The Reward Feedback Mechanism in VR Serious Games for Intervening in Children with Attention Deficits: A Pre- and Post-Test Experimental Control Group Study

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Table of Contents

Original Manuscript **5**
Supplementary Files **19**
.... **19**
Multimedia Appendixes **20**
Multimedia Appendix 0 .... **21**

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Abstract

Background: Virtual reality serious games, due to their high level of freedom and realism, influence the rehabilitation training of inhibitory control abilities in children with ADHD. Although reward feedback has a motivating effect on improving inhibitory control, the effectiveness and differences between various forms of rewards lack empirical research.

Objective: To investigate the effectiveness of different forms of reward feedback on the inhibitory control abilities of children with attention deficits in a virtual reality serious game environment.

Methods: This study used a 2 (material reward: coin reward, token reward) × 2 (mental reward: verbal encouragement, badge reward) between-subjects factorial design (N=84), with a control group (N=15), conducting a pre- and post-test experiment. The intervention effects were evaluated using behavioral experiments and multiple assessment tools. The specific evaluation tools included the SNAP-IV questionnaire and three tasks programmed in Eprime 2.0: the Stop-Signal Task, the Inhibition Conflict Task, and the Simon Task. These tasks and surveys were used to comprehensively assess performance differences before and after the intervention, thereby verifying the behavioral intervention effects of material and mental rewards on the participants.

Results: Reward feedback was more effective than no reward feedback in improving behaviors related to attention deficits in children. Material rewards showed significant effects in the Stop-Signal Task ($F=13.043$, $p<.05$), Inhibition Conflict Task ($F=7.34$, $p<.001$), and SNAP-IV test ($F=69.232$, $p<.001$); mental rewards showed significant effects in the Stop-Signal Task ($F=38.537$, $p<.001$) and SNAP-IV test ($F=70.775$, $p<.001$); the interaction between the two showed significant effects in the Stop-Signal Task ($F=4.468$, $p<.05$) and SNAP-IV test ($F=23.847$, $p<.001$).

Conclusions: The virtual reality intervention training platform, through both material and mental reward feedback—especially their combination—can effectively improve attention deficit behaviors in children.

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Abstract

Background: Virtual reality serious games, due to their high level of freedom and realism, influence the rehabilitation training of inhibitory control abilities in children with ADHD. Although reward feedback has a motivating effect on improving inhibitory control, the effectiveness and differences between various forms of rewards lack empirical research.
Objective: To investigate the effectiveness of different forms of reward feedback on the inhibitory control abilities of children with attention deficits in a virtual reality serious game environment.
Methods: This study used a 2 (material reward: coin reward, token reward) × 2 (mental reward: verbal encouragement, badge reward) between-subjects factorial design (N=84), with a control group (N=15), conducting a pre- and post-test experiment. The intervention effects were evaluated using behavioral experiments and multiple assessment tools. The specific evaluation tools included the SNAP-IV questionnaire and three tasks programmed in Eprime 2.0: the Stop-Signal Task, the Inhibition Conflict Task, and the Simon Task. These tasks and surveys were used to comprehensively assess performance differences before and after the intervention, thereby verifying the behavioral intervention effects of material and mental rewards on the participants.
Results: Reward feedback was more effective than no reward feedback in improving behaviors related to attention deficits in children. Material rewards showed significant effects in the Stop-Signal Task (F=13.043, p<.05), Inhibition Conflict Task (F=7.34, p<.001), and SNAP-IV test (F=69.232, p<.001); mental rewards showed significant effects in the Stop-Signal Task (F=38.537, p<.001) and SNAP-IV test (F=70.775, p<.001); the interaction between the two showed significant effects in the Stop-Signal Task (F=4.468, p<.05) and SNAP-IV test (F=23.847, p<.001).
Conclusions: The virtual reality intervention training platform, through both material and mental reward feedback—especially their combination—can effectively improve attention deficit behaviors in children.

Keywords: Serious Games; Virtual Reality; Attention Deficit; Inhibitory Control Ability; Reward Feedback

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder in children, with primary clinical symptoms including inattention and behaviors related to attention deficits [1]. Current research indicates that attention deficits in ADHD patients are primarily caused by damage or deficiencies in the inhibitory control centers. This damage leads to impairments in executive function, which is a major cause of attention deficit behaviors in children[2],[3]. With the development of digital healthcare, virtual reality (VR) technology, characterized by immersion, interactivity, and user engagement with the environment and narrative, has emerged as a promising tool for ADHD rehabilitation training in children[4],[5]. Previous studies have demonstrated the feasibility of using virtual reality in treating children with ADHD[6]-[8]. However, these studies remain in the experimental and exploratory phases, particularly regarding the psychological mechanisms related to inhibitory control[9],[10]. Therefore, it is crucial to study the effects of different mechanisms on children's inhibitory control abilities within a VR environment.

