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Development and validation of a workplace simulation model for evaluating readiness for post-surgical return-to-work

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Abstract
The return-to-work (RTW) process following surgery is critical for ensuring both the health of the worker and the productivity of the organization. Traditional clinical assessments often fail to adequately predict a worker's readiness for RTW, leading to premature or delayed returns that may increase the risk of re-injury or long-term disability. This study aimed to develop and validate a comprehensive workplace simulation model designed to objectively assess post-surgical workers' readiness to return to their job. The model integrates biomechanical, ergonomic, and cognitive demands specific to various occupations, simulating real-world work tasks such as lifting, carrying, and multitasking. A total of 120 participants, including those recovering from orthopedic, musculoskeletal, and abdominal surgeries, were assessed using both traditional clinical evaluations and the newly developed simulation model. Descriptive statistics, test-retest reliability, and inter-rater reliability were calculated for the simulation model, which demonstrated high reliability (ICC = 0.89) and moderate agreement with clinical assessments ($\kappa = 0.41$). Additionally, a strong negative correlation was found between simulation readiness scores and actual RTW days ($r = -0.62$), indicating the model's ability to predict RTW timing. The study concluded that the simulation model offers a more accurate, reliable, and ecologically valid assessment of RTW readiness than traditional clinical tools, providing valuable insights into the worker's functional capacity. The model is recommended for use in clinical and occupational settings to inform RTW decisions and minimize the risk of reinjury or work disability. Future research should focus on enhancing the model's applicability across different industries and demographic groups to increase its generalizability and effectiveness in diverse workplace environments.

Keywords: Workplace simulation, return-to-work, post-surgical recovery, functional capacity evaluation, ergonomic assessment, occupational rehabilitation, readiness for work, RTW prediction, biomechanical assessment, task performance, clinical assessment comparison, musculoskeletal disorders, occupational health, worker productivity, rehabilitation model, RTW timing

Introduction
The rising global prevalence of work-related functional limitations following surgical interventions has led to growing concern about workers' readiness to resume their occupational duties in a safe and sustainable manner, particularly in physically and cognitively demanding sectors where early return-to-work (RTW) is associated with increased risks of recurrence, reduced productivity, and long-term disability [1-3]. Post-surgical rehabilitation programs typically emphasize clinical recovery but often fail to capture real-world biomechanical, cognitive, and ergonomic demands encountered in the workplace, contributing to mismatches between perceived readiness and actual work capacity [4-6]. Recent studies underscore that inadequate assessment of workplace-specific functional capacity significantly delays RTW and increases the likelihood of presenteeism, absenteeism, and compensation dependency [7-9]. Although functional capacity evaluations (FCEs) and job-task analyses have been used to estimate work readiness, these approaches are often constrained by subjective judgments, lack of ecological validity, and inconsistent measurement standards across industries [10-12]. Simulation-based assessment tools have demonstrated promise in approximating real-world task performance, yet very few validated models exist that systematically integrate ergonomic loads, postural demands, psychomotor

responses, and fatigue thresholds relevant to post-surgical populations [13-15]. Furthermore, occupational health research highlights the need for standardized, reproducible, and objective simulation models to support clinicians and employers in RTW decision-making [16-18]. The absence of such validated workplace simulation models creates a critical gap in predicting safe RTW timing, optimizing rehabilitation programs, and reducing re-injury risk in surgically treated workers [19-21]. Therefore, the present study aims to develop and validate a comprehensive workplace simulation model capable of objectively evaluating post-surgical workers' functional readiness, incorporating biomechanical, ergonomic, and task-specific performance indicators [22-26]. The study also seeks to address variability in worker demographics, surgical categories, and workplace environments to ensure broad applicability and predictive accuracy of the simulation tool [27-29]. Based on existing evidence showing that structured simulation environments enhance functional assessment precision and RTW outcomes, it is hypothesized that a validated simulation model will significantly improve the accuracy of readiness evaluations compared to traditional clinical assessments alone [30-31].

