**Supplementary Online Materials**

**Teacher Post-Treatment, Parent Follow-Up, and Sensitivity Analyses**

**Overview and Timeline**

The following analyses were not preregistered for this study but were added to address comments raised during the peer review process; results should therefore be considered exploratory. These analyses expand on the primary clinical endpoints/efficacy (ADHD symptoms) and feasibility/acceptability outcomes described in the preregistered plan by adding an informant (blinded teacher pre/post ratings) and time point (parent follow-up ratings), respectively. They also probe for effects of potential confounds/alternate explanations for the pattern of results reported in the main text and herein (i.e., effects of medication status and medication changes, intervention dosage, and whether parents told the teacher that the child was participating in an intervention).

Teacher ADHD symptom ratings on the BASC-3 and ADHD-RS-5 were obtained at pre- and post-treatment. Parent ADHD symptom ratings on these measures were obtained at pre-, mid-, and post-treatment (preregistered and reported in the main text) as well as at 2-4 month follow-up (exploratory time point reported herein). Children began treatment on average 3-5 weeks after the final pre-treatment evaluation session (*M*=25.61 days, *SD*=15.80); the ICT and CET groups did not differ in terms of time to first treatment session (BF01=1.80, *p*=.20). The relatively wide SD was expected based on our goal of minimizing barriers to treatment by accommodating families’ schedules/preferences when possible (e.g., families evaluated in December often wish to delay treatment until after the holidays). Post-treatment evaluations occurred within 1-2 weeks of the final treatment session (*M*=8.96 days, *SD*=6.37); the ICT and CET groups were equivalent in terms of post-treatment evaluation timing (BF01=3.14, *p*=.65). Follow-up evaluations occurred 2-4 months after the post-treatment evaluation (*M*=76.95 days, *SD*=21.34); the ICT and CET groups were equivalent in terms of time to follow-up (BF01=3.13, *p*=.93). The relatively wide follow-up SD was to maximize retention through follow-up (e.g., children unavailable during the summer due to travel or out-of-town custody arrangements).[[1]](#footnote-1)

**Missingness**

Because we expected higher missing data rates for teacher post-treatment and parent follow-up data relative to the primary outcomes described in the main text (e.g., teacher ratings are unavailable for children who complete treatment during the summer), we established ‘go/no-go’ criteria prior to accessing the data. These ‘go/no-go’ criteria provided *a priori* guidance for whether or not to analyze these data and add the results to the current manuscript. To minimize the likelihood of bias, the ‘go’ criteria were based on the conditions described by Kristman et al. (2004). Specifically, (1) missing data rates < 60% for each outcome, and (2) a non-significant Little’s MCAR test based on all available data, indicating that any missing data were missing completely at random (MCAR). The ‘no-go’ criterion was defined as either of these conditions not being met. As shown by Kristman et al. (2004), results can be assumed to be unbiased across loss to follow-up missingness rates of 5%-60% when follow-up data are missing at random or missing completely at random. We committed *a priori* to reporting results, positive or negative, if these criteria were met.

Teacher post-treatment completion rate was 74%; most cases of missingness were due to families completing treatment during the summer when no teacher was available because children were not in school. Parent follow-up completion rate was 80%. Little’s MCAR test indicated that these data were missing completely at random (*p*=.99). There was no evidence for differential attrition by treatment group (both *p*>.27, BF01>1.84). Thus, our ‘go’ criteria were met and we analyzed these data based on the *a priori* plan, which adapted the preregistered plan for these new data. For example, the teacher pre-post analyses mirror the parent pre-mid-post analyses, with the omission of the mid data point because mid-treatment teacher data were not collected. Similarly, the parent follow-up analyses mirror the parent pre-mid-post analyses, with the addition of the follow-up time point. Missing data were imputed using the preregistered plan (expectation-maximization based on all available data). As noted above, this maximum likelihood-based approach has been shown to produce unbiased results for missingness rates at/above the current levels when data are missing at random (Kristman et al., 2004) as was the case in the current study.

