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Effectiveness of a Theory-Driven mHealth Intervention in Promoting Post-Surgery Rehabilitation Adherence in Patients Who Had Anterior Cruciate Ligament Reconstruction: A Randomized Clinical Trial

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Highlights

- This study examined the effects of a mHealth intervention on the recovery of patients with an ACL rupture.
- The smartphone application prevented further decline of orthopedic outpatients' motivation and adherence to treatment.
- The smartphone application fell short in promoting recovery.

Abstract

Rationale: Patients with anterior cruciate ligament (ACL) reconstruction often have poor adherence to post-surgery rehabilitation.

Objective: This study applied the integrated model of self-determination theory and the theory of planned behavior to examine the effects of a smartphone-delivered intervention on the recovery outcomes of patients with an ACL rupture during post-surgery rehabilitation period. Additionally, we explored the effects of the intervention on participants with different beliefs toward rehabilitation at baseline.

Method: The randomized control trial recruited 96 eligible participants (M_{age} = 27.82, *SD* = 8.73; female = 39%) who underwent ACL reconstruction surgery. Participants were randomly assigned to an intervention group (*n* = 41), which received standard post-surgical treatment (usual-care) and smartphone application ("ACL-Well"), or a usual-care control group (*n* = 55). The primary outcomes were recovery outcomes from ACL surgery measured by knee muscle strength and laxity, and subjective knee evaluation completed 4-month post-intervention. Secondary outcomes were the psychological and behavioral outcomes measured at baseline, at 2- and 4-month post-intervention.

Results: ANCOVA indicated no significant between-group differences in primary outcomes: knee muscle strength, knee laxity and subjective knee evaluation, $F(1, 27 \text{ to } 55) = 0.01$ to 1.36, $p = .25$ to .99, $\eta 2 = .01$ to .03. For the secondary outcomes, growth mixture modelling revealed self-determined treatment motivation declined significantly over the intervention period in the control group (*M* slope = -.39 to -.12, *p* =.01 to .04), but not in the intervention group (*M* slope = -.19 to -.08, *p* = .06 to .38).

Conclusions: The smartphone application fell short in promoting orthopedic outpatients'

recovery outcomes. Yet, it shows some promises as a mean to maintain patients' motivation and adherence to treatment.
Keywords: mHealth; Integrated model; Motivation; Social cognition beliefs; Treatment adherence, ACL; Self-determination theory; Theory of planned behavior

After the reconstruction surgeries of anterior cruciate ligaments (ACL), patients are typically prescribed extensive self-administered home-based rehabilitation (e.g., strength and flexibility training) for six to twelve months. Adherence to rehabilitation during this long treatment period is associated with better recovery outcomes, but is often problematic as rates of non-adherence can reach 70% (Essery et al., 2017). The development of efficacious interventions that promote patients' rehabilitation adherence is therefore warranted and likely to have a substantive impact on recovery rates. Hence, this study aims to examine the effectiveness of a theory-driven mHealth intervention in promoting post-surgery rehabilitation for patients who ruptured and reconstructed their anterior cruciate ligaments (ACL).

Our proposed intervention comprised a smartphone application, "ACL-Well", and incorporated content targeting change in constructs from an integrated theoretical model (Hagger & Chatzisarantis, 2009). The model is based on two prominent theories of motivation from psychology and behavioral science: self-determination theory (Deci & Ryan, 1985) and the theory of planned behavior (Ajzen, 1991). A key prediction of the model is that long-term behavioral adherence and adaptive health/ recovery outcomes occur more likely when individuals possess high self-determined motivation (i.e., a motivational pattern characterized by a pattern of high autonomous motivation and low controlled motivation), positive attitudes (instrumental and affective evaluations of the behavior), positive subjective norms (perceived social appropriateness of the behavior), positive perceived behavioral control (PBC; perceived capacity to perform the behavior), and high intention of performing the behavior (Hagger & Chatzisarantis, 2009; Teixeira et al., 2020). The integrated model provides a comprehensive explanation on the determinants of rehabilitation adherence and the process involved (Hagger & Chatzisarantis, 2009), and the psychological pathways of the model have been supported by empirical evidence in the context of rehabilitation from ACL surgery (Chan et al., 2017; Lee et al., 2020). Intervention studies have independently applied the behavior change strategies of SDT (e.g., the provision of clear rationale and meanings of following the treatment) and TPB (e.g., promoting the benefits of engaging in the behaviors) to facilitate adaptive behavioral patterns in various health contexts, including weight management (LaRose et al., 2022), physical activities (Ha et al., 2018), and HIV/AIDS prevention (Siuki et al., 2019). As far as we know, there have not been any theory-driven interventions that applied either the concepts of SDT, TPB, or an integration of both theories to enhance patients' adherence to post-surgery rehabilitation. Using the integrated model to develop a mHealth intervention to facilitate patients' adherence to post-surgery rehabilitation would offer novel insights valuable to research and practice.

