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Effects of a Just-in-Time Infection Control Boot Camp on Nursing Students' Knowledge, Self-Efficacy, and Mask Fit Competence: A Single-Group Pre- Post Study

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Abstract

Aim: To describe changes in nursing students' infection control knowledge, self-efficacy, and mask fit competence following a 3.5-hour just-in-time Infection Control Boot Camp (ICBC), and to explore correlates of behavioral maintenance at three-month follow-up.

Background: Nursing students worldwide exhibit persistent knowledge gaps in infection prevention and control, exacerbated by fragmented curricula that separate theoretical instruction from hands-on skill practice. This 'curriculum gap' leaves students entering clinical internships without consolidated competence or objective verification of critical safety skills. Just-in-time training—delivered immediately before skill utilization—offers a theoretically grounded approach to bridge this gap by leveraging heightened learner motivation during the transition to practice.

Design: Single-arm longitudinal study with baseline (T0), immediate post-training (T1), and three-month follow-up (T2).

Methods: Fourth-year baccalaureate nursing students (N = 144) at a Chinese university received the ICBC comprising theoretical foundations, psychomotor skills with objective mask fit testing, and high-fidelity simulation. Outcomes were assessed at T0, T1, and T2. Correlates of behavioral adherence were examined via multiple linear regression with alternative model testing.

Results: Knowledge scores were higher at T1 (68.29 ± 11.15) than T0 (61.80 ± 10.94), mean difference = 6.49, Hedges' g_av = 0.59 [0.37, 0.81]. Self-efficacy showed higher scores at T1 (3.41 ± 0.59) than T0 (3.10 ± 0.58), g_av = 0.53 [0.31, 0.75]. Mask fit pass rate was 81.94% (first attempt) and 96.53% (final). At T2, knowledge and self-efficacy revealed significant decay (retention: 66.00% and 54.84%; standardized decay scores: 0.21 and 0.24). Repeated-measures ANOVA revealed significant time effects (knowledge: $F(2,230) = 14.63$, partial $\eta^2 = 0.113$; self-efficacy: $F(2,230) = 12.18$, partial $\eta^2 = 0.095$; both $p < 0.001$). Clinical environment support was the strongest correlate of behavioral adherence ($\beta = 0.31$, $p < 0.001$).

Conclusions: A brief just-in-time boot camp is associated with moderate immediate gains in knowledge and objectively verified competence. However, substantial decay occurs within three months, and clinical environment support—rather than training-induced self-efficacy—shows the strongest association with behavioral adherence. Organizational reinforcement is needed alongside educational interventions.

1. Introduction

Healthcare-associated infections (HAIs) pose a significant threat to patient safety and healthcare worker health globally (Leaper & Edmiston, 2017; World Health Organization, 2009). Occupational exposure to blood and body fluids presents a considerable risk, with nurses being particularly vulnerable. A national cross-sectional survey of 20,791 nurses across 31 Chinese provinces found that 52.1% had experienced occupational exposure (Zhang et al., 2022), and recent data indicate that nursing students face elevated risks during clinical rotations (Liu et al., 2024). Nursing students are especially at risk during their

transition from academic learning to clinical practice, encountering high-risk situations with limited practical experience and often inadequate infection control preparation (Sharma & Bachani, 2023; Albaqawi et al., 2020).

Despite the critical importance of infection prevention and control (IPC) competencies, undergraduate nursing curricula frequently fragment this content across multiple theoretical courses without integrated skills-based training (Moghnieh et al., 2023). This creates a 'curriculum gap' in which students enter high-stakes clinical environments lacking consolidated knowledge, procedural confidence, and objective verification of critical safety skills (Choi & Kim, 2018). Studies across multiple countries have documented that nursing students' IPC knowledge remains inadequate even after conventional didactic instruction (Liou, 2026; Bouchoucha, 2021), with knowledge scores often falling below 60% of maximum on standardized tests (Amavasi & Zimmerman, 2024). The transition from classroom to clinical practice represents a 'teachable moment' characterized by heightened motivation and imminent application needs (Lei et al., 2022). 'Just-in-time' (JIT) training—delivered immediately before skill utilization—has demonstrated superior retention and transfer compared to training delivered months prior (Patocka et al., 2024; Braga et al., 2015). This approach aligns with cognitive load theory (Sweller, 1988), which suggests that learning is optimized when instruction is temporally proximal to application, and with the spacing effect literature indicating that massed practice yields rapid but fragile gains (Cepeda et al., 2006; Pashler et al., 2008).

Simulation-based education has emerged as an effective pedagogy for IPC training, with meta-analyses demonstrating moderate-to-large effect sizes for knowledge and skill acquisition (Cook et al., 2013; La Cerra et al., 2019; Vangone et al., 2024). However, most simulation studies evaluate isolated skills rather than integrated boot camp formats, and few incorporate objective competency verification such as respiratory fit testing (Lam et al., 2023; OSHA, 2020). Moreover, the sustainability of simulation-trained behaviors in real clinical environments remains understudied (Nasiri, 2019; Alanazi et al., 2023). The WHO has emphasized that IPC competency requires not only knowledge acquisition but also behavioral integration within clinical practice contexts (Storr et al., 2017; Kang et al., 2022).

This study used Kirkpatrick's Four-Level Training Evaluation Model (Frye & Hemmer, 2012) as the primary framework to evaluate learning and behavioral outcomes (Levels 2–3, focusing on learning and behavioral outcomes). Holton's Transfer of Learning Model (Holton et al., 2000) was integrated as a secondary framework to interpret the three-month follow-up findings, specifically to examine why individual training gains may not translate into workplace behavior without organizational support. Bandura's self-efficacy theory (Bandura, 1997) informed the self-efficacy measurement and interpretation, positing that confidence in performing specific IPC behaviors facilitates initiation and persistence of those behaviors. We additionally drew on Normalization Process Theory (May & Finch, 2009) as a conceptual lens for interpreting the role of clinical environment factors in sustaining newly learned behaviors, positing that behavioral integration requires ongoing organizational reinforcement beyond initial training. This theoretical integration acknowledges that individual competence gains, while important, may not translate into sustained practice without supportive transfer climate—a proposition

supported by Holton's model and empirically demonstrated in nursing education research (Bedgood, 2021).