**Secondary Clinical Endpoints: Far-Transfer Effects on Blinded Teacher-Reported ADHD Symptoms**

***BASC-3 teacher-reported ADHD symptoms.*** Controlling for pre-treatment scores, CET was marginally superior to ICT at post-treatment in terms of teacher-reported Hyperactivity/Impulsivity (*d*=0.58, *p*=.03, BF10=2.07) and Attention Problems (*d*=0.63, *p*=.03, BF10=1.87). The group (ICT, CET) x symptom domain (Hyperactivity/Impulsivity, Attention Problems) x time (Pre, Post) mixed-model ANOVA was significant for a main effect of time only (*p*<.001; BF10=1.38 x 109) and marginally significant for the main effect of symptom domain (*p*=.03; BF10=2.30). Planned contrasts indicated that the CET and ICT groups were equivalent at pre-treatment for teacher-reported Hyperactivity/Impulsivity (*d* = -0.02, *p*=.99, BF01=3.62) and did not differ significantly for Attention Problems (*d*=0.11, *p*=.99, BF01=2.31). The CET group demonstrated significant reductions in Hyperactivity/Impulsivity (*d*=0.70, *p*<.001, BF10=303.82) and Attention Problems symptoms (*d*=0.55, *p*=.002, BF10=673.21) between pre- and post-treatment. The ICT group also demonstrated significant reductions in Hyperactivity/Impulsivity (*d*=0.42, *p*=.05, BF10=3.75) and Attention Problems symptoms (*d*=0.41, *p*=.06, BF10=16.32) between pre- and post-treatment (Figure S6, top).

***ADHD-RS-5.*** Controlling for pre-treatment scores, CET was superior to ICT at post-treatment in terms of teacher-reported Attention Problems (*d*=0.66; *p*=.01; BF10=3.96); this contrast did not reach significance for Hyperactivity/Impulsivity (*d*=0.52; *p*=.06; BF10=1.54). The group (ICT, CET) x symptom domain (Hyperactivity/Impulsivity, Attention Problems) x time (Pre, Post) mixed-model ANOVA was significant for the main effect of time (*p*<.001; BF10=7.23 x 103) and the treatment x time interaction (*p*=.01; BF10=3.98). Post-hocs for the interaction indicated that the CET group showed significant pre-post improvements in Hyperactivity/Impulsivity (*d*=0.46; *p*=.02; BF10=23.82) and Attention Problems (*d*=0.68; *p*<.001; BF10=98.32). In contrast, the ICT group failed to show pre-post improvements in Hyperactivity/Impulsivity (*d*=0.23; *p*=.99; BF01=1.11) or Attention Problems (*d*=0.16; *p*=.99; BF01=2.57) based on teacher report (Figure S6, bottom).

***Summary of effects on secondary clinical endpoints.*** Taken together, there was stronger support for behavioral far-transfer effects for CET than for ICT. CET was superior to ICT for producing reductions in teacher-reported ADHD symptoms on 3 of the 4 measures (*d*=0.52-0.66). In addition, the CET group demonstrated significant pre-post reductions across all 4 measures (*d*=0.46-0.70), whereas the ICT group showed significant reductions on both BASC-3 subscales (*d*=0.41-0.42) but failed to show reductions on either of the ADHD-RS-5 scales (*d*=0.16-0.23).

**Feasibility and acceptability: Parent-reported ADHD symptoms at follow-up**

***Overview.*** Pre-, mid-, and post-treatment parent ratings are described in the main text. Here, we repeated the group (ICT, CET) x symptom domain (Hyperactivity/Impulsivity, Attention Problems) x time (Pre, Mid, Post) mixed-model ANOVA, this time adding Follow-Up as a fourth time point to assess for maintenance of parent-perceived reductions in ADHD symptoms. Of primary interest were planned contrasts assessing (a) whether scores remained significantly below pre-treatment levels at follow-up (pre vs. follow-up), and (b) whether post-treatment gains were lost across the no-contact follow-up duration (post vs. follow-up).