In this study, we aim to apply this integrated model to develop a mobile phone app, "ACL-Well", to promote better post-surgery recovery outcomes among ACL surgery patients. Using a 4-month randomized controlled design, we examined the efficacy of the app on patients' post-surgery recovery outcomes, rehabilitation adherence, and changes in the psychological constructs from the integrated model. We also explored the effects of the app on participants with different beliefs toward rehabilitation at baseline. It is hypothesized that:

(H1) The intervention group would have better recovery outcomes (i.e., knee muscle strength, knee laxity and subjective knee evaluation) compared to the control group at follow-up.

(H2) The control group who received 'usual care' post-intervention and did not receive the "ACL-Well" app would have significant declines in the behavioral and psychological outcomes (i.e., rehabilitation adherence and psychological factors of the integrated model).

(H3) The intervention group who received the app would have no significant declines in the behavioral and psychological outcomes.

Method

Participant

The study is a registered clinical trial (HKUCTR-2761) which received ethical approval from the Institutional Review Board of the first author's institution [Blinded for review]. Patients who had ACL reconstruction (*N* = 124) were recruited to the study from the orthopedic clinic of a major public hospital in Hong Kong. Patients were recruited during their first post-operation hospital consultation after discharge. Patients were eligible for inclusion in the study if they: (1) were adults aged between 18 and 60 years, (2) had received ACL reconstruction surgery in the previous 2 weeks, and (3) were regular smartphone users. The clinic specialists referred eligible patients to the lead researcher, who provided them with a written information sheet regarding the study and the opportunity to participate. Patients were recruited between August 15, 2017, and August 31, 2018, with follow-up data collection completed on January 4, 2019. A statistical power analysis specifies a power level of 80%, an alpha level of .05, and a medium-to-large effect size of .32 (Sonnery-Cottet et al., 2019), indicating a minimum sample size of 78 patients was needed to find effects in ANOVA. Assuming an attrition rate of 20%, we determined at least 94 participants needed to be recruited for the study. Finally, 96 eligible participants (M_{age} = 27.82, *SD* = 8.73, range = 18 to 53; female = 39%) provided informed consent. All the participants were Chinese from Hong Kong. On average, participants ruptured their ACL 8.91 (*SD* = 15.75) months before baseline assessment and 46% of participants also suffered from meniscus injuries. The participants' flow diagram is presented in Figure 1.

Study Design and Procedures

The study adopted a 4-month randomized controlled design using surveys and clinical assessments. Data were collected in three waves of assessment, at baseline and 2- and 4-month follow-up, by a project team member. Participants completed self-report measures of study variables, including rehabilitation adherence and constructs from the integrated model at baseline, 2-month, and 4-month in-person in the clinic. Clinical assessments of the participant's knee muscle strength, knee laxity, and subjective knee evaluation were completed at 4-month. These assessments were performed only at the 4-month follow-up because, at baseline and 2-month post-surgery, most patients could not perform these tests, as they involved contraindicated movements. After the baseline assessment, participants were randomly assigned to the intervention (n = 41) or control (n = 55) group using a computer ballot by an independent research assistant. Both groups received standard rehabilitation programs the hospital physiotherapists and orthopedic surgeons prescribed. The standard rehabilitation program included cryotherapy, mobilization exercise, stretching exercises, magnetotherapy, neuromuscular electrical stimulation, hydrotherapy, balance exercises, isokinetic and isotonic strengthening exercises, jumping exercises, proprioceptive training, functional training, and home exercises (Fu et al., 2013). The participants from the intervention group received the smartphone app ("ACL-Well") that delivered the behavioral intervention after the baseline assessment. A project team member provided instructions and assistance to the participants on the app's installation, usage, and specific settings (e.g., daily notifications/ reminders). Detailed intervention instructions and procedures for the smartphone app were provided in Appendix I.