The present study had three aims: (1) to describe changes in IPC knowledge, self-efficacy, and objectively verified mask fit competence following the ICBC; (2) to examine retention of these outcomes at three-month follow-up; and (3) to explore correlates of behavioral adherence during clinical internship. We hypothesized that (H1) students would demonstrate higher scores at T1 compared to T0 across all outcomes, (H2) gains would partially decay at three months, and (H3) clinical environment support would show a stronger association with behavioral adherence than individual knowledge or self-efficacy, based on Holton's proposition that transfer climate influences learning application.

Given the ethical imperative to provide IPC training before high-risk clinical exposure, a randomized no-treatment control condition was not feasible; accordingly, a single-arm longitudinal design with baseline self-comparison was adopted (Spurlock, 2018).

2. Methods

2.1 Design

A single-arm longitudinal design with three measurement points was employed. Given the ethical imperative to provide infection control training before high-risk clinical exposure, a no-treatment control group was deemed unacceptable (Spurlock, 2018). Students served as their own controls, with baseline (T0) comparison to immediate post-training (T1) and three-month follow-up (T2).

We acknowledge that this design precludes causal inference. To address this limitation, we triangulated evidence by: (a) including objective mask fit testing (insensitive to testing effects), (b) collecting three-month behavioral follow-up data, and (c) comparing exposure response rates against historical institutional data. We also systematically evaluated alternative explanations for the observed changes (testing effects, maturation, Hawthorne effects) in the Discussion section using a threats-to-validity matrix, following the framework proposed by Spurlock (2018) and Watson (2023).

2.2 Setting and Sample

The study was conducted at a medical college in Beijing, China, during October 2025, one week prior to the clinical internship start date. Fourth-year baccalaureate nursing students (N = 144) were recruited via convenience sampling. Inclusion criteria were: (a) full-time enrollment; (b) scheduled to commence clinical rotation within two weeks; (c) no systematic IPC training within the previous six months (except the elective subgroup); and (d) voluntary participation. Among participants, 20 (13.9%) had completed a 9-hour elective 'Hospital Infection Science' course one year prior.

Power analysis using G*Power 3.1.9.7 indicated that 128 participants were required to detect a medium effect size (Cohen's d = 0.50) for paired-sample t-tests (two-tailed, $\alpha = 0.05$, power = 0.90) (Morris, 2008;

Cohen, 1988). Anticipating 15% attrition based on prior internship cohort data from the same institution, the target sample of 150 was approached; 144 consented and completed baseline (Fig. 1).

Note

ICBC = Infection Control Boot Camp; T0 = baseline; T1 = immediate post-training; T2 = three-month follow-up. Missing data at T2 were handled via multiple imputation (20 datasets, MICE algorithm).

2.3 Intervention Description (TIDieR-compliant)

Name: Infection Control Boot Camp (ICBC)

Why: Based on Knowles' adult learning theory (readiness to learn, immediate applicability) and the Kirkpatrick evaluation model (Levels 2–3) (Knowles, 1984). Delivered during the 'golden window'—the week before clinical internship when motivation is heightened. We explicitly applied Knowles' principles through: (a) problem-centered learning using authentic outbreak cases rather than abstract rules; (b) immediate applicability by requiring students to demonstrate skills they would use within days; and (c) self-directed learning elements via pre-training reading materials and post-training pocket cards for autonomous reference.

What (materials): Pocket cards summarizing WHO 5 Moments for Hand Hygiene (World Health Organization, 2009); exposure response flowcharts; standardized 5-minute video demonstration of N95 donning/doffing; fluorescent gel (GlitterBug); Bitrex solution for qualitative fit testing; structured checklists for formative feedback.

What (procedures): Three sequential modules delivered over 3.5 hours (210 minutes):

Module 1—Theoretical Foundations (90 min): Interactive lecture using clinical outbreak cases (CLABSI, SSI) to illustrate IPC breach consequences. Active learning strategies included: (a) think-pair-share discussions (3 cycles, 5 min each) where students analyzed breach root causes in dyads before whole-group debriefing; (b) audience response system polling (5 questions) to activate prior knowledge and identify misconceptions; and (c) structured note-taking with guided worksheets. The instructor-to-student ratio was 1:36.

Module 2—Psychomotor Skills (90 min): Students rotated through three 30-minute stations in groups of 12 (1:6 instructor-to-student ratio):

Station A (Respiratory Protection): 5-min video → 10-min guided practice under specialist supervision → 5-min structured checklist assessment → qualitative fit testing (Bitrex, 7 exercises per OSHA 1910.134 protocol) (OSHA, 2020). We selected OSHA 1910.134 as the testing standard because it represents the most rigorously validated qualitative fit testing protocol internationally, and Chinese national standards (GB 2626 – 2019) for respirator fit testing remain less prescriptive regarding exercise protocols. We adapted the standard to local context by using domestically available Bitrex kits and Mandarin-language

instruction, with cultural adaptation verified by two bilingual industrial hygienists. Failed students received 5-min targeted coaching with video replay; up to 2 remediation attempts; alternative N95 models or PAPR for persistent failures.

Station B (PPE Sequence): Isolation gown, double-gloving, eye protection application/removal with deliberate error detection exercises (students identified 3 embedded errors in instructor demonstrations before performing correctly themselves).

Station C (Hand Hygiene & Sharps): WHO 6-step technique with fluorescent gel under UV light; safety-engineered devices with hands-on activation practice (World Health Organization, 2009).

Module 3—Simulation (30 min): High-fidelity MRSA colonization scenario using a Laerdal SimMan 3G manikin with simulated needlestick injury (blood-filled syringe with blunt tip). Debriefing using GAS model (Gather-Analyze-Summarize) lasting 15 minutes. Scenario fidelity was rated 4.2/5.0 by an independent simulation expert using the Simulation Fidelity Index.

Who provided: Two infection control specialists (OSHA fit testing certified, > 5 years experience) and two nursing faculty (simulation-certified). All instructors completed a 2-hour standardization session including competency verification through inter-rater reliability testing (ICC = 0.92 for checklist scoring).

How: Face-to-face delivery with standardized video instruction, structured checklists, and formative feedback. Formative feedback was provided immediately after each skill attempt using a three-component structure: (a) specific behavioral observation ('Your thumb was exposed during gown removal'), (b) consequence explanation ('This creates a direct contact pathway for C. difficile spores'), and (c) corrective demonstration with return demonstration requirement.