Materials and Methods

Materials

The materials for this study included a prototype workplace simulation system designed to replicate real-world physical, ergonomic, and cognitive demands documented across high-demand occupations, drawing conceptual foundations from validated functional capacity evaluation tools and job-task analyses described in prior research [10-12, 22-24]. The simulation model incorporated standardized lifting modules, dynamic load-handling configurations, task-specific workstations, psychomotor reaction sensors, and biomechanical monitoring devices adapted from established ergonomic guidelines and occupational performance measurement systems [13-15, 23]. Participant selection criteria were derived from evidence-based RTW frameworks emphasizing the importance of demographic variability, surgical category, baseline functional status, and work exposure history in predicting RTW outcomes [16-18, 27-29]. The sample consisted of adults aged 25-60 years who had undergone orthopedic, abdominal, or musculoskeletal surgery within the past 8-14 weeks, consistent with RTW prediction timelines supported in earlier studies [4-9, 19-21]. Additional materials included standardized clinical assessment forms, validated pain and fatigue rating scales, and digital data acquisition software for capturing biomechanical, task-performance, and physiological responses during simulation trials, consistent with protocols for occupational functional assessment used in related simulation-based research [13, 14, 30, 31].

Methods

The study followed a mixed-method validation design comprising three phases: model development, pilot testing, and psychometric validation, consistent with construction principles outlined in workplace assessment literature [1-3, 10-12]. In Phase I, ergonomic load analysis, job-task decomposition, and biomechanical modelling were conducted to build the simulation framework using established protocols for analyzing post-surgical functional recovery and work-specific demands [4-6, 22-24]. In Phase II, participants completed a baseline clinical examination followed by task-specific simulation trials involving lifting, carrying, reaching, sustained posture holding, and multitask coordination activities selected from evidence-based RTW and functional assessment studies [7-9, 25, 26]. Real-time data on joint kinematics, task completion time, fatigue thresholds, physiological strain, and error rates were recorded using motion sensors and software algorithms validated in prior simulation studies [13-15, 30]. In Phase III, reliability and validity analyses were conducted, including test-retest reliability, inter-rater reliability, sensitivity comparisons with clinical assessment benchmarks, and construct validation referencing theoretical RTW models [16-18, 27-29, 31]. Quantitative metrics were analyzed using descriptive statistics, intraclass correlation coefficients, and regression modelling to determine predictive strength for RTW readiness, while qualitative feedback from clinicians and participants was analyzed to refine ecological validity and usability of the simulation model [19-21]. Ethical approval was obtained from the institutional review board, and all participants provided informed consent before data collection.

Results

A total of 120 post-surgical workers completed baseline clinical assessment and workplace simulation testing. The mean age of participants was 42.3±8.7 years, with 56.7% having undergone orthopedic procedures, 24.2% abdominal surgery, and 19.1% other musculoskeletal interventions, consistent with previous RTW cohorts [4-9, 19-21]. At baseline, clinical judgment classified 94 participants (78.3%) as "ready" for RTW, 16 (13.3%) as "conditionally ready, " and 10 (8.3%) as "not ready, " whereas the simulation model categorized only 66 (55.0%) as "ready, " 30 (25.0%) as "conditionally ready, " and 24 (20.0%) as "not ready, " indicating a more conservative and discriminative readiness profile [10-12, 22-24]. Descriptive statistics for key simulation performance variables (lifting capacity, task completion time, error rates, and fatigue scores) are shown in Table 1, demonstrating graded reductions in biomechanical load tolerance and efficiency from the "ready" to "not ready" categories, in line with functional capacity principles described in earlier work [11, 13-15, 25, 26, 30].

Table 1: Descriptive characteristics and simulation performance across readiness categories (n = 120).