mHealth Intervention

The "ACL-Well" smartphone app used to deliver the intervention was developed based on previous research using the integrated model (Chan et al., 2009; Lee et al., 2020), and research applying its component theories (Ajzen, 1991; Deci & Ryan, 1985). The app provided patients with text, pictorial, and video demonstrations, which outlined how their prescribed post-surgery home-based rehabilitation exercises should be done. The app could also send daily notifications to remind and encourage patients to complete the rehabilitation exercises. It also highlighted the benefits of adhering rehabilitation program and listed possible scenarios in which participants might encounter during their rehabilitation period with suggested solutions. The screenshots of the "AC-Well" app are displayed in Appendix II. The educational materials in the "ACL-Well" app adopted behavior change techniques proposed to affect change in the behavioral determinants identified in the integrated model and its component theories (Hagger & Chatzisarantis, 2009; Teixeira et al., 2020). Descriptions of the behavior change techniques were operationalized using the Coventry, Aberdeen, and London – Refined (CALO-RE) taxonomy of behavior change techniques (Hagger et al., 2014). Appendix III summarizes the specific behavior change techniques used in the "ACL-Well" app.

Outcomes

Primary outcomes. We adopted two clinical measures and one subjective measure of our primary outcome variable, participants' recovery progress. For *knee muscle strength*, we measured patients' quadriceps and hamstring muscle strength, common indicators of knee function for patients with ACL rupture, using a biodex isokinetic dynamometer (Multi-Joint System 4 Pro, Biodex) following a standardized protocol (Cvjetkovic et al., 2015). We computed the limb symmetry index (LSI) using the formula, ([involved limb/uninvolved limb] x 100) for each participant. An LSI closer to 100 means the muscle strengths of both legs are more symmetrical, which reflects better recovery of the patient's knee strength. For *knee laxity*, we measured the average side-to-side difference between the involved and uninvolved legs in two measurements of passive drawer test at 133 N using KT-1000 knee ligament arthrometer (MEDmedtric, San Diego, California) (Bowerman et al., 2006). Good recovery progress was indicated by a side-to-side knee laxity difference smaller than 3mm. For *subjective knee evaluation*, we used the Chinese version of the International Knee Documentation Committee subjective knee evaluation form (IKDC; Collins et al., 2011). Following the scoring system, each participant received a score ranging from 0 to 100, with higher scores referring to the absence of symptoms or no limitations in daily or sporting activities.

Secondary outcomes. Our psychological and behavioural outcomes included rehabilitation adherence (Self-Reported Injury Rehabilitation Adherence Scale; Chan et al., 2009; Lee et al., 2020), and injury rehabilitation version of the Treatment Self-Regulation Questionnaire (TSRQ; Levesque et al., 2006), and social cognition (i.e., injury rehabilitation version of TPB scale; Lee et al., 2020). Details of the secondary measures can be found in Appendix IV.

Data Analysis

For the primary outcome measures (i.e., knee muscle strength, knee laxity, and subjective knee evaluation), we used one-way ANCOVAs implemented in SPSS v. 25 to examine differences on each measure across the intervention and control groups at follow-up. Age, sex, months of post-ACL-rupture, and meniscus injury were covariates in each model. The intervention effects were examined by the bootstrapping procedure (1,000 times), providing 95% confidence intervals.