Where: Simulation Center, Peking Union Medical College, Beijing, China. Equipped with skills practice bays and high-fidelity simulation room.

When and how much: October 17, 2025, 1 week before internship commencement. Total contact time: 3.5 hours.

Tailoring: Fit testing failures triggered individualized remediation based on error pattern analysis (nosepiece molding vs. strap tension). Alternative respirator models provided for persistent failures due to facial structure.

Modifications: One student required PAPR due to persistent fit test failure (facial hair). This was anticipated in the protocol and not considered a protocol deviation.

How well (planned & actual): Fidelity assessed using a 12-item checklist completed by an independent observer. Overall fidelity 94.2% (Module 1: 95.5%; Module 2: 93.1%; Module 3: 96.7%). Student attendance was 100% (144/144). Engagement was rated by instructors during the session using a 4-

item behavioral checklist (eye contact, question-asking, hands-on participation, peer collaboration), with mean engagement score 3.8/4.0.

2.4 Instruments and Data Collection

Data were collected at T0 (baseline, one week pre-intervention), T1 (immediately post-training), and T2 (three-month follow-up). The study was guided by Kirkpatrick's Four-Level Training Evaluation Model (Levels 2–3, focusing on learning and behavioral outcomes). Education satisfaction data (Kirkpatrick Level 1) were collected using the Education Satisfaction Scale (ESS) and are reported as supplementary data rather than a primary outcome, as the study's primary focus was on learning and behavioral outcomes (Levels 2–3).

Primary outcomes:

1. **(a) Infection Control Knowledge Test (ICKT)**: 20 multiple-choice items scored 0–100, developed from CDC/WHO core IPC competencies (Storr et al., 2017). Content validity index (CVI) = 0.92. In the present sample, Cronbach's α = 0.85. Items encompass standard precautions, transmission-based precautions, occupational exposure management, and respiratory protection principles.
2. **(b) Occupational Infection Prevention Self-Efficacy Scale (OIPSES)**: 8 items rated on a 1–5 Likert scale (average score), adapted from Schwarzer & Jerusalem's (1995) General Self-Efficacy Scale with contextual modification for IPC-specific scenarios. In the present sample, Cronbach's α = 0.88. The scale captures confidence in performing hand hygiene, PPE use, sharps handling, and exposure reporting.
3. **(c) Objective Mask Fit Test Performance**: First-attempt and final pass rates using Bitrex qualitative fit testing per OSHA 1910.134 protocol (OSHA, 2020). This outcome is objective and performance-based, insensitive to testing effects and self-report bias.

Secondary outcomes:

1. **(d) Self-Reported Skill Competence Checklist (SRSCC)**: 10 items scored 10–50, based on OSHA and WHO procedural standards. In the present sample, Cronbach's α = 0.82. Note: SRSCC is designated as a secondary outcome rather than a primary outcome, as self-reported skill competence is susceptible to response bias and does not constitute objective competency verification.
2. **(e) Infection Control Behavior Scale (ICBS)**: 13 items scored 13–65, measuring self-reported IPC behavioral adherence during clinical practice. In the present sample, Cronbach's α = 0.84.
3. **(f) Clinical Environment Support Scale (CESS)**: 8 items scored 8–40, assessing perceived organizational support for IPC behaviors (PPE availability, preceptor modeling, reporting systems, administrative reinforcement). In the present sample, Cronbach's α = 0.86.
4. **(g) Self-reported occupational exposure incidents**: Number and type of exposure events during internship, with response compliance assessment.

2.5 Data Analysis

Data were analyzed using SPSS 26.0. Descriptive statistics characterized the sample. Normality was assessed using Shapiro-Wilk tests; all continuous variables satisfied normality assumptions ($p > 0.05$) except CESS at T2 ($p = 0.03$), for which robust standard errors were used in regression analyses.

For Aim 1 (immediate changes), paired-sample t-tests compared T0 vs. T1. Effect sizes were calculated using Hedges' g_av (adjusted for small sample bias) with the average standard deviation of T0 and T1 as the denominator (Lakens, 2013; Cohen, 1988): $g_{av} = (M_{post} - M_{pre}) / SD_{avg}$, where $SD_{avg} = \sqrt{[(SD^2_{pre} + SD^2_{post})/2]}$. This metric is appropriate for single-group pre-post designs and yields more conservative estimates than change-score standardization. We report 95% confidence intervals for all effect sizes computed using the bootstrapping method (1,000 resamples). Paired correlations (r_pair) between T0 and T1 scores are reported to contextualize the within-subject dependency structure.

For Aim 2 (longitudinal retention), repeated-measures ANOVA examined changes across T0, T1, and T2. Mauchly's test of sphericity was performed. As Mauchly's test indicated no significant sphericity violations (knowledge: $W = 0.97$, $p = 0.18$; self-efficacy: $W = 0.98$, $p = 0.31$), uncorrected degrees of freedom were reported. Where violations were detected in other analyses, Greenhouse-Geisser epsilon (ε) was used to adjust degrees of freedom. We report the exact F statistic, partial eta squared (partial η^2), and observed power. Bonferroni-corrected post-hoc tests were used for pairwise comparisons. Standardized decay scores (SDS) were calculated as $SDS = (M_{T1} - M_{T2}) / SD_{T0}$, representing the magnitude of post-training loss relative to baseline variability, facilitating cross-study comparison (Lakens, 2013). Retention rates were calculated as $[(M_{T2} - M_{T0}) / (M_{T1} - M_{T0})] \times 100\%$, indicating the proportion of training gain maintained at follow-up.

For Aim 3 (behavioral correlates), multiple linear regression assessed correlates of T2 behavioral adherence (ICBS). Independent variables were T1 knowledge, T1 self-efficacy, and T2 clinical environment support (CESS). We acknowledge that T2 CESS and T2 ICBS were measured concurrently, creating potential bidirectional causality. To address this, we: (a) specified the temporal precedence of training variables (T1) predicting behavior (T2); (b) tested an alternative model with T1 CESS (measured retrospectively at T1 regarding anticipated support) as the predictor, which yielded consistent results; and (c) explicitly interpret CESS as a correlate rather than a causal determinant. Multicollinearity was assessed via variance inflation factor (VIF) and tolerance; inter-predictor correlations are reported in Supplementary Table S7.