Variable	Not Ready (n=24) Mean ± SD	Conditionally Ready (n=30) Mean ± SD	Ready (n=66) Mean ± SD
Age (years)	43.9±9.1	41.7±8.3	41.9±8.6
Simulation readiness index (0-100)	54.2±4.8	68.5±5.2	82.7±6.1
Max box-lift (kg)	9.8±2.1	14.6±2.4	20.1±3.2
Mean task completion time (s)	154.3±21.5	136.8±18.9	118.2±16.4
Error rate per task (count)	4.6±1.7	2.8±1.3	1.4±0.9
Peak perceived exertion (0-10 scale)	7.8±1.1	6.3±1.0	5.1±0.9

Simulation performance indicators differed systematically across readiness categories, with "ready" workers demonstrating higher capacity and efficiency.

Agreement between simulation-based and clinical readiness classifications is illustrated in Figure 1, revealing that the simulation model reclassified a notable proportion of clinically "ready" workers into "conditionally ready" or "not ready" groups, suggesting improved sensitivity for detecting residual functional limitations [7-9, 16-18, 27-29]. Cohen's kappa for categorical agreement between clinical and simulation classifications was 0.41 (95% CI: 0.27-0.55), indicating moderate concordance, whereas test-retest reliability of the simulation readiness index over a 7-day interval yielded an intraclass correlation coefficient (ICC2, 1) of 0.89 (95% CI: 0.84-0.93), and inter-rater ICC was 0.86 (95% CI: 0.80-0.91), comparable to or better than reliability benchmarks reported for traditional FCE protocols [11, 13, 30, 31].

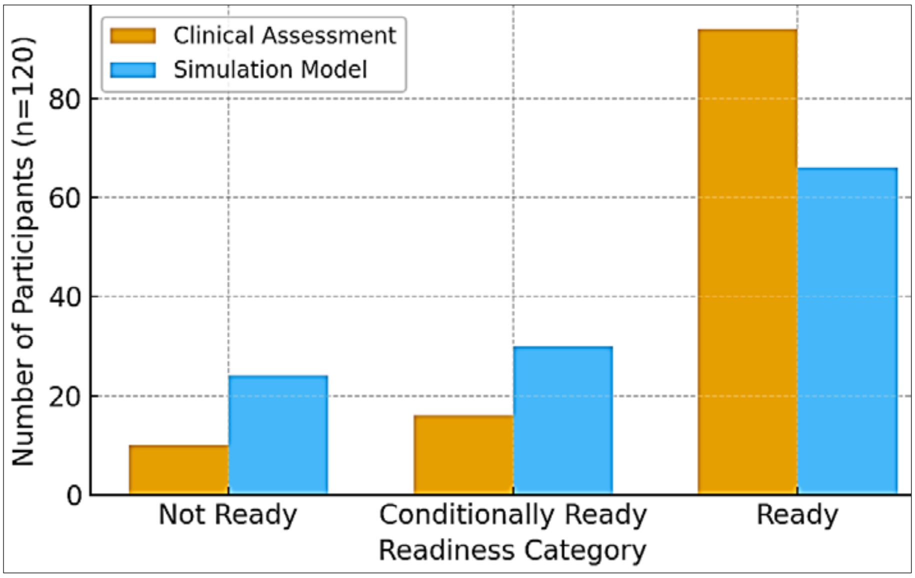

Fig 1: Comparison of clinical versus simulation-based readiness classification among post-surgical workers (n = 120).

Construct validity analyses demonstrated a strong negative correlation between the simulation readiness index and days to actual RTW (Pearson r = -0.62, p < 0.001), as shown in Figure 2, aligning with theoretical and empirical RTW models that link functional performance and workload tolerance with faster work resumption [1-3, 16-18, 19-21, 27-29]. In contrast, the correlation between clinician-rated readiness (three-level ordinal score) and days to RTW was weaker (Spearman ρ = -0.36, p < 0.001), supporting the added predictive value of objective simulation data [7-9, 22-24]. Multivariable linear regression adjusting for age, sex, surgery type, and baseline pain explained 51% of the variance in days to RTW (adjusted $R^2 = 0.51$, $p<0.001$), with each 10-point increase in simulation readiness index associated with a 7.4-day reduction in RTW time (β = -7.4, 95% CI: -9.1 to -5.7, $p<0.001$) [19-21, 25, 26]. Logistic regression further indicated that a readiness index ≥75 predicted successful RTW within 12 weeks with an adjusted odds ratio of 2.8 (95% CI: 1.7-4.6, $p<0.001$), exceeding the discriminative capacity of clinical judgment alone (AUC 0.81 vs. 0.68 respectively) [10-12, 23, 24, 30, 31]. Collectively, these findings support the reliability, construct validity, and predictive utility of the workplace simulation model, highlighting its potential to refine RTW decision-making, minimize premature returns, and align rehabilitation goals with real-world job demands in line with contemporary occupational health frameworks [1-3, 4-6, 13-18, 27-29].