Studies have found that inhibitory control interventions typically use reinforcers during training. Using rewards as reinforcers can normalize the inhibitory control of children and adolescents with ADHD to a manageable baseline level. The reward mechanism serves as a supplementary intervention for ADHD, offering a potential approach to improving inhibitory control in affected children[11]. Feedback is also considered a part of reinforcement, as it is real-time and continuous, helping players continuously improve their behavior. Rewards, on the other hand, are provided after a summary of performance and serve as an incentive to reinforce long-term participation and progress. Specifically, reward feedback involves motivating children toward desired goals through external targets outside of the task[12], such as parental recognition, badges, or praise. By utilizing external rewards to achieve objectives, correct behaviors are repeatedly practiced and reinforced, guiding and strengthening proper awareness to achieve the goal of behavioral training. This method has proven to be highly effective in the rehabilitation training of children with ADHD[13],[14]. Existing studies on the impact of reward feedback on children's cognitive behavior choices focus largely on factors such as the form, timing, content, and conditions of the feedback[15]. The most frequently examined aspect is the form of reward—whether material rewards, social rewards, activity-based rewards, or token rewards—on ADHD children's cognitive behavior choices. In multimedia learning environments, the introduction of various reward forms such as electronic badges, points, coins, verbal praise, and animated expressions has enriched the feedback system for children[16]-[20]. However, few studies have further refined the comparison of different reward feedback characteristics to determine whether there are differences in their impact on inhibitory control.

In VR training environments, the forms of reward feedback are also highly diverse. Covington, Cai Qing, and others have noted the use of virtual currencies, electronic badges, points, visual feedback, auditory feedback, and combined visual-auditory feedback (e.g., graphics, animations, sound effects, graphic-sound combinations) in training environments[21]. Among these, point-based feedback is considered the most representative form of material reward feedback. Points can quantitatively reflect students' cumulative learning behaviors and outcomes. On various platforms, points often appear in the form of coins, diamonds, stars, or small red flowers[22]. Mental reward feedback is primarily provided through evaluations from parents, teachers, or psychological experts, with feedback presented as verbal assessments of overall status or positive reinforcement[23],[24]. Additionally, badges are seen as symbols or markers of achievement or skill, reflecting the holder's training habits and serving as a tool for motivation and personal habit development. Therefore, further exploration of feedback optimization and innovation in virtual reality environments, especially regarding physiological and dynamic feedback, remains of significant importance for more effective ADHD intervention training[25].

Based on the aforementioned studies, researchers have identified deficits in self-control abilities among ADHD children, specifically in sustained response inhibition, dominant response inhibition, and interference response inhibition[26]. The high level of freedom and complexity in VR platforms may exacerbate these issues and increase the difficulty of task selection and judgment. The realism and diversity in virtual environments cause ADHD children to overly focus on stimuli that attract them, making it difficult to concentrate on targets, with unclear reward feedback guidance [9],[11],[12],[19].At the same time, current research focuses on the presence of reward feedback and the differential effects of material versus mental feedback on inhibitory control. [27],[28]However, few studies have examined the differences between various forms of reward feedback in virtual reality environments. This study aims to fill this research gap by conducting a content analysis of existing reward feedback intervention forms, designing different levels of independent variables, and mapping them into the virtual reality environment to explore the effects of various reward feedback forms on the inhibitory control abilities of children with attention deficits.

Methods

Participants

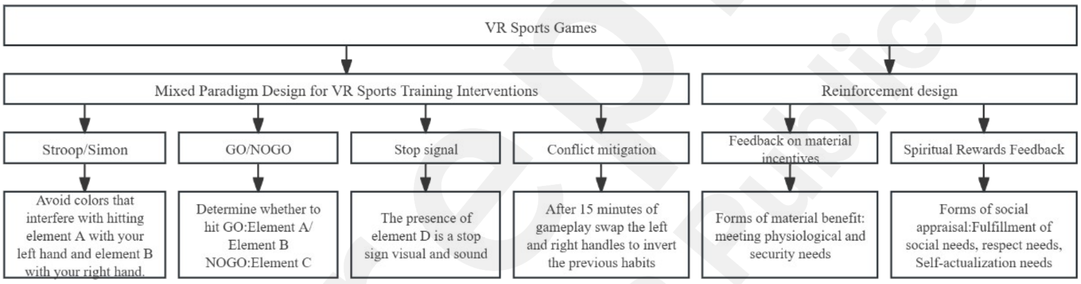
The experiment began by contacting the parents of the children to fill out the SNAP-IV scale (with scores ranging from 0 to 3, where a score above 1.6 indicates a tendency toward ADHD). Children aged 5-6 with ADHD tendencies were selected as participants based on the scale results. The experiment was conducted offline to ensure ecological validity, with a teacher explaining the experimental process and requirements to the participants. After signing informed consent forms, the teacher accompanied the participants throughout the entire experiment.To ensure the validity of the experiment, we set a statistical power of 80% and a significance level of α=0.05. The sample size was estimated using G*Power software, requiring approximately 15 participants per group[29].