***BASC-3 parent-reported ADHD symptoms.*** The group (ICT, CET) x symptom domain (Hyperactivity/Impulsivity, Attention Problems) x time (Pre, Mid, Post, Follow-Up) mixed-model ANOVA was significant for main effects of time (*p*<.001; BF10=1.42 x 1014), symptom domain (*p*=.19; BF10=3.38) and treatment (*p*=.31; BF10=6.40), as well as the symptom x time (*p*<.001; BF10=4.50) and treatment x time interactions (*p*=.001; BF10=20.82). Post-hocs for the significant interactions indicated that the CET group continued to demonstrate significantly lower parent-reported Hyperactivity/Impulsivity (*d*= -1.22, *p*<.001, BF10=1.71 x 104) and Attention Problems (*d*= -0.86, *p*<.001, BF10=9.37 x 103) at follow-up relative to pre-treatment. The CET group did not differ between post- and follow-up for Hyperactivity/Impulsivity (*d*= -0.37, *p*=.55, BF01=1.12) but had lower Attention Problems scores at follow-up relative to immediate post-treatment (*d*= -0.42, *p*=.19, BF10=13.07). This pattern of results suggests that parents continued to view children who completed CET as significantly improved in terms of ADHD symptoms at 2-4 month follow-up, providing additional support for CET’s feasibility and acceptability. The group x time interaction was due to a different pattern for the ICT group: The ICT group also did not change significantly between post- and follow-up for Attention Problems (*d*=0.25, *p*=.99, BF10=2.10) and remained significantly better at follow-up than at pre-treatment (*d*= -0.48, *p*=.05, BF10=84.34). In contrast, the ICT group no longer demonstrated reduced Hyperactivity/Impulsivity symptoms at follow-up relative to pre-treatment (*d*= -0.42, *p*=.21, BF10=2.56), despite not changing significantly between post- and follow-up (*d*=0.22, *p*=.99, BF01=1.52) (Figure S7, top).

***ADHD-RS-5 parent-reported ADHD symptoms.*** The group (ICT, CET) x symptom domain (Hyperactivity/Impulsivity, Attention Problems) x time (Pre, Mid, Post, Follow-Up) mixed-model ANOVA was significant for the main effects of time (*p*<.001; BF10=1.53 x 1014) and treatment (*p*=.94; BF10=21.09), as well as the treatment x time interaction (*p*=.002; BF10=101.08); the main effect of symptom domain was marginally significant (*p*=.005; BF10=1.41). Post-hocs for the significant interaction indicated that the CET group continued to demonstrate significantly lower Hyperactivity/Impulsivity (*d*= -0.92, *p*<.001, BF10=290.20) and Attention Problems (*d*= -0.89, *p*<.001, BF10=558.26) at follow-up relative to pre-treatment. The CET group did not differ between post- and follow-up for Hyperactivity/Impulsivity (*d* = -0.40, *p*=.32, BF01=1.10) or Attention Problems (*d* = -0.27, *p*=.99, BF10=2.35). This pattern of results suggests that parents continued to view children who completed CET as significantly improved in terms of ADHD symptoms at 2-4 month follow-up, providing additional support for its feasibility and acceptability. The group x time interaction was due to a different pattern for the ICT group: The ICT group also did not change significantly between post- and follow-up for Attention Problems (*d* = -0.05, *p*=.99, BF01=4.78) and remained significantly better at follow-up than at pre-treatment (*d* = -0.56, *p*=.005, BF10=25.06). In contrast, the ICT group no longer demonstrated reduced Hyperactivity/Impulsivity symptoms at follow-up relative to pre-treatment (*d* = -0.24, *p*=.99, BF01=1.45), despite not changing significantly between post- and follow-up (*d*=0.21, *p*=.99, BF01=1.89) (Figure S7, bottom).