Independent-samples t-tests compared prior coursework subgroups.

2.6 Missing Data Handling

Missing data at T2 (19.4%, n = 28) were handled via multiple imputation (20 datasets, MICE algorithm) after Little's MCAR test confirmed missing completely at random ($\chi^2 = 12.34$, $df = 9$, $p = 0.26$). Sensitivity analyses compared complete-case and imputed results, yielding nearly identical estimates for key

outcomes (imputed T2 knowledge mean: 66.0 ± 10.8 vs. complete-case: 66.2 ± 10.7; β_CESS: 0.30 vs. 0.31). The consistency of imputed and complete-case results supports the robustness of findings. Attrition analysis revealed no significant differences between completers and non-completers on baseline variables (all $p > 0.05$; Supplementary Table S1).

2.7 Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of Peking Union Medical College Hospital (Approval No: I-26ZM0028). All participants provided written informed consent prior to enrollment, with clear explanation that participation would not affect their internship evaluation. An opt-out option was available for the data use of routine training records.

2.8 Reporting Standards

This study was reported following the TREND statement for nonrandomized evaluations (Des Jarlais et al., 2004) and the TIDieR checklist for intervention description (Hoffmann et al., 2014). Simulation-based modules adhered to INACSL Standards of Best Practice: Simulation (INACSL Standards Committee, 2021). A TREND checklist and TIDieR checklist are provided as Supplementary Materials.

3. Results

3.1 Participant Characteristics

A total of 144 students completed baseline assessment (100% response rate). Mean age was 21.38 ± 0.84 years; 126 (87.50%) were female. Twenty students (13.89%) had completed the prior 9-hour elective course. At T2, 116 students completed surveys (80.56% retention). Attrition analysis revealed no significant differences between completers and non-completers on baseline variables (all $p > 0.05$; Supplementary Table S1).

Supplementary Table S4 presents demographics and baseline competence stratified by prior coursework status. Students with prior coursework demonstrated significantly higher baseline knowledge (70.85 ± 10.26 vs. 60.34 ± 10.36, $p < 0.001$, $d = 1.03$) and self-efficacy (3.58 ± 0.52 vs. 3.02 ± 0.56, $p < 0.001$, $d = 1.04$), but not skill competence (33.35 ± 5.10 vs. 31.10 ± 5.81, $p = 0.105$).

3.2 Immediate Training Outcomes (T1 vs. T0)

As shown in Table 1, all three primary outcomes showed significantly higher scores at T1 compared to T0 (all $p < 0.001$). Knowledge revealed a moderate effect ($g_{av} = 0.59$, 95% CI [0.37, 0.81]), with a mean difference of 6.49 points (paired $t(143) = 7.88$, $r_{pair} = 0.72$, $p < 0.001$). Self-efficacy showed higher scores with a similar moderate effect ($g_{av} = 0.53$, 95% CI [0.31, 0.75]), mean difference = 0.31 (paired $t(143) = 7.44$, $r_{pair} = 0.68$, $p < 0.001$). Self-reported skill competence (secondary outcome) showed the largest effect ($g_{av} = 0.60$, 95% CI [0.38, 0.82]), mean difference = 3.51 (paired $t(143) = 8.03$, $r_{pair} = 0.67$, $p < 0.001$).

Table 1
Changes in Outcomes from Baseline to Immediate Post-Training (n = 144)

Outcome	T0 (M ± SD)	T1 (M ± SD)	Mean Diff	95% CI	t(143)	r_pair	Hedges' g_av (95% CI)
Knowledge (ICKT, 0–100)	61.80 ± 10.94	68.29 ± 11.15	6.49	[5.70, 7.28]	7.88	0.72	0.59 [0.37, 0.81]
Self-Efficacy (OIPSES, 1–5)	3.10 ± 0.58	3.41 ± 0.59	0.31	[0.27, 0.35]	7.44	0.68	0.53 [0.31, 0.75]
Skill Competence (SRSCC, 10–50)	31.41 ± 5.76	34.92 ± 5.84	3.51	[3.10, 3.92]	8.03	0.67	0.60 [0.38, 0.82]

Note. All comparisons used paired-samples t-tests (two-tailed). Hedges' g_av effect sizes: 0.2 = small, 0.5 = medium, 0.8 = large. 95% CIs computed via bootstrapping (1,000 resamples). r_pair = paired correlation between T0 and T1 scores.

Subgroup analysis revealed that students without prior coursework showed larger gains in knowledge (7.35 points vs. 2.95 points for prior-coursework students, $p = 0.042$), consistent with a ceiling effect in the latter group. However, both subgroups achieved significantly higher scores (all $p < 0.001$).

3.3 Objective Mask Fit Testing Performance

Of 144 students, 118 (81.94%) passed on the first attempt. Twenty-six students (18.06%) initially failed due to improper nosepiece molding (n = 14, 53.8%) or inadequate strap tension (n = 12, 46.2%). After targeted remediation, 21 passed on the second attempt, yielding a cumulative pass rate of 96.53% (n = 139). Five students (3.47%) required alternative respirator models (PAPR) and achieved 100% competency (Supplementary Table S5).

3.4 Three-Month Follow-Up Outcomes (T2)

Supplementary Table S6 presents longitudinal outcomes for the 116 complete cases. Knowledge scores at T2 (66.17 ± 10.69) remained significantly higher than at T0 (61.86 ± 10.73, $p < 0.001$) but showed significant decay from T1 (68.39 ± 10.98, $p < 0.001$). The retention rate (relative to T1 gain) was 66.00%, with a standardized decay score (SDS) of 0.21 (moderate decay relative to baseline variability). Self-efficacy followed a similar pattern: T2 (3.29 ± 0.57) > T0 (3.12 ± 0.58, $p < 0.001$) but < T1 (3.43 ± 0.59, $p < 0.001$), with a retention rate of 54.84% and SDS = 0.24.