In this experiment, the independent variables were the forms of material and mental reward feedback in the virtual reality platform. A 2 (material rewards: coins, tokens) × 2 (mental rewards: badges, verbal expressions) factorial design was employed, with a control group and pre- and post-tests. The experimental group (N=84) participated in virtual reality feedback-enhanced training, while the control group (N=15) received regular virtual reality training without feedback (correct or incorrect).Before and after the training, participants completed the SNAP-IV scale, Stop-Signal Task, Inhibition Conflict Task, and Simon Task tests. The total training duration was 0.5 months, with each intervention session lasting 25 minutes, conducted twice per day with an interval of more than 5 hours between sessions, for a total of 28 sessions.Outcome variables included the error rate as an indicator of sustained response inhibition deficits, error rate as an indicator of dominant response inhibition deficits, and error rate effect size (i.e., the difference between error rates in inconsistent and consistent trials) as an indicator of interference response inhibition deficits. Additionally, the ADHD index and task completion scores were evaluated.

Experimental Materials

The virtual reality training game integrates cognitive and physical training, simulating a VR-based small ball game. In the game, players use a controller to hit three types of dynamic objects (Element A, B, C) launched from four random positions in front of them, adjusting their movements according to the launch angle.[30]

Figure 1. Game Logic and Interaction Posture Diagram



This study categorized virtual reality reward feedback designs by analyzing 33 products across 9 children's virtual reality platforms. Results showed that material rewards in virtual reality are primarily based on a points system, with coins accounting for 61%. While coins function similarly to other tokens, their symbolic meaning as currency requires further exploration. Thus, material rewards were divided into coin rewards and other token rewards for comparison. Mental rewards include encouraging comments, certificates, and emoticons, with verbal encouragement and badges being the main forms. The study focused on the combined effects of mental and material rewards. (As shown in Table 1)

Table 1. Classification of Reward Feedback in Learning Products

Reward feedback	Level of incentive feedback	N	N/S
Material rewards	Coin reward	20	61%
	Token rewards	13	39%
Mental rewards	Verbal rewards	19	58%
	Emoji rewards	14	42%
	Badge rewards	17	51%
	Trophy rewards	3	9%
	Honorary title rewards	2	6%

Based on children's preference for bright colors, correct answers were associated with a yellow-dominant theme. The experimental group materials were designed as illustrated: from left to right and top to bottom, they represent Coin Reward + Verbal Encouragement, Token Reward + Verbal Encouragement, Coin Reward + Badge, and Token Reward + Badge.

Figure 2. Graph of feedback level of experimental group

Procedure and Outcome Measurement

In the pre-test, the SNAP-IV scale was first used to assess the participants' hyperactivity index, followed by the Stop-Signal Task, Simon Task, and Inhibition Conflict Task to evaluate inhibitory control abilities.
The post-test repeated the same testing procedure after the virtual reality rehabilitation training was completed. The collected data were entered into SPSS for statistical analysis. An independent samples t-test was conducted to compare the pre-test and post-test results of the experimental and control groups to infer significant differences between the two group means. Additionally, a paired-samples t-test was conducted to compare the differences between the pre-test and post-test results of the SNAP-IV scale.

(1) Stop-Signal Task In this task, participants needed to complete two objectives. First, when symbols appeared to the left or right of a blue star, they responded by pressing the corresponding arrow key on the keyboard based on the symbol's position relative to the star. Second, participants were instructed not to respond when a yellow sun appeared. There were a total of 120 trials, 30 of which were stop trials, accounting for 25% of the total. The error rate served as a reference indicator for sustained response inhibition deficits.

(2) Inhibition Conflict Task The task was divided into two parts: First, participants pressed the "B" key (blue) when a blue square appeared, and pressed the "G" key (green) when a green square appeared, regardless of the spatial location of the squares. This part included 80 trials. Second, the task reversed—participants pressed the "G" key when a blue square appeared and the "B" key when a green square appeared, with 80 trials in total. The error rate in the second part served as an indicator of dominant response inhibition deficits.

(3) Simon Task Participants were instructed to ignore the spatial location of the arrows and press the key corresponding to the arrow's direction, even if their response was incorrect, and continue to the next trial. The trials in which the spatial location and arrow direction matched were called "consistent trials," while those in which they did not match were called "inconsistent trials." The error rate effect size was calculated as the difference between the error rates in inconsistent and consistent trials. There were 80 inconsistent trials and 80 consistent trials, with each trial separated by a 1500ms interval. The error rate effect size was used as an indicator of interference inhibition deficits.