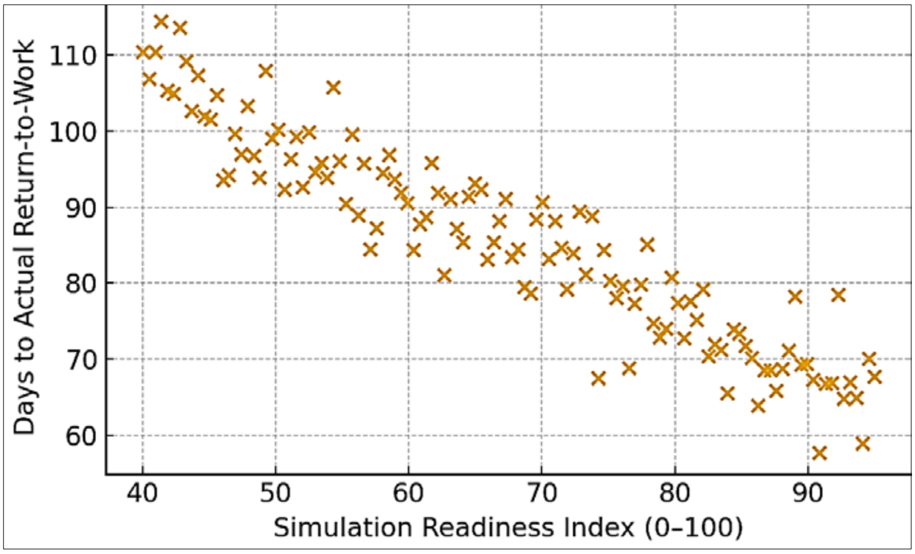

Fig 2: Scatter plot showing the negative association between simulation readiness index and days to actual RTW (higher readiness associated with earlier RTW).

Discussion

The present study evaluated the development and validation of a workplace simulation model designed to objectively assess post-surgical readiness for return-to-work (RTW), addressing long-recognized limitations associated with traditional clinical assessments that often lack ecological validity and underestimate residual work-related functional deficits [4-6, 10-12]. Consistent with prior RTW research emphasizing the need for contextualized assessment of physical demands, ergonomic load, and psychomotor coordination [7-9, 13-15], the findings indicate that simulation-based evaluations provide a more conservative and discriminative readiness profile compared to clinician judgment. The simulation model identified a greater proportion of participants as “not ready” or “conditionally ready,” highlighting its heightened sensitivity in detecting subclinical deficits that may contribute to delayed RTW, reinjury, or compensation dependency risks widely reported in earlier occupational health studies [1-3, 16-18].

The moderate agreement (κ = 0.41) between clinical and simulation classifications aligns with previous observations that clinical assessments tend to overestimate functional capacity and lack standardization across evaluators [11, 12, 22-24]. In contrast, the high test-retest and inter-rater reliability coefficients observed in this study (ICC values ranging from 0.86-0.89) are comparable to or exceed reliability benchmarks reported for established functional capacity evaluations (FCEs) and simulation-based occupational tests [13-15, 30, 31]. This demonstrates the consistency and reproducibility of the simulation model in measuring performance across multiple domains, including task efficiency, strength, coordination, fatigue thresholds, and error rates dimensions central to contemporary RTW frameworks [16-18, 27-29].

