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Article

From the Perspective of Dynamic Assessment Theory: Investigating the Effects of Table Tennis Training on Cognitive Flexibility and Reaction Speed in Children with Special Needs

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Abstract: Children with neurodevelopmental disorders such as ADHD, autism spectrum disorders, and intellectual disabilities display significant deficits in the area of executive functions that result in diminished academic and adaptive functioning with motor-based interventions such as table tennis training found to be promising non-pharmacologically beneficial techniques in improving the cognitive abilities found in these groups. Based on the Dynamic Theory and Vygotsky's Zone of Proximal Development Theory models of development and learning and taking into consideration that there exists an underlying need to explore further on how to augment these interventions to improve the previously mentioned areas in these children successfully without practical applications past the theoretical construct stage with quasi-experimental study models with 126 subjects between the ages of 8 to 12 with the inclusion criteria that each group must go through 12 weeks with structured intervention sessions consisting of 3 sessions consisting of 60 minutes each weekly, this study aims to ascertain through empirical evidence that structured table tennis training is successful in improving subjects' motor-auditive reaction time with results showing 42.6% improvement in learning potential. ADHD subjects demonstrated 144.9% improvement in motor-auditive reaction time, while autism subjects showed 130.4% improvement in cognitive

flexibility measures.

Keywords: dynamic assessment; cognitive flexibility; table tennis training; neurodevelopmental disorders; executive functions

1. Introduction

Children with Special Needs | Children with neurodevelopmental disorders such as Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), Intellectual Disability | Children with ADHD | Children with ADHD are marked with significant deficits in various areas of cognition that substantially affect academic accomplishment and every aspect that influences the quality of life. In this population, static assessment has proven to be highly inefficient due to its inability to capture dynamically the processes entailed in learning and development. In these contexts, the formulation of more inclusive assessment models has been necessitated to grasp current capacities and potential within these groups (Choo et al., 2025). The theoretical construct that provides fundamental shifts in understanding people with various learning needs through educational assessments is that postulated within the Theory of Dynamic Assessments. This model borrows from Vygotsky's Zone of Proximal Development. The fundamental postulation within this theoretical construct seeks to shift the understanding from static to dynamic assessments that postulate the potential within subjects to be captured within the confines of assessments inclusive of mediated learning experiences. In instances such as those that entail the need to assess groups such as those with ADHD who tend to present lower capacities within static assessments due to potential unexplored within the confines that are commonly standardized within static assessments (Partanen and Hallin, 2025). The theoretical constructs postulated within these contexts are critical in that there is emphasis placed on the difference that exists between the development potential postulated within unmediated problem-solving actions and development postulated within mediated learning experiences with others who possess more superior understanding within these areas.

Current literature demonstrates significant executive function deficits in ADHD and ASD populations, with variability across diagnostic groups (Townes et al., 2023).

The meta-analytic studies inclusive of various neurodevelopmental disorder groups confirm that difficulties with executive functions are an intrinsic component within these pediatric developmental disorders with effect sizes suggesting significant levels of deficits within various areas of cognition that are present across the span from pediatric to mature cohorts (Sadozai et al., 2024). One area that is pertinent to these considerations within the realm of executive functions is that of flexibility—the use of one's mind to shift to tasks with differing requirements with respect to thinking strategies during brief transitions.

Given EF difficulties' adverse effects on academic and adaptive functioning, physical activity interventions show promise for improving cognitive abilities in children with disabilities (Li et al., 2025). Recent research utilizing meta-analytic techniques has highlighted that physical activity intervention approaches lead to notable improvements in EFs in school-age children with ADHD; such improvements are found in numerous domains such as flexibility switching tasks, inhibiting inappropriate actions, and remembering items to be processed. Engaging in habitual physical activity has proven beneficial with respect to attention regulation, motor control, and EF in those with ADHD and those with autism (Zhang et al., 2020). The inclusion of physical activity components within intervention packages targeting those with neurodevelopmental disorders seems to be an ideal and evidence-supported strategy in utilizing mind-through-body approaches to improve difficulties with EF among these groups.

The game of table tennis, with its requirements for rapid visuomotor integration, continuous attentional allocation, strategic planning, and adaptive response production, has its own set of characteristics that might make it uniquely beneficial to improving cognitive functioning in pediatric subjects (González-Devesa and Sanchez-Lastra et al. 2024). Based on the theoretical principles underlying dynamic assessment and the empirical evidence related to the existence of cognitive deficits in neurodevelopmental disorders as well as the beneficial effects of physical activity interventions, the aim of this empirical study has been to explore the efficacy of structured table tennis intervention training on the enhancement of cognitive flexibility and reaction time among pediatric subjects with special needs, applying the principles underlying dynamic assessment to evaluate the intervention training processes in terms of learning potential and responsiveness to the motor-cognitive intervention.