Results

In this study, participants with higher familiarity averages were removed, and outliers and invalid data were excluded based on the pre-test data. The number of participants in each group was balanced, resulting in 99 valid data sets. These included 21 participants in the coin reward + badge group, 21 in the token reward + badge group, 21 in the token reward + verbal expression group, 21 in the coin reward + verbal encouragement group, and 15 in the no-reward feedback group.

Comparison of Material and Mental Rewards on ADHD Children's Hyperactivity Index

The error rates of the experimental and control groups before and after training in different tasks (Stop-Signal Task, Inhibition Conflict Task, and Simon Task) were compared. A paired-sample t-test was conducted to compare pre-test and post-test results. The results are shown in Table 2.

Table 2. Comparison Between the Experimental and Control Groups Before and After the Intervention

	Pre-testing		Post-test		
	Mean	SD	Mean	SD	*T*-value
SNAP-IV score					
Experimental group(n=84)	1.362	0.074	1.089	0.089	24.939
Control subjects(n=15)	1.351	0.017	1.306	0.015	8.347
Stop Signal Task Error Rate					
Experimental group(n=84)	0.205	0.014	0.100	0.017	77.765
Control subjects(n=15)	0.205	0.007	0.140	0.005	29.404
Suppressing Conflict Task Error Rates					
Experimental group(n=84)	0.270	0.011	0.157	0.011	108.27
Control subjects(n=15)	0.270	0.001	0.185	0.006	28.766
Simon mission error rate					
Experimental group(n=84)	0.206	0.017	0.086	0.014	82.034
Control subjects(n=15)	0.203	0.010	0.122	0.003	32.601

Before the intervention, there were no statistically significant differences between the experimental and control groups in SNAP-IV scores, Stop-Signal Task error rates, Inhibition Conflict Task error rates, and Simon Task error rates ($P > .05$), indicating good comparability between the two groups. After the intervention, paired-sample t-tests showed significant statistical differences between the pre-test and post-test results of both groups ($P < .05$), indicating intervention effects. However, post-intervention comparisons showed that the experimental group had significantly lower scores or error rates across all indicators compared to the control group ($P < .05$). This result suggests that interventions with reward feedback in virtual reality training are more effective than those without reward feedback in improving ADHD-related behavioral deficits in children.

Comparison of ADHD Children's Inhibitory Control Improvement Across Different Reward Feedback Levels

Independent-sample t-tests were conducted on pre- and post-test results of sustained response inhibition training (Stop-Signal Task), dominant response inhibition deficit training (Inhibition Conflict Task), and interference response inhibition deficit training (Simon Task) for six groups that received different reward feedback combinations. The results are as follows:

Table 3. Results of the Two-Way ANOVA

Source of variation	Square sum	*df*	Mean square	*F*	*p*	*Partial Eta square*
Stop signal task ($R^2 = 0.412$)						
Intercept	0.832	1.000	0.832	4,837.316	0.000	0.984
Material	0.002	1.000	0.002	13.043	0.001	0.140
Mental	0.007	1.000	0.007	38.537	0.000	0.325
Material*Mental	0.001	1.000	0.001	4.468	0.038	0.053

Inaccuracies	0.014	80.000	0.000			
Conflict suppression task(R^2=0.241)						
Intercept	2.080	1.000	2.080	18,821.416	0.000	0.996
Material	0.001	1.000	0.001	7.340	0.008	0.084
Mental	0.000	1.000	0.000	3.225	0.076	0.039
Material*Mental	0.000	1.000	0.000	0.455	0.502	0.006
Inaccuracies	0.009	80.000	0.000			
Simon mission (R^2=0.08)						
Intercept	0.626	1.000	0.626	3,752.462	0.000	0.979
Material	0.000	1.000	0.000	2.416	0.124	0.029
Mental	0.000	1.000	0.000	1.169	0.283	0.014
Material*Mental	0.000	1.000	0.000	1.827	0.180	0.022
Inaccuracies	0.013	80.000	0.000			
SNAP-IV task (R^2=0.672)						
Intercept	101.900	1.000	101.900	37,599.073	0.000	0.998
Material	0.188	1.000	0.188	69.232	0.000	0.464
Mental	0.192	1.000	0.192	70.775	0.000	0.469
Material*Mental	0.065	1.000	0.065	23.847	0.000	0.230
Inaccuracies	0.217	80.000	0.003			