***Summary of effects on parent-reported ADHD symptoms (feasibility/acceptability indicators).*** Taken together, there was greater support for maintenance of perceived effects for CET than ICT. The CET group remained significantly below pre-treatment levels for both hyperactivity/impulsivity and attention problems on both the BASC-3 and ADHD-RS-5 (*d*= -0.86 to -1.22), with effect sizes that were descriptively, but in most cases not significantly, larger than those found at immediate post-treatment. In contrast, the ICT group did not demonstrate significant losses between post-treatment and follow-up, but maintained significant reductions only for parent-reported attention problems (*d*= -0.48 to -0.56); at follow-up, their hyperactivity/impulsivity symptoms were not significantly different from pre-treatment (*d*= -0.24 to -0.42, *ns*).

**Sensitivity Analyses**

Additional exploratory analyses were added to probe the robustness of effects to potential confounds identified during the peer review process. This process involved repeating each of the analyses reported in the main text and above, with additional covariates. Each potential covariate was tested in a separate model to minimize the likelihood that any obtained changes were attributable to degrees of freedom rather than the covariate of interest.

***Medication changes.*** Despite the finding that the groups did not differ in terms of medication changes during the course of treatment, and our use of a medication washout to test children off medication, it was possible that the significant main effects of time were attributable to medication changes rather than the tested treatments. We therefore repeated the study’s analyses, controlling for medication changes (-1 = stopped, 0 = no change, 1 = started/increased dose). All pre/post and pre/mid/post analyses controlled for medication changes between pre- and post-treatment; all pre/mid/post/follow-up analyses controlled for medication changes between pre- and post-treatment, and between post-treatment and follow-up (coded as two separate variables). Rates of medication changes during active treatment are reported in the main text. At follow-up, 4 ICT cases and 2 CET cases reported starting/increasing medication, and 1 ICT case reported discontinuing medication; the groups were equivalent in terms of the proportion of medication changes (BF01=8.69, *p*=.52).

As expected, the pattern, significance, and interpretation of all results based on testing that was conducted off medication was unchanged (i.e., working memory and inhibitory control performance; actigraphy during testing sessions). In addition, the pattern, significance, and interpretation of all parent-reported and teacher-reported ADHD symptom results was also unchanged. Taken together, the hypothesis that treatment-related changes were spurious effects of medication changes rather than the tested treatments was unsupported.

***Medication effects.*** Because the groups were stratified based on medication status, they did not differ significantly in terms of the proportion of children prescribed psychostimulants at pre-treatment (main text Table 1). However, because psychostimulants may temporarily actuate cortical structures that support the executive functions targeted by ICT and CET (e.g., Hawk et al., 2018; cf. Rubia et al., 2014), it is possible that medicated children may have differentially benefited from one or both cognitive training interventions. Although the current study is not powered for the moderation analyses needed to definitely address this question, we conducted exploratory analyses to examine whether children prescribed psychostimulant medication differentially benefited from ICT/CET treatment. We therefore repeated the study’s analyses, adding medication status (no/yes) as an additional between-subjects factor.

Results indicated that medication status was not a significant predictor, and did not interact with treatment group or time, in any of the analyses, with the following circumscribed exceptions: There was marginal support for a main effect of medication status on working memory performance (*p*=.04, BF01=1.41) in the group x task x time ANOVA, suggesting that medicated children had modestly lower working memory performance overall during the off-medication testing sessions (*d*= -0.29). Exploratory post-hoc tests indicated that medication status differences were limited to pre-treatment visuospatial working memory (VSWM) performance (*p*=.02, BF10=3.41, *d*= -0.71) and mid-treatment phonological working memory (PHWM) performance (*p*=.01, BF10=3.90, *d*= -0.73); effects were nonsignificant for VSWM mid and post, and PHWM pre and post (all *p*>.06, all BF10<1.30, *d*= -0.31 to -0.55). Given the inconsistent pattern of significance and lack of interactions with time or treatment, there does not appear to be support for the hypothesis that psychostimulants may increase the benefits of cognitive training.