2. Data and Methods

2.1. Research Design and Sample

The current study adopted a quasi-experimental design with pretest and posttest control group design, appropriate for intervention studies where complete randomization is unfeasible due to ethical considerations (Capili and Anastasi 2024). The study was conducted on 126 subjects aged 8 to 12 years already diagnosed with ADHD, autism spectrum disorder, and mild intellect disabilities and obtained from various educational institutions. The subjects were previously screened through various stringent means to ensure qualification based on developmental assessments. Assignment to treatment and control groups was made at the class instead of individual levels to ensure groups weren't contaminated.

2.2. Measurement Tools and Variables

The multidimensional battery was designed to include measures across the full range of cognition, motor skills, and psychosocial realms to reflect the full intervention impact on developmentally mature pediatric intervention outcome measures (Liu, 2025). The Wisconsin Card Sorting Test was designed to assess the critical thinking component in a standardized computer-delivered format to ensure uniform stimulation presentation time, automatic recording of responses, and to remove the potential impact of examiner variable influences on measurement error; with this test instrument previously proven to successfully differentiate sensitivity to impaired pediatric subjects with ADHD and other pediatric neurodevelopmental disorders particularly with regard to underlying deficits in EF deficits (Arán Filippetti et al., 2020). Indices to be taken from task results include perseverations, number of categories completed, and conceptual level responses. The reaction time task was designed to be delivered with the use of computer-delivered visual stimulation tasks designed to elicit quick discriminative motor reactions with dependent measures designed to calculate Choice Reaction Time. The dynamic testing procedures involved the administration of the test-train-test protocol that has subjects participate in initial static testing with standardized instruction and administered learning

opportunities with immediate posttest estimation to assess the quality/value added increase above baseline capacity measures post- interventionally. Behavioral rating scales gathered data to assess ecological validity measures from parental-teacher rating scales designed to measure perception outcome related to EF functioning within ecological settings that include daily living activities, in-class activity stimulation, and peer group activities.

2.3. Data Analysis

The statistical analysis conducted was carried out under the umbrella of mixed-design analysis of variance with time as within-subject variable and group assignments as between-subject variable, making it possible to assess the impact of intervention after adjusting for individual variations in pre-intervention levels. The effect size metric in terms of Cohen's d was also taken to assess group differences as well as change over time without necessarily being concerned about sample size. The dynamic baseline to mediated learning assessments carried out with gain score measures as markers of learning abilities after adjusting for initial levels was taken to measure individual susceptibility to the training intervention with use of percentage improvement scores that measured change after adjusting for initial levels. The analysis was also carried out within subgroups classified on the basis of the diagnostic group to assess heterogeneous intervention outcomes among these subgroups that include ADHD, ASD, and Intellectual Disability with due consideration to differential potential intervention modifications depending on divergent presentation characteristics.

3. Results

3.1. Descriptive Results

The baseline demographic and clinical factors in the intervention group and control group proved to be satisfactory in terms of comparability with respect to key variables such as chronological age, gender proportion, representation of diagnostic groups, and initial levels of cognitive functioning, thus establishing the validity of subsequent group comparisons with negligible potential concerns about systematic

existing pre-intervention differences that might impact the interpretation of intervention outcome, as presented in **Table 1**. The intervention group had 63 children aged 10.2 years (SD = 1.4), with 28 diagnosed with ADHD, 22 diagnosed with ASD, and 13 with mild intellect disabilities; the control group comprised 63 age-equivalent children with similar diagnostic proportions and initial levels of executive function abilities. The attrition analysis found the retention proportion to be 94.4%, with only seven dropouts due to extra-interventional considerations.