Table 4. ANOVA of Material and Mental Rewards

		Square sum	Degrees of freedom	Mean square	*F*	*P*-value
Stop signal task						
Material	Comparison	0.002	1.000	0.002	13.043	0.001
	Inaccuracies	0.014	80.000	0.000		
Mental	Comparison	0.007	1.000	0.007	38.537	0.000
	Inaccuracies	0.014	80.000	0.000		
Conflict suppression task						
Material	Comparison	0.001	1.000	0.001	7.340	0.008
	Inaccuracies	0.009	80.000	0.000		
Mental	Comparison	0.000	1.000	0.000	3.225	0.076
	Inaccuracies	0.009	80.000	0.000		
SNAP-IV task						
Material	Comparison	0.001	1.000	0.001	3.506	0.065
	Inaccuracies	0.015	80.000	0.000		
Mental	Comparison	0.000	1.000	0.000	2.040	0.157
	Inaccuracies	0.015	80.000	0.000		
SNAP-IV task						
Material	Comparison	0.188	1.000	0.188	69.232	<0.05
	Inaccuracies	0.217	80.000	0.003		
Mental	Comparison	0.192	1.000	0.192	70.775	<0.05
	Inaccuracies	0.217	80.000	0.003		

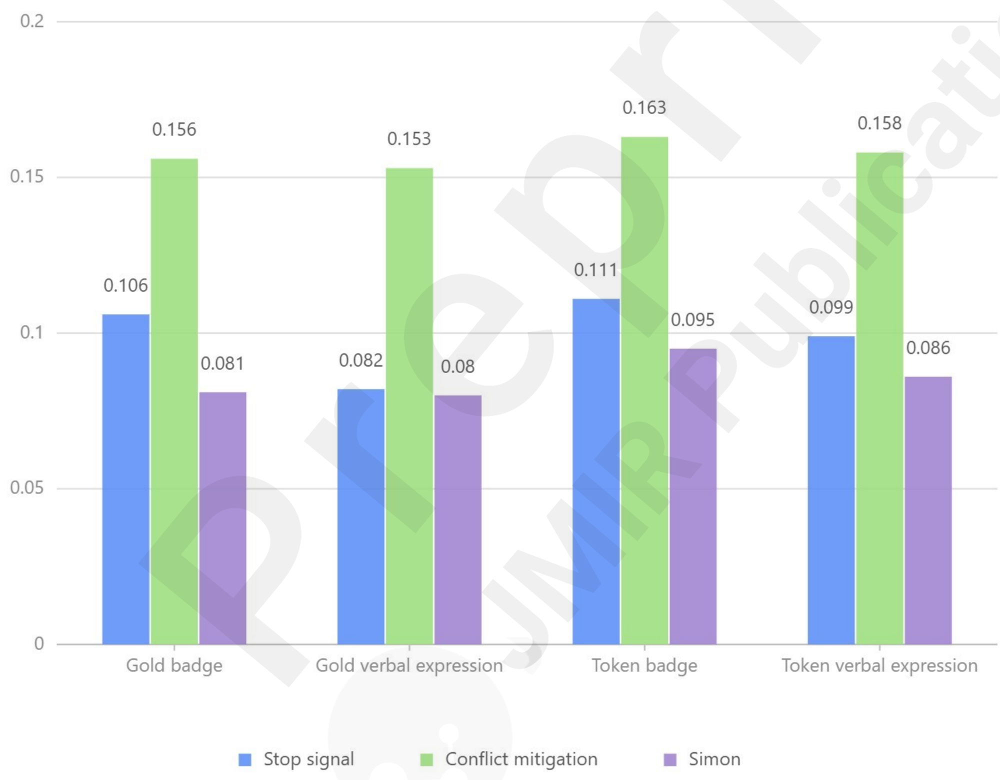
Analysis of Stop-Signal Task Error Rate

The dependent variable was the Stop-Signal Task error rate, and the independent variables were material and mental rewards. A two-way ANOVA was performed. As shown in Table 3, the two-way ANOVA revealed that material rewards had a significant effect on Stop-Signal Task error rates (F=13.043, p<.05), indicating a main effect of material rewards on error rates. Mental rewards also showed a significant effect (F=38.537, p<.001), suggesting a main effect of mental rewards on Stop-Signal Task error rates. Furthermore, the interaction between material and mental rewards was significant (F=4.468, p<.05).

According to Figure 3.1, a comparison of the error rates between the material and mental reward groups shows that the verbal expression group performed better than the badge group in both reward types (0.082 < 0.106 for material rewards, 0.099 < 0.111 for mental rewards). Additionally, the coin group outperformed the token group overall (0.106 < 0.111 for material rewards, 0.082 < 0.099 for mental rewards).