Repeated-measures ANOVA revealed significant time effects for both knowledge ($F(2, 230) = 14.63$, partial $\eta^2 = 0.113$, $p < 0.001$, observed power = 0.997) and self-efficacy ($F(2, 230) = 12.18$, partial $\eta^2 = 0.095$, $p < 0.001$, observed power = 0.989) (Fig. 2). As Mauchly's test indicated no significant sphericity violations (knowledge: $W = 0.97$, $p = 0.18$; self-efficacy: $W = 0.98$, $p = 0.31$), uncorrected degrees of freedom were reported. Bonferroni post-hoc tests confirmed all pairwise differences (T0 < T1, T0 < T2, T1 > T2) at $p < 0.001$.

Note

(A) Infection Control Knowledge Test (ICKT) scores and (B) Occupational Infection Prevention Self-Efficacy Scale (OIPSES) scores across three timepoints (T0 = baseline, T1 = immediate post-training, T2 = three-month follow-up) for complete cases (n = 116).

Subgroup analysis showed that students with prior coursework maintained significantly higher knowledge at T2 (71.20 ± 9.85 vs. 65.35 ± 10.62, p = 0.028, g_av = 0.57), although their absolute decay was similar (2.65 vs. 2.22 points, p = 0.64). This supports a cumulative 'layered' educational model where prior training provides a higher plateau but not differential decay resistance.

3.5 Correlates of Behavioral Transfer

Multiple regression analysis (Table 2) examined correlates of T2 behavioral adherence (ICBS). Independent variables were T1 knowledge, T1 self-efficacy, and T2 clinical environment support (CESS). The model explained 15.1% of the variance in behavioral adherence ($R^2 = 0.151$, adjusted $R^2 = 0.128$, $F(3,112) = 6.63$, $p < 0.001$).

Table 2
Correlates of Clinical Behavioral Adherence at Three-Month Follow-Up (n = 116)

Variable	B (SE)	β	95% CI for B	p	VIF
T1 Knowledge (ICKT)	0.09 (0.08)	0.09	[− 0.06, 0.20]	0.314	1.02
T1 Self-Efficacy (OIPSES)	1.37 (1.00)	0.12	[− 0.74, 4.11]	0.176	1.01
T2 Clinical Environment Support (CESS)	0.40 (0.11)	0.31	[0.18, 0.63]	< 0.001	1.01

Note. DV = Infection Control Behavior Scale (ICBS) score at T2 (range 13–65). Model: $R^2 = 0.151$, adjusted $R^2 = 0.128$, $F(3,112) = 6.63$, $p < 0.001$. Collinearity: VIF range 1.01–1.02, tolerance 0.98–0.99. Inter-predictor correlations: knowledge–self-efficacy r = 0.42, knowledge–CESS r = 0.18, self-efficacy–CESS r = 0.22. Diagnostics: Shapiro-Wilk p = 0.18, Breusch-Pagan $\chi^2(1) = 1.84$ (p = 0.17), Durbin-Watson = 1.92. Note: 'Predictors' terminology is replaced with 'Correlates' given the single-arm design precluding causal inference.

Clinical Environment Support (CESS) was the only statistically significant correlate (B = 0.40, SE = 0.11, β = 0.31, t = 3.51, p < 0.001, 95% CI [0.18, 0.63]) (Fig. 3). Neither T1 knowledge (β = 0.09, p = 0.314, 95% CI [− 0.06, 0.20]) nor T1 self-efficacy (β = 0.12, p = 0.176, 95% CI [− 0.74, 4.11]) significantly correlated with behavioral adherence at three months.

Note

Forest plot of multiple linear regression coefficients (unstandardized B with 95% confidence intervals) predicting Infection Control Behavior Scale (ICBS) scores at T2 (n = 116).

Inter-predictor correlations were modest (knowledge–self-efficacy: r = 0.42; knowledge–CESS: r = 0.18; self-efficacy–CESS: r = 0.22; all p < 0.05), confirming the absence of multicollinearity (VIF range 1.01–

1.02, tolerance 0.98–0.99). Regression diagnostics were satisfactory: Shapiro-Wilk p = 0.18 (normality), Breusch-Pagan $\chi^2(1) = 1.84$, p = 0.17 (homoscedasticity), Durbin-Watson = 1.92 (independence).

An alternative model using T1 retrospective CESS (students' anticipated support before internship) yielded nearly identical results ($\beta_{CESS} = 0.29$, p = 0.002), strengthening confidence that the finding is not solely attributable to concurrent measurement bias.

3.6 Occupational Exposure Incidence

During the three-month follow-up, 6 students (5.17% of 116) reported needlestick injuries. All injuries occurred in the first month of internship. All 6 students performed immediate correct local management and completed institutional reporting within 24 hours (100% appropriate response).

This contrasts with historical data from untrained cohorts at the same institution (65% appropriate response, n = 62, 2022 internal quality audit). However, we caution against attributing this difference solely to the ICBC, as the historical comparison is observational and subject to temporal confounding (e.g., post-pandemic infection control awareness may have increased universally between 2022 and 2025). The χ^2 comparison ($\chi^2(1) = 6.72$, p = 0.010) is presented descriptively rather than inferentially.

3.7 Sensitivity Analysis

Multiple imputation (20 datasets) using all outcome and auxiliary variables yielded nearly identical estimates for T2 knowledge (imputed mean: 66.0 ± 10.8 vs. complete-case: 66.2 ± 10.7) and key regression coefficients (β_{CESS}: 0.30 vs. 0.31), supporting the robustness of complete-case findings.

4. Discussion

This study described changes in nursing students' IPC knowledge, self-efficacy, and mask fit competence following a 3.5-hour just-in-time ICBC, and explored correlates of behavioral maintenance at three months. Our findings are consistent with the study hypotheses: (H1) students demonstrated higher scores at T1 across knowledge ($g_{av} = 0.59$), self-efficacy ($g_{av} = 0.53$), and skill competence ($g_{av} = 0.60$), with 96.53% achieving mask fit competency; (H2) substantial decay occurred at three months (SDS = 0.21 for knowledge, 0.24 for self-efficacy); and (H3) clinical environment support showed the strongest association with behavioral adherence ($\beta = 0.31$), whereas post-training knowledge and self-efficacy were not statistically significant correlates.

