goal-directed systems and habitual systems. The habitual system leads to a tendency of individuals to repeat behaviors that have led to desirable outcomes in the past. Furthermore, goal-directed systems organize actions for future states. For tasks of this study, the habitual system calls for a thumb-up grip to grasp the cup because it was thought to be the fundamental manner of human grasping. The goal-directed system, by contrast, calls for a thumb-down grip to accomplish the ESC effect. It is natural to infer that the habitual system and the goal-directed system call for different initial grips in this study. For a superior goal-directed system on the habitual system in the context of the ESC effect, it is necessary that a person achieve maturation of various cognitive abilities such as cognitive planning (Stöckel & Hughes, 2016) and knowledge of comfortable postures (Stöckel et al., 2012). The error-response analyses revealed that adults with ID tended to show the thumb-up grip in the inverted condition. This tendency apparently reflects the inefficient work of the goal-directed system.

If the participant showed inappropriate reactions such as the hand use response and no-rotation response, experimenter again instructed the participant verbally before the next trial began. However, participants showed a tendency to repeat these inappropriate reactions. This tendency seems to be similar to that for preservation, which is a symptom of executive dysfunction (Lamar & Libon, 2011). Some participants might have had difficulty understanding the verbal instructions. Future studies should be conducted with more detailed evaluation of the participant's intellectual function, including executive function and verbal comprehension. The relation between goal-directed systems to produce the ESC effect and intellectual function must be analyzed.

The correct responses of trial 4 were the most within the inverted condition. This tendency suggests that the learning effect occurred in some participants with non-specific ID. More trials should be conducted to elucidate this possibility. For this study, instructions for participants were provided verbally. Some investigation must be done of observational learning effects in adults with ID. Studies of this type are expected for development of new intervention methods for motor control in adults with ID. Finally, investigating ESC effects in adults with ID using other tasks such as the Bar Transport task, Handle Rotation task, and Overturned Glass task are expected to be important.

In conclusion, this study revealed the importance of intellectual function in producing the ESC effect. Error-response analyses of adults with non-specific ID support the idea that manifestation of the ESC effect is based on two competitive systems of goal-directed systems and habitual systems.

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Disclosure statement

The authors declare that they have no conflict of interest related to this report or the study it describes.

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