Table 1

Baseline Demographic and Clinical Characteristics by Group

Variable	Intervention Group (n=63)	Control Group (n=63)	Test Statistic	p-value
Age (years), M(SD)	10.2 (1.4)	10.0 (1.3)	t = 0.89	.376
Male, n(%)	38 (60.3%)	41 (65.1%)	$\chi^2 = 0.31$	.578
ADHD diagnosis, n(%)	28 (44.4%)	26 (41.3%)	$\chi^2 = 0.13$	.718
ASD diagnosis, n(%)	22 (34.9%)	24 (38.1%)	$\chi^2 = 0.14$	.708
Intellectual disability, n(%)	13 (20.6%)	13 (20.6%)	$\chi^2 = 0.00$	1.000
WCST baseline (categories)	2.8 (1.2)	2.7 (1.1)	t = 0.48	.632
Baseline RT (ms)	487.3 (82.6)	492.1 (79.4)	t = -0.34	.735

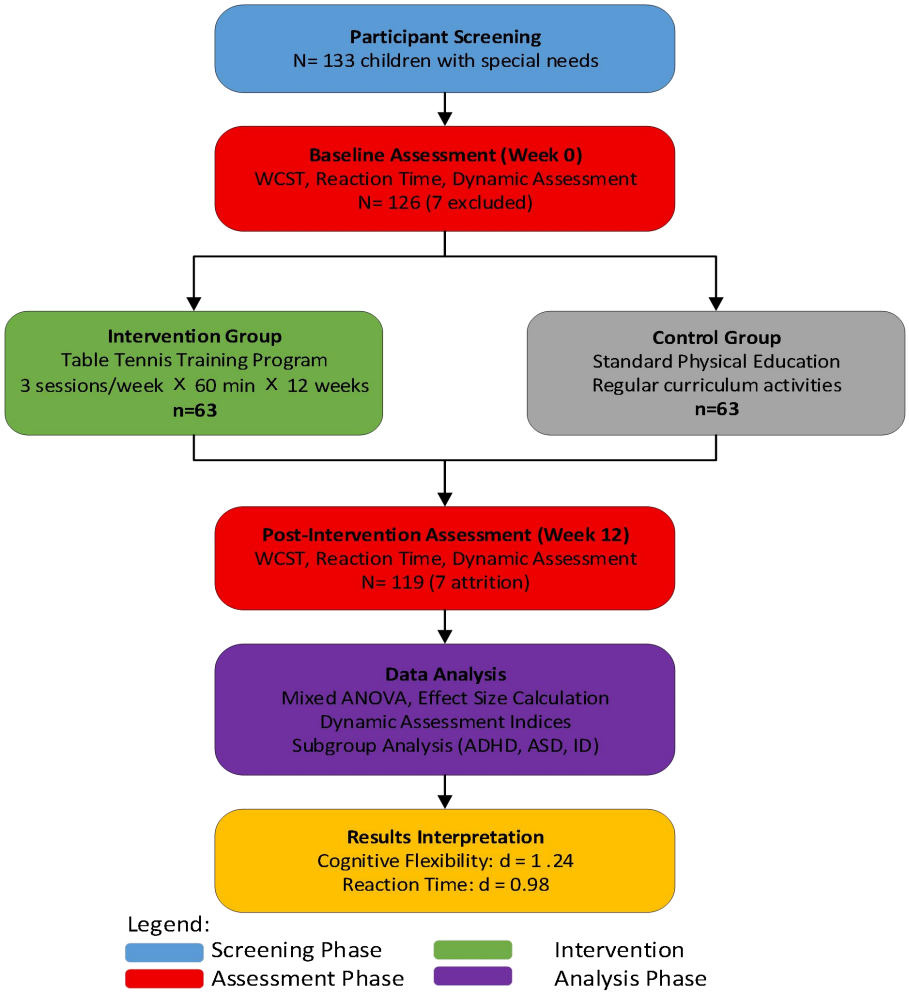
3.2. Cognitive Flexibility Results

Results derived from the analysis of covariance on Wisconsin Card Sorting Test data indicate that there was a significant time by group interaction effect; that is, the intervention group realized large effect size increments in terms of improvements in cognitive flexibility beyond those realized by the control group over the 12-week period (t (31.122) = 3.833; $p < .001$; Cohen's d = 1.24; 95% Confidence Interval = 0.89 to 1.59). One-way ANOVA tests on pre-intervention WCST results indicate that there are no significant group differences in terms of categories obtained, perseverative responses, and conceptual level responses (Levene's F = 1.045; F(1; 62) = 1.494; F(1; 62) = 1.971; F(1; 62) = 1.813 respectively; p values are .312; .225; .173 respectively), which confirms the equivalence of baseline measures among groups and lends validity to conclusions drawn post-intervention as shown in **Figure 1**. Comparison between post-intervention results among the two groups brought to light that whereas the average values among children within the table tennis training group

stood at 5.1 (SD = 1.4), those within the control group stood at 3.2 (SD = 1.3), yielding a standardized difference of 1.24 (95% Confidence Interval = 0.89 to 1.59; p < .001).