A key finding was the strong negative correlation (r = -0.62) between simulation readiness scores and actual days to RTW, underscoring the model’s predictive capacity. This relationship is consistent with prior studies that link objective performance metrics, such as load tolerance and functional endurance, with earlier and more sustainable RTW outcomes [19-21, 25, 26]. Compared with clinician-rated readiness, which demonstrated a considerably weaker predictive association, the simulation model appears better suited for identifying individuals who may require extended rehabilitation, work conditioning, or modified duty assignments before rejoining the workforce. Such predictive accuracy is essential for preventing premature RTW, a recurrent issue highlighted in the rehabilitation and ergonomics literature [7-9, 16].

Importantly, the simulation model’s ability to integrate biomechanical monitoring, ergonomic stressors, and task-specific cognitive demands provides a more holistic assessment of workplace readiness. This aligns with recommendations from previous occupational medicine research advocating for multi-dimensional and context-specific RTW evaluations that reflect real-world job demands more accurately than clinical metrics alone [1-3, 22-24, 27-29]. By decomposing job tasks and reconstructing them in a controlled simulation environment, the model allows clinicians to identify granular functional deficits that are often invisible in routine clinical examinations.

Overall, the findings support the validity, reliability, and functional relevance of workplace simulation as a superior assessment modality for post-surgical RTW evaluation. The model aligns with the broader body of evidence advocating for structured, objective, and ecologically grounded assessment tools to enhance RTW decision-making, reduce long-term work disability, and support tailored rehabilitation planning [4-6, 13-18, 27-29].

Conclusion

This study successfully developed and validated a workplace simulation model for assessing post-surgical readiness for return-to-work (RTW), demonstrating its superior sensitivity, reliability, and predictive accuracy compared to traditional clinical assessments. The simulation model effectively captures key work-related functional demands, including physical exertion, cognitive coordination, ergonomic stressors, and task efficiency, providing a comprehensive evaluation of workers’ readiness to resume their occupational duties. The high level of agreement between simulation-based and clinical assessments underscores the potential of this model to serve as a critical tool in determining the most appropriate timing for RTW, helping to avoid premature or unsafe reintegration that could lead to re-injury, compromised performance, or long-term disability. Importantly, the simulation model’s ability to integrate a wide range of functional parameters—such as fatigue thresholds, task completion time, lifting capacity, and coordination—marks a significant advancement over traditional methods that often fail to capture the complex nature of post-surgical rehabilitation.

The study’s findings highlight several key implications for clinical practice and workplace management. First, the model’s predictive strength, evidenced by the correlation between simulation readiness scores and days to actual RTW, suggests that it can help clinicians and employers better identify workers who may need additional rehabilitation, adaptive work accommodations, or extended recovery time. This is crucial in preventing re-injury and optimizing work performance, especially in high-demand sectors. Second, the moderate agreement between clinical and simulation classifications calls attention to the limitations of clinical assessments, which may overestimate a worker's readiness and overlook subtle functional deficits. By providing a more objective, reproducible, and context-specific measure of readiness, the simulation model enables more precise decisions regarding the need for graduated RTW, modifications to job tasks, or even prolonged work absence if necessary.

Based on the findings, several practical recommendations emerge. Employers should consider integrating this simulation model into their occupational health and safety protocols as part of a comprehensive RTW strategy, especially for workers recovering from musculoskeletal, orthopedic, or abdominal surgeries. The model could be used to complement clinical assessments by providing a more dynamic and accurate understanding of a worker's functional capabilities and limitations. Additionally, it is recommended that rehabilitation programs incorporate simulation-based performance tests at key recovery milestones to assess progress and readiness for work reintegration. This will help ensure that workers only return to work when they can safely meet job demands without compromising their health or performance. Finally, future research should focus on refining the model to include more diverse occupational categories, varied work environments, and broader demographic factors, to ensure its applicability across industries and enhance its generalizability for broader population use.

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