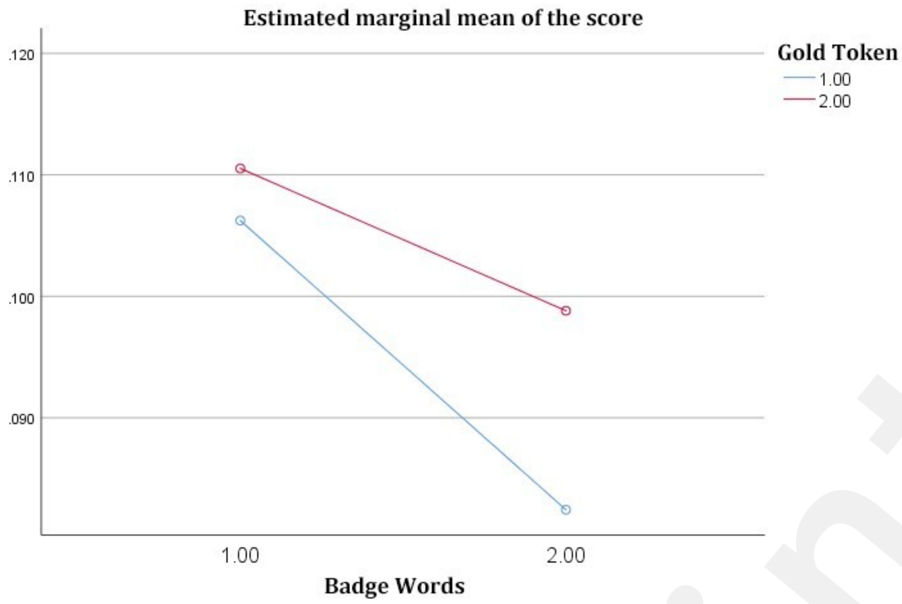
From Table 4, ANOVA analysis showed that the differences within the material and mental reward groups were statistically significant. In both the coin and token groups, the mean error rates in the Stop-Signal Task differed significantly between the badge and verbal expression groups.

Figure 3. Comparison of error rates



Further simple effect tests, as shown in Figure 4, indicate that the coin-verbal group performed better than both the coin-expression group and the coin-badge group (with average scores of 0.082 and 0.099 for the two verbal expression reward groups, respectively). The improvement in the badge group was slightly less effective.

Figure 4. Interaction diagram



Analysis of Inhibition Conflict Task Error Rate Effect

The dependent variable was the error rate in the Inhibition Conflict Task, and the independent variables were material and mental rewards. A two-way ANOVA was conducted. As shown in Table 3, the analysis revealed that material rewards had a significant effect (F=7.34, p<0.001), indicating a main effect of material rewards on the error rate in the Inhibition Conflict Task. Mental rewards did not show a significant effect (F=3.225, p>0.05), indicating that the main effect of mental rewards on the error rate does not exist. Additionally, the interaction between material and mental rewards was also not significant (F=0.455, p>0.05).

A comparison between material and mental rewards (Figure 3) shows that in both cases, the verbal expression group outperformed the badge group (0.153 < 0.156 for material rewards, 0.158 < 0.163 for mental rewards). ANOVA results in Table 4 show that the differences within the material reward groups were statistically significant (p=0.008), with the coin group (M=0.154) outperforming the token group (M=0.160). Although the differences within the mental reward groups were not statistically significant (p=0.076), the verbal expression group had a better overall performance than the badge group. Both material and mental rewards were more effective than the control group (M=0.184), confirming the effectiveness of reward feedback.

Analysis of Simon Task Error Rate Effect Size

The dependent variable was the error rate effect size in the Simon Task, and the independent variables were material and mental rewards. A two-way ANOVA was conducted. As shown in Table 3, material rewards did not show a significant effect (F=2.416, p=.124), indicating that there is no main effect of material rewards on the error rate effect size in the Simon Task.Mental rewards also did not show a significant effect (F=1.169, p=.283), indicating that there is no main effect of mental rewards on the error rate effect size. Additionally, the interaction between material and mental rewards was not significant either (F=1.827, p=.181).