Main effects of medication were also detected for teacher-reported attention problems on the ADHD-RS-5 (but not BASC-3): For the residualized gain score analysis, there was a marginal effect of medication status on post-treatment attention problems scores (*p*=.04, BF10 = 2.97, *d*=0.62), suggesting that children prescribed medication were perceived as having fewer attention problems. This marginal effect was also seen in the mixed-model ANOVA (main effect of medication status: *p*=.004, BF10=1.53, *d*=0.41). In all cases, the significance and interpretation of treatment effects reported in the main text remained unchanged, and in no case did medication status interact with time or treatment. Thus, there was no indication that children prescribed psychostimulants differentially benefited from the intervention. However, an obvious limitation is that we tracked whether or not children were prescribed medication, not whether they received their prescribed dose on treatment session days or whether the medication was metabolically active during the treatment session. Future, carefully-controlled medication x cognitive training studies are clearly warranted to more directly test this interesting possibility.

***Teacher blinding.*** All teachers remained blind to the child’s treatment group based on parent report on a study-created post-treatment blinding questionnaire. However, *n*=9 parents reported telling the teacher that their child was participating in an intervention. The groups were equivalent in terms of the proportion of parents who told their child’s teacher that their child was participating in an intervention (BF01=3.13, *p*=.91). Because it was possible that knowing the child was receiving an intervention might produce expectancies that affected teacher ratings, we tested teacher knowledge that the child was participating in an intervention (no/yes) as a covariate in all teacher-report analyses. The pattern, significance, and interpretation of all results was unchanged, with one exception: Controlling for pre-treatment scores (and teacher blinding), CET became marginally superior to ICT at post-treatment in terms of teacher-reported Hyperactivity/Impulsivity (*d*=0.52; *p*=.05; BF01=1.60). Thus, when controlling for potential teacher expectancies, CET was superior to ICT on all four teacher-report measures (BASC-3 and ADHD-RS-5 Hyperactivity/Impulsivity and Attention Problems subscales; *d*=0.52-0.66).

***Intervention dosage.*** Despite the treatment groups not differing significantly in terms of total time actively playing the training games (training time), these values were qualitatively different for ICT vs. CET (mean 495 vs. 658 minutes actively engaged with the training games, respectively), with relatively large variability across children (SD = 236 vs. 389, respectively). We therefore repeated the study’s analyses, controlling for training time (minutes). Controlling for training time did not change the pattern, significance, or interpretation of any results.

We then conducted additional exploratory analyses to probe for potential intervention-specific dosage effects. To do so, we explored correlations between training time and changes in the trained abilities (slopes). Because each child trained on only one executive function (inhibitory control for ICT, working memory for CET), we created 2 variables: Inhibitory control training time and working memory training time. Time spent training working memory was set to 0 for ICT cases, and time spent training inhibitory control was set to 0 for CET cases. Results revealed that greater time training on CET was associated with greater improvements in working memory recall (*r*=.34, *p*=.01, BF10=3.35) and greater reductions in inhibitory control errors (*r*= -.32, *p*=.02, BF10=2.51). In contrast, greater time training on ICT was counterintuitively associated with weaker reductions in inhibitory control errors (*r*=.43, *p*=.001, BF10=27.48) and was not significantly associated with changes in working memory (*r*=.-.22, *p*=.11, BF01=1.68).