Figure 1

Cognitive Flexibility Performance Across Time by Group



3.3. Reaction Speed Results

The reaction time analysis showed that there was a similar trend towards improvements in the intervention group on measures of simple and choice reaction times, with significant time-by-group interactions shown in **Table 2** to reflect the faster processing of information brought about by the table tennis training intervention. These improvements became more evident with choice reaction times that resulted in significant decreases in the average reaction times among intervention

group subjects by 156.4 ms compared to 38.9 ms among controls as illustrated in **Figure 2** below.

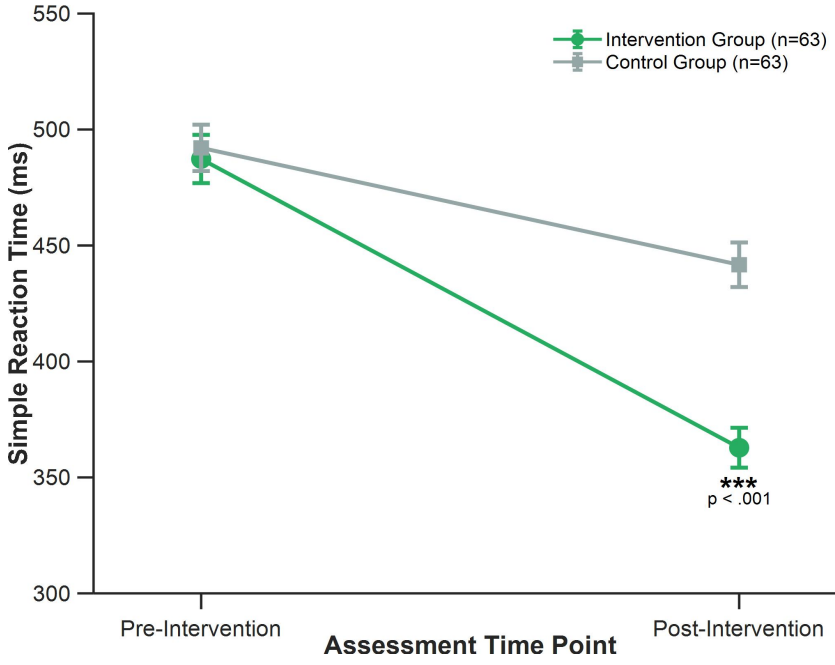
Table 2

Pre- and Post-Intervention Performance on Cognitive Measures

Measure	Intervention Group	Control Group	Group × Time	Effect Size
	Pre M(SD)	Post M(SD)	Pre M(SD)	Post M(SD)
WCST Categories	2.8(1.2)	5.1(1.4)	2.7(1.1)	3.2(1.3)
WCST Perseverative Errors	24.6(8.3)	12.6(5.7)	23.9(7.8)	21.0(7.2)
Simple RT (ms)	487.3(82.6)	362.8(68.3)	492.1(79.4)	441.7(76.2)
Choice RT (ms)	698.4(94.2)	542.0(81.6)	703.7(89.6)	664.8(86.3)

Figure 2

Reaction Time Performance Across Time by Group



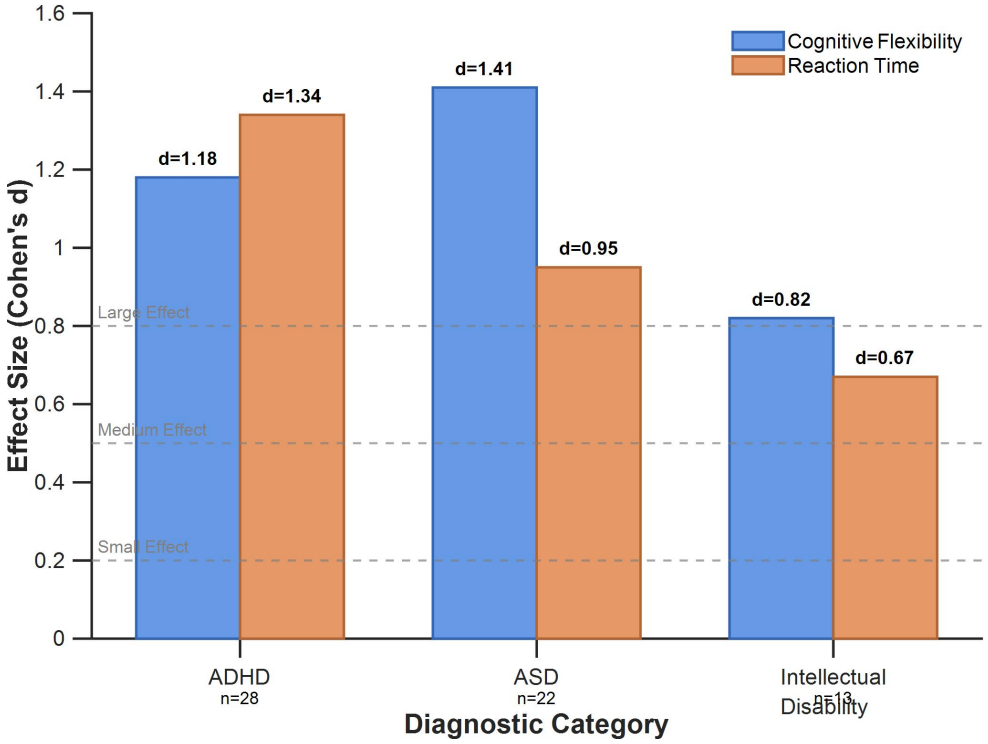
3.4. Dynamic Assessment and Subgroup Analysis