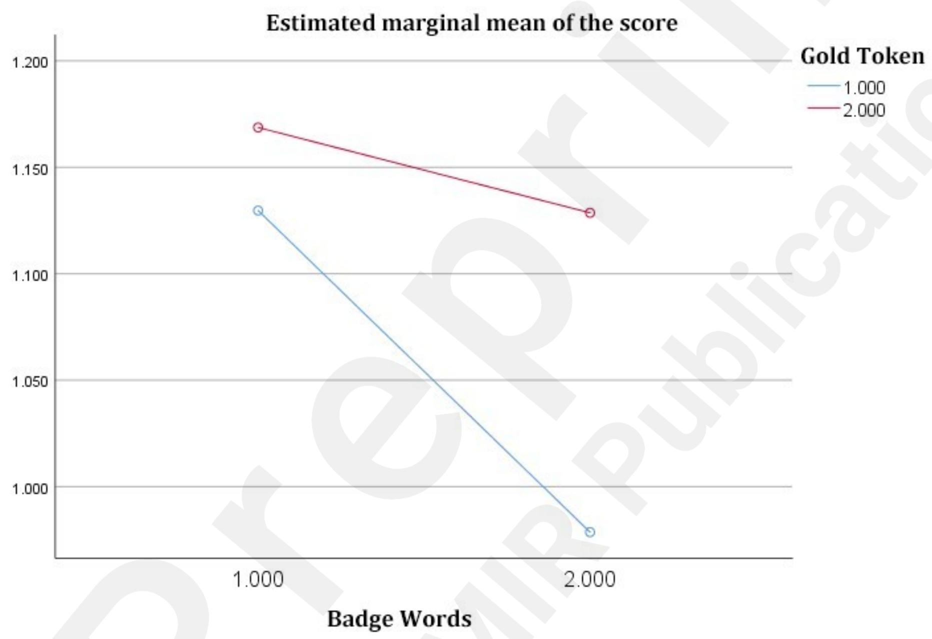
A comparison of material and mental rewards (Figure 3) shows that, based on the mean values, the coin-verbal group (M=0.080) outperformed the coin-badge group (M=0.081), the token-verbal group (M=0.086), and the token-badge group (M=0.095). The coin group overall outperformed the token group, and the verbal expression group outperformed the badge group.However, ANOVA results showed that the differences within the material and mental reward groups were not statistically significant (as shown in Table 4).

Analysis of SNAP-IV Hyperactivity Index

The dependent variable was the SNAP-IV hyperactivity index, and the independent variables were material and mental rewards. A two-way ANOVA was conducted to study the relationship between material and mental rewards and the hyperactivity index. As shown in the table, material rewards had a significant effect (F=69.232, p<.001), indicating that material rewards have a main effect on the hyperactivity index. Mental rewards also showed a significant effect (F=70.775, p<.001), indicating that mental rewards have a main effect on the hyperactivity index. Additionally, the interaction between material and mental rewards was significant (F=23.847, p<.001).

A comparison between material and mental rewards shows that the verbal expression group outperformed the badge group for both reward types, and the coin group outperformed the token group overall. ANOVA analysis revealed statistically significant differences within the material and mental reward groups, indicating that the mean hyperactivity index in the badge and verbal expression groups differed between the coin and token groups. Further simple effect tests, as shown in Figure 5, indicated that in both the material and mental reward categories, the verbal expression group performed significantly better than the badge group, with differences reaching statistical significance (p < .05).

Figure 5. Interaction diagram



Discussion

Main Results

In this study, the experimental results showed that the group with reward feedback outperformed the control group without reward feedback. These findings align with Sagvolden's dynamic developmental theory model of ADHD (2005), which emphasizes the complex interaction between genetic predispositions and environmental influences in ADHD[31]. Therefore, given the conflict between the freedom in virtual reality environments and the developmental characteristics of ADHD children, incorporating the motivating effect of reward feedback into intervention training is both important and necessary.

The results indicate that material rewards had significant main effects in the Stop-Signal Task (p<0.05), Inhibition Conflict Task (p<0.001), and SNAP-IV (p<0.001) tests, with coin rewards proving significantly more effective than token rewards. The experimental study found that material rewards increase individuals' focus and effort on tasks, thereby improving inhibitory control. When individuals are aware that they will receive a tangible material reward after completing a task, they are more motivated to suppress impulses and temptations, focusing on achieving the goal. This may be because material rewards are directly related to individuals' physiological needs and desires, which activate the reward system, thus enhancing cognitive control. This finding is consistent with Fosco et al. (2015), who demonstrated that coin rewards significantly improve task performance in children with ADHD[32]. Additionally, studies using functional magnetic resonance imaging (fMRI) have found that material rewards enhance activity in the prefrontal cortex, particularly in the control networks related to inhibitory control. This suggests that material rewards actively improve individuals' inhibitory control by activating neurobiological mechanisms. Meyer (2021) further demonstrated that increasing coin rewards more effectively enhances task performance in children with ADHD, particularly by improving attention and inhibitory abilities [33]. However, the difference in effectiveness between coin and token rewards may be due to several factors. Studies have suggested that while both coin and token rewards operate effectively in symbolic economic environments, the actual use of money is less likely. However, the stronger monetary significance of coins makes them more effective in encouraging correct behavior in children. This type of reinforcement has been shown to be effective in children with similar disorders, such as autism spectrum disorder. This finding is consistent with the current study, where the controlling significance of coin rewards prompted children to adjust their learning behavior to obtain rewards [34].