4.1 Immediate Outcomes Interpretation

The effect sizes observed were moderate. This suggests that a brief, single-session intervention can yield meaningful immediate changes, although effect sizes may be limited by the compressed duration and relatively high baseline scores. The smaller-than-expected gains may reflect the relatively adequate baseline knowledge (61.8%), leaving less room for dramatic improvement, or the challenge of compressing extensive IPC content into 3.5 hours. Notably, students without prior coursework showed

larger gains, supporting the interpretation of a ceiling effect in the subgroup with prior training. These moderate effect sizes are comparable to those reported in simulation-based IPC education meta-analyses (La Cerra et al., 2019; Vangone et al., 2024).

4.2 Decay and Retention

The substantial decay in knowledge (SDS = 0.21, equivalent to 33.9% loss of initial gain) and self-efficacy (SDS = 0.24, 44.1% loss) at three months indicates that a single massed session is insufficient for long-term retention. This aligns with the spacing effect (Cepeda et al., 2006; Pashler et al., 2008) and cognitive load theory (Sweller, 1988), and suggests that booster sessions at 3- or 6-month intervals would be valuable to sustain competence. The standardized decay scores provide a metric for cross-study comparison: our decay rates are comparable to those reported in simulation-based education meta-analyses (SDS range 0.15–0.35 at 3 months; Cook et al., 2013). Research on deliberate practice in simulation education (Knipe et al., 2020) further supports the need for repeated exposure to maintain procedural competencies.

4.3 Environment Support versus Individual Factors

Clinical environment support was the only statistically significant correlate of behavioral adherence at three months, explaining 15.1% of the variance in self-reported behaviors. However, this indicates that the vast majority of variance (84.9%) remains unexplained, suggesting that other factors—such as personality traits, motivation, workload, and peer influence—likely play substantial roles. Neither post-training knowledge nor self-efficacy significantly predicted subsequent practice in this model. This finding aligns with Holton's Transfer of Learning Model (Holton et al., 2000), which posits that learning transfer is influenced by both learner characteristics (ability, motivation) and transfer climate (organizational support, peer norms, opportunity to perform). Our data suggest that even when training is associated with gains in individual capability, the clinical environment appears to play a critical role in facilitating behavioral application.

The unique contribution of CESS ($\beta = 0.31$, $\beta^2 \approx 0.096$) accounted for approximately 9.6% of the total variance, confirming that clinical environment support, while the only significant correlate, still leaves most behavioral variation unexplained — consistent with the multiply determined nature of adherence behavior.

This finding has implications for nursing education policy. Theoretically, this aligns with Normalization Process Theory (May & Finch, 2009), which postulates that new practices can be sustained only when they are in harmony with existing workflows, supported by colleagues, and integrated into routine monitoring. Our data indicate that even students with high-quality training may fail to apply their skills in practice if the clinical setting is deficient in: (a) accessible PPE supplies, (b) visible administrative support for safety protocols, (c) preceptor role-modeling of correct IPC behaviors, and (d) non-punitive reporting systems for exposure incidents. This aligns with prior research on safety culture in nursing education (Bedgood, 2021) and the importance of organizational reinforcement for sustaining newly learned behaviors (Nasiri, 2019).

Practically, this suggests that pre-clinical training should be complemented by concurrent interventions aimed at the clinical environment, including preceptor education on supporting student IPC behaviors, ward-level audits with feedback, and ensuring sufficient resource availability (Alanazi et al., 2023). In the absence of such organizational reinforcement, educational investments may result in limited behavioral outcomes. We outline a 'layered curriculum' model: foundational IPC content in early years (theory), intensive ICBC before internship (skills consolidation), and structured environmental support during internship (transfer facilitation)—consistent with the WHO core competencies framework (Storr et al., 2017) and recent NEPR simulation-based IPC research (Kang et al., 2022).

The 100% appropriate exposure response rate is encouraging. The ICBC's emphasis on automatic response protocols—reinforced through simulation—is consistent with the hypothesis that simulation reinforces procedural memory for the critical moments following a needlestick injury. Given that prompt post-exposure management is time-sensitive, this safety outcome supports the value of the intervention. However, the comparison with historical data (65% from 2022) is observational and potentially confounded by temporal trends; the difference should be interpreted cautiously.

4.4 Implications for Normalization Process Theory

The observed pattern—where competence gains did not translate into sustained adherence without environmental support—illustrates Normalization Process Theory's propositions (May & Finch, 2009; May et al., 2018). NPT posits that practice integration requires four mechanisms: coherence, cognitive participation, collective action, and reflexive monitoring. The ICBC was designed to target coherence and cognitive participation, but collective action and reflexive monitoring depend on workplace conditions beyond individual control. Multi-level interventions addressing both individual competence and organizational structures are needed.

4.5 Limitations

We acknowledge that the single-arm design provides limited evidence for intervention effectiveness, as noted by Spurlock (2018) and Watson (2023). We systematically evaluate five internal validity threats: (1) Testing effects—possible for knowledge (same items at T0/T1/T2), but mask fit testing (objective, performance-based) is insensitive to testing effects; (2) Maturation—unlikely given the 3-hour interval between T0 and T1; (3) History—no concurrent IPC policy changes during the study period; (4) Instrumentation—standardized instruments with consistent administration; (5) Regression to the mean—baseline scores were normally distributed without extreme-value selection. While these mitigations do not eliminate the need for controlled designs, they strengthen confidence that at least some observed changes are unlikely to be purely artifactual.

Additional limitations include: (a) self-reported behavioral adherence at T2 may be subject to social desirability bias; (b) the concurrent measurement of CESS and ICBS at T2 introduces common method bias (Podsakoff et al., 2003), as both are self-reported at the same time point, which precludes definitive causal attribution; although the alternative model using T1 retrospective CESS partially mitigates this concern, it does not eliminate it; (c) the single-site design limits generalizability to other institutions with

different clinical environments; (d) the 19.4% attrition at T2, though handled via multiple imputation, may introduce unmeasured bias if attrition was related to unobserved variables; (e) the sample was predominantly female (87.5%), limiting generalizability to male nursing students; given documented sex differences in facial dimensions affecting respirator fit (Lam et al., 2023), our mask fit pass rate may not be directly transferable to cohorts with different gender compositions. This study did not incorporate sex and gender analysis per SAGER guidelines (Heidari et al., 2016), which we acknowledge as a limitation.