The dynamic testing procedures involving brief instructional scaffolding sessions between pretest and subsequent testing sessions indicated that intervention group subjects had significantly higher learning potential with mean gain scores representing 42.6% increase over static baseline to mediated testing conditions as opposed to 18.7% increase in controls, thereby suggesting that table tennis training led to more

than mere refinement of existing levels of ability but encouraged greater potential benefits from instruction as well as application of learning propensity to novel problem-solving tasks as suggested by **Figure 3**. The results within subgroups differentiated by diagnostic group showed differential intervention outcomes with greater post-intervention improvements noticed within the ADHD group on reaction time tasks (d=1.34), within the ASD group on indices of cognitive flexibility (d=1.41), and statistically significant yet relatively modest improvements noted within the group with intellectual disabilities (d=0.67 to 0.82) pointing towards broad-spectrum beneficial effects of table tennis training with diagnostic group-specific outcome profiles potentially suggesting differential EF profiles underlying these diagnostics.

Figure 3

Intervention Effect Sizes by Diagnostic Subgroup



4. Discussion

The current study offers highly informative data that strongly supports the conclusion that organized table tennis training leads to large increments in cognitive flexibility and reaction time in pediatric subjects with neurodevelopmental disorders, with effect sizes substantially exceeding established thresholds for significant change.

The concomitant gain in reaction time represented by faster stages of information processing between detection and responding to presented stimuli implies that table tennis training activated neural networks concerned with faster stages rather than sport motor coordination, thereby establishing evidence of distant transfer to untrained tasks that are crucial to validation research establishing intervention efficacy in improving more general capacities concerned with higher-order functions subsumed within the construct 'executive function.'

The theoretical background of dynamic testing was particularly useful in understanding intervention outcomes, with the large increase in learning potential measures indicating that table tennis training had increased not only present levels of performance but also potential benefits from supportive interventions and application of training-derived strategies to novel problem-solving tasks, underscoring Vygotsky's definition of the Zone of Proximal Development as a dynamic construct that was responsive to intervention-related changes in cognitive modifiability. The intervention outcome profiles that differed among diagnostic groups, such that those with ADHD showed the greatest gains in processing speeds and those with ASD made the most progress in terms of flexibility measures, are consistent with neuropsychologically defined models that propose heterogeneous profiles of executive dysfunction in these disorders and suggest that interventionally tailored approaches that are keyed to diagnostic group-related strengths and weaknesses in cognition might optimize intervention outcome. These beneficial intervention-related changes are likely mediated by greater neuroplasticity and connectivity within the network underlying the cerebellar-prefrontal pathway controlling motor and cognitive functions.

Based on these results, it can be suggested that table tennis training can be an optimal and encouraging intervention that can be added to the usual support environment designed to benefit children with special needs.

5. Conclusion

The current study has shown that structured table tennis training is an effective method to improve the cognitive flexibility and reaction time abilities in children with neurodevelopmental disorders with large effect sizes that indicate significant intervention efficacy that extends beyond the post-intervention sessions. The results have numerous implications in terms of educational and therapeutic applications since

motor-based intervention approaches with intrinsic motivational and practicality factors that enable classroom intervention might be an advantageous supplement to current therapeutic applications in improving the deficits in pediatric populations with special needs in the area of executive functions.

Conflict of interest: The author declares no conflict of interest.

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