For the secondary outcomes, we conducted seven sets of growth mixture models (Muthén & Muthén, 2017) following intent-to-treat principles, respectively for the psychological and behavioral outcomes. The classes would be categorized based on participants' baseline scores. For example, a high and low class would refer to having higher and lower baseline scores for each study variable, respectively. This analytic strategy enabled us to examine our hypotheses in heterogeneous groups of individuals with varied psychological characteristics and behavioral patterns (Muthén & Muthén, 2017). H2 and H3 would be supported if significant negative slopes for self-determined treatment motivation, social cognition, intention and rehabilitation adherence were observed in the control group (H2) but not in the intervention group (H3). All models were estimated using the Mplus 7.1 statistical software using the robust maximum likelihood estimator (Muthén & Muthén, 2017). Missing data were imputed using the full-information maximum likelihood method (Muthén & Muthén, 2017). Data files, analysis scripts, and outputs for this study are available online. Detailed analytical procedures for growth mixture modelling are presented in Appendix V.

Results

Preliminary analyses and descriptive statistics, zero-order correlation, reliability estimates, skewness and kurtosis are presented in Appendix VI.

Intervention Effects: Primary Outcomes

For muscle strength, ANCOVAs reported no significant main effect of the intervention on all four LSIs ($F(1, 42) = 0.01$ to 1.36, $p = .25$ to .96), knee laxity ($F(1, 27) = 0.01$, $p = .96$), and subjective knee evaluation ($F(1, 55) = 0.03$, $p = .85$). Therefore, findings did not support H1, and the recovery outcomes of the intervention group were not significantly better than the control group. ANCOVA results and descriptive statistics for the primary outcome measures are summarized in Table 1. The results of sensitivity analyses for missing data and covariates are presented in Appendix VII.

Intervention Effects: Secondary Outcomes

We explored the intervention effects on the secondary outcomes using growth mixture models. A two-class solution indicated sub-groups of high-class and low-class in rehabilitation adherence. In support of H2, significant negative mean slopes were present in the high-class and low-class solutions for the control group. H3 was partially supported because no significant negative mean slope was reported in the low-class for the intervention group (*M* slope = .04, $p = .78$), but the mean slope of the high-class for the intervention group was negative and significant (mean slope = -.50 to -.15, *p* =.01 to .04).

A two-class solution comprising high-class and low-class of self-determined treatment motivation was formed. Both high-class and low-class revealed consistent findings in support of H2 and H3. In particular, negative mean slopes were significant in the control group (*M* slope = -.39 to -.12, *p* = .01 to .04) but not in the intervention group (*M* slope = -.19 to -.08, *p* = .06 to .38).

For social cognition, a single-class solution displayed the best fit indices. Both intervention and control groups showed negative mean slopes (*M* slope = -.12 to -.07, *p* = .01 to .04). The results supported H2, but not H3. A two-class solution was formed for intention. H2 was partially supported as a significant negative mean slope was reported in the high-class group for the control group (*M* slope = -.16, $p < .001$), but not in the low-class group for the control group (*M* slope = .12, $p = .18$). Similarly, H3 was partially supported no significant negative mean slope was found in the low-class of the intervention group (mean slope = .26, p = .02), but surprisingly a significant means slope was found in the high-class group for the intervention group (M slope = -.19, p < .001).

Class solutions, model fit indices, and estimates of the growth trajectories from the linear growth mixed models are presented in Appendix VIII.

Discussion

This study tested the efficacy of a theory-based mHealth intervention delivered using the "ACL-Well" app in promoting post-intervention recovery, rehabilitation adherence, and change in social cognition constructs and motivation in ACL-surgery patients. Results indicated no significant between-group differences in knee muscle strength, knee laxity, and subjective knee evaluation, contradicting H1. The control group exhibited significant declines throughout the intervention in rehabilitation adherence, self-determined motivation, and social cognition, but not in intention. To a large extent, H2 was supported. The intervention group had no significant declines in self-determined treatment motivation and rehabilitation adherence and intention in patients with lower levels of motivational and behavioral factors at baseline, supporting H3. However, H3 was not supported for the social cognition constructs, as both the intervention and control groups reported significant declines in these constructs.

Intervention Effects on Primary Outcomes

Our objective (i.e., knee muscle strength and knee laxity) and subjective assessments (i.e., subjective knee evaluation) regarding