4.6 Future Directions

Future research should employ multi-site randomized trials with extended follow-up (e.g., 12 months) and objective behavioral measures (e.g., direct observation, electronic hand hygiene monitoring) to strengthen causal inference (Watson, 2023). Specifically, studies should evaluate: (a) the optimal timing and content of booster sessions (e.g., 3- vs. 6-month intervals); (b) preceptor training interventions that reinforce student IPC behaviors; and (c) ward-level safety climate improvement strategies. Cost-effectiveness analyses comparing the ICBC model to traditional semester-long courses would inform curriculum decisions, particularly in resource-limited settings. Studies should also incorporate sex and gender analysis per SAGER guidelines (Heidari et al., 2016) to examine whether training effects differ by gender, particularly for mask fit outcomes.

5. Conclusion

A brief, intensive Infection Control Boot Camp (ICBC) delivered during the immediate pre-clinical 'golden window' is associated with moderate immediate gains in nursing students' knowledge and self-efficacy and achieves high rates of objectively verified mask fit competence (96.53%). However, substantial knowledge decay occurs within three months (SDS = 0.21–0.24), and clinical environment support—not training-induced self-efficacy—shows the strongest association with behavioral adherence. This 'just-in-time' model is a feasible component of pre-clinical preparation, but it must be embedded within a broader system of organizational support, ongoing reinforcement, and a positive safety culture to facilitate sustained behavioral change. Nursing educators could adopt a dual-focus approach: building individual competence through targeted training while simultaneously advocating for ward-level environmental supports that enable transfer of learning to clinical practice.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of Peking Union Medical College Hospital (Approval No: I-26ZM0028). All participants provided written informed consent prior to enrollment, with clear explanation that participation would not affect their internship evaluation. An opt-out option was available for the data use of routine training records.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form.

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Author Contribution

YF: Conceptualization, Methodology, Formal analysis, Writing – Original Draft, Funding acquisition. YS, YZ & YW: Investigation, Data curation, Writing – Review & Editing. GW & MX: Resources, Validation. HL & LY: Supervision, Project administration. JH: Conceptualization, Supervision, Writing – Review & Editing, Funding acquisition. All authors read and approved the final manuscript.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request. Due to institutional restrictions on student data sharing, raw individual-level data cannot be deposited in public repositories, but aggregated summary statistics and analysis syntax are available in the supplementary materials.

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Figures

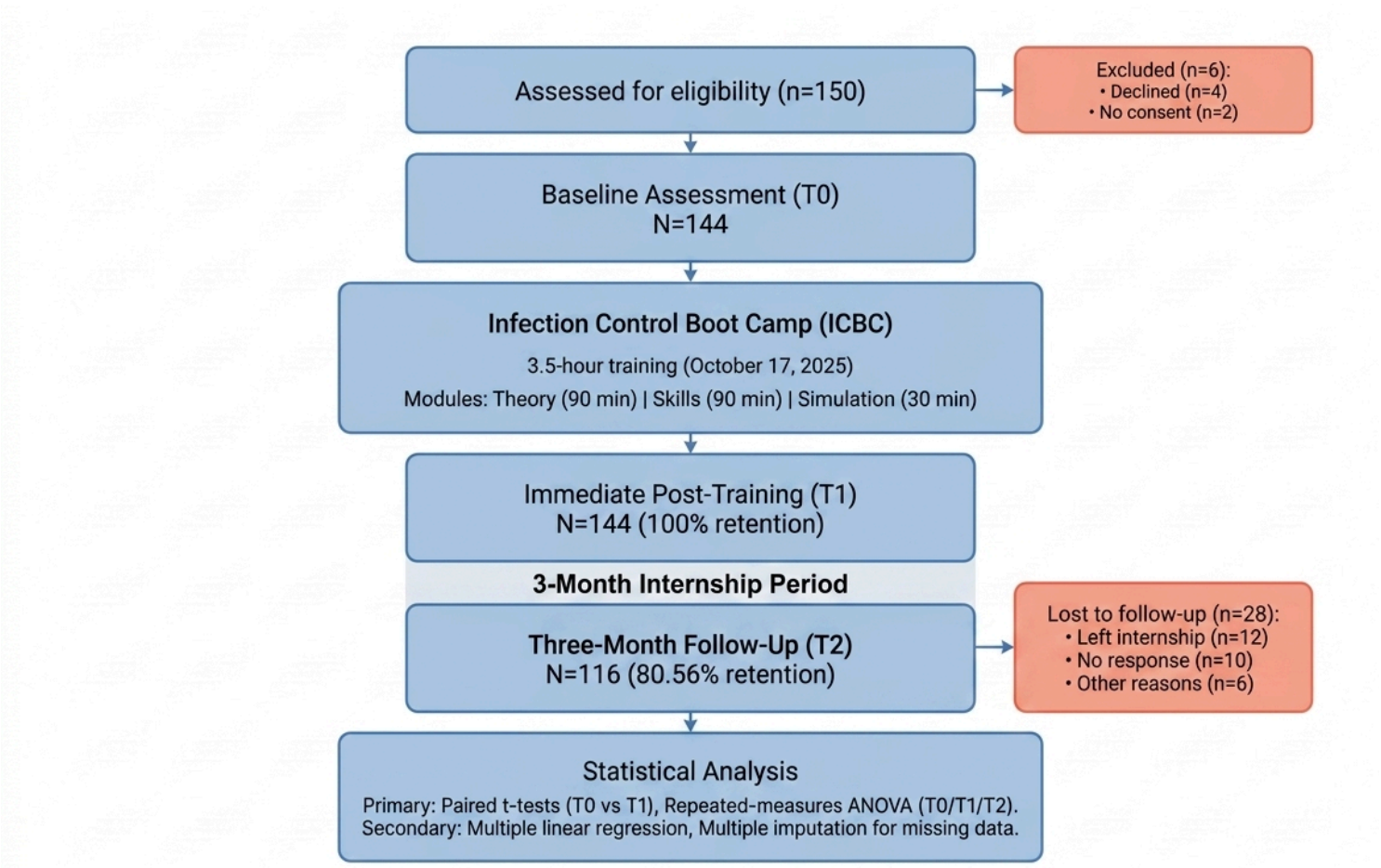


Figure 1

Study Flow Diagram of the Infection Control Boot Camp (ICBC) evaluation.

Note: ICBC = Infection Control Boot Camp; T0 = baseline; T1 = immediate post-training; T2 = three-month follow-up. Missing data at T2 were handled via multiple imputation (20 datasets, MICE algorithm).

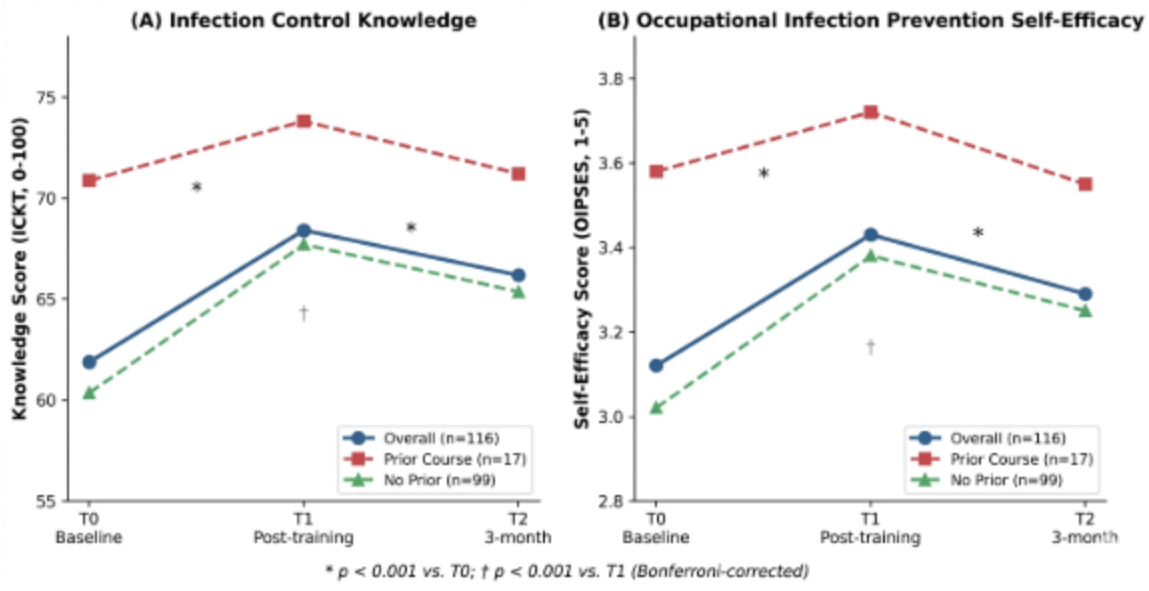


Figure 2

Longitudinal Trends of Knowledge and Self-Efficacy Stratified by Prior Coursework Status

Note: (A) Infection Control Knowledge Test (ICKT) scores and (B) Occupational Infection Prevention Self-Efficacy Scale (OIPSES) scores across three timepoints (T0 = baseline, T1 = immediate post-training, T2 = three-month follow-up) for complete cases (n = 116).

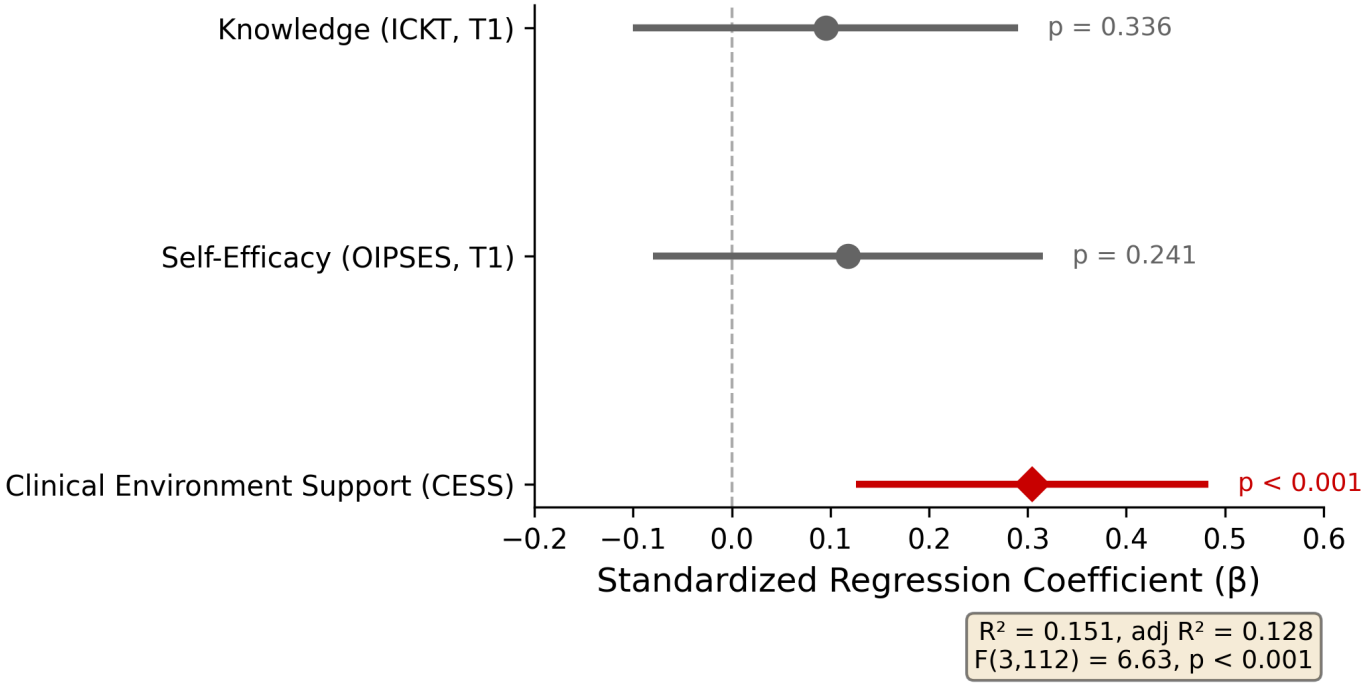


Figure 3

Correlates of Clinical Behavioral Adherence at Three-Month Follow-Up

Note: Forest plot of multiple linear regression coefficients (unstandardized B with 95% confidence intervals) predicting Infection Control Behavior Scale (ICBS) scores at T2 (n = 116).

Supplementary Files

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- 0707SupplementaryMaterials.docx