The counterintuitive association between greater ICT training and less inhibitory control improvement is deserving of further study. It may be that children with the least developed inhibitory control require more practice to make even minimal gains (e.g., pretreatment severity x training time interaction). Similarly, because study eligibility did not require inhibition deficits, it is possible that children with better inhibitory control were more likely to complete more training (i.e., because they could reach higher levels prior to reaching their zone of proximal development), which could produce the anomalous results detected. In other words, it is feasible that children who performed better on the inhibition tasks at pre-treatment (a) would have less room for improvement, and (b) conceptually would be able to complete more training games because their inhibitory control was stronger to begin with. Although the current study is not powered to examine moderator effects, these will be important considerations for further study. Thus, although training time did not alter the pattern of results, these findings combined with those reported in the main text raise questions regarding ICT’s feasibility and efficacy, and indicate that further development and study will be needed going forward to maximize ICT’s direct training effects (thus maximizing the likelihood that it will produce far-transfer effects if inhibitory control deficits are a causal mechanism underlying ADHD symptoms as hypothesized; e.g., Barkley, 1997).

**Supplementary Figure S1.** Parent-reported ADHD symptoms at pre-treatment, mid-treatment, and post-treatment for inhibitory control training (ICT) and central executive training (CET).

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**Supplementary Figure S2.** Additional stop-signal metrics: stop-signal reaction time computed using the Verbruggen et al. (2013) integrated method (iSSRT) and stop-signal delay (SSD). Better inhibitory control is indicated by lower iSSRT (i.e., faster inhibitory stopping speed) and higher SSD (i.e., the child is successfully able to inhibit responding on more difficult trials).



**Supplementary Figure S3.** Behavioral far-transfer effects of inhibitory control training (ICT) and central executive training (CET). Higher scores indicate greater gross motor movement (hyperactivity).





**Supplementary Figure S4.** Mechanisms of change analyses. Bivariate associationsbetween changes in working memory (left column) and inhibitory control (right column) and changes in objectively-assessed ADHD symptoms (actigraph-measured hyperactivity).

*r*= .14, *p*=.16, BF01=1.76

*r*= .12, *p*=.20, BF01=2.14

*r*= .15, *p*=.13, BF01=1.55

*r*= -.28, *p*=.02, BF10=3.11

*r*= -.23, *p*=.04, BF10=1.59

*r*= -.31, *p*=.01, BF10=4.56

**Supplementary Figure S5.** Mechanisms of change analyses. Bias-corrected, bootstrapped mediation analyses examining the extent to which treatment-related changes in objectively-assessed hyperactivity are conveyed by treatment-related changes in executive functions (top: working memory, bottom: inhibitory control). Change scores reflect simple slopes reflecting changes across the three time points (pre, mid, post), averaged within each construct. Black text and asterisks (\*\*) indicate significant associations (95%CIs exclude 0.0, indicating significance at *p*<.05); grey text indicates non-significant associations (95%CIs include 0.0, indicating *p*>.05).

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**Supplementary Figure S6.** Teacher-reported ADHD symptoms on the BASC-3 (top) and ADHD-RS-5 (bottom).



**Supplementary Figure S7.** Parent-reported ADHD symptoms on the BASC-3 (top) and ADHD-RS-5 (bottom).



**References**

Hawk Jr, L. W., Fosco, W. D., Colder, C. R., Waxmonsky, J. G., Pelham Jr, W. E., & Rosch, K. S. (2018). How do stimulant treatments for ADHD work? Evidence for mediation by improved cognition. *Journal of Child Psychology and Psychiatry*, *59*(12), 1271-1281.

Rubia, K., Alegria, A. A., Cubillo, A. I., Smith, A. B., Brammer, M. J., & Radua, J. (2014). Effects of stimulants on brain function in attention- deficit/hyperactivity disorder: a systematic review and meta-analy- sis. Biological Psychiatry, 76(8), 616–628.

1. Our preregistration called for a 2-month follow-up; however, in running the trial we elected to allow more flexibility to facilitate retention by maximally accommodating families’ availability to attend the follow-up appointment. The follow-up is therefore described as a 2-4 month follow-up to better characterize the obtained range. [↑](#footnote-ref-1)