Additionally, the study found that mental rewards did not show significant main effects in the Inhibition Conflict Task and Simon Task ($p>0.05$). ADHD children may exhibit differences in their sensitivity to rewards and motivation levels[35], being more responsive to immediate and tangible material rewards, while their response to abstract mental rewards may be weaker. Material rewards typically have clear and immediate effects, such as snacks or toys. Mental rewards, such as praise or recognition, tend to be more indirect and abstract, and may not be as immediately noticeable as material rewards. For ADHD children, immediacy and visibility are crucial to the effectiveness of rewards, making mental rewards relatively less effective. This may also be related to the characteristics of ADHD children, such as difficulty with attention, impulsivity, and delayed gratification [36]-[37][38][39]. ADHD is associated with abnormalities in the dopamine system, which plays a key role in reward processing and motivation regulation. Mental rewards typically involve internal satisfaction and motivational activation, but ADHD children may have dopamine regulation deficits, leading to a diminished response to mental rewards.

The study further examined the interaction between material and mental rewards on inhibitory control abilities. The interaction effect was significant only in the Stop-Signal Task and SNAP-IV test, with the verbal expression group outperforming the badge group. The combination of verbal expression and coin rewards was superior to the combination of badges and tokens, indicating that combining material and mental rewards can enhance the motivational effect for ADHD children. Material rewards provide direct external motivation, while mental rewards offer intrinsic and social motivation. The two complement each other, enhancing ADHD children's responses to rewards. Research has shown that compared to token-based material rewards, the monetary nature of coin rewards can stimulate higher training motivation. This aligns with previous studies using fMRI and ERP, which demonstrated that monetary rewards more significantly activate brain regions involved in reward feedback processes[40],[41]. In the combination of token rewards and verbal encouragement, verbal encouragement dominated the reward effect, contributing to a gradual and lasting improvement in intervention outcomes [42]. The superiority of verbal encouragement over badges is consistent with BERNIS's findings, where smiley face (expression) feedback showed a significant negative correlation with P2, P3, and FRN amplitudes, indicating that smiley faces as reinforcers were not particularly effective. Additionally, related studies have shown that children with ADHD lack awareness of others' emotions [43],[44], similar to children with autism spectrum disorder (ASD). ADHD patients often have difficulty understanding social cues [45]. While ADHD patients may have social interest, they often struggle to evaluate social feedback, such as facial expressions[46]. In contrast, verbal encouragement provides more positive informational value, enhancing children's sense of competence and, in turn, increasing their intrinsic motivation[47], which positively impacts task performance. This further explains why verbal encouragement outperforms badges.

However, the study should also consider certain influencing factors. The characteristics and environmental backgrounds of each ADHD child may differ, resulting in individual differences in their responses to rewards. Some children with ADHD may be more sensitive to mental rewards, while others may respond more positively to material rewards. Additionally, the reward culture within the family, school, and social environments may also affect the effectiveness of rewards. While ALICE et al. (2023) demonstrated that reward feedback can strengthen correct behavior and improve inhibitory control in children aged 5 to 8, they also noted that the types of reward feedback vary significantly across different studies [48]. However, for children aged 5-6, further research is needed to determine how to differentiate between types of reward feedback. Future studies should increase the sample size to include children with varying levels of ADHD, confirm the consistency across different groups, and explore the effects of using only material or mental rewards. Additionally, the impact of reward intensity should be evaluated. Lastly, this study did not utilize precise neuro-monitoring instruments. In the future, wireless EEG or eye-tracking devices should be integrated into virtual reality headsets to monitor children's attention control more accurately.

Conclusion

This empirical study explored the design of reward feedback to enhance inhibitory control in children with attention deficits. It examined the effects of virtual reality interventions with and without reward feedback in ADHD training, as well as the influence of material and mental rewards on three main components of ADHD in children (sustained response inhibition deficit, dominant response inhibition deficit, and interference response inhibition deficit). The study further investigated the impact of the levels of independent variables on inhibitory control ability.

The study yielded the following conclusions: (1) A virtual reality intervention platform using both material and mental rewards as feedback can effectively improve sustained response inhibition deficits, dominant response inhibition deficits, and interference response inhibition deficits in children with ADHD, thereby enhancing overall inhibitory control abilities. (2) Material reward feedback using coin rewards is more effective in improving inhibitory control abilities in children than token (candy) rewards. (3) Mental reward feedback using verbal encouragement is more effective in improving inhibitory control abilities than badge rewards. (4) The combination of coin rewards and verbal encouragement feedback yields the best results in enhancing children's inhibitory control abilities.

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Supplementary Files

Multimedia Appendixes

It is experimental datas.
URL: http://asset.jmir.pub/assets/ce548e55275f5e4b4fb8637a75ea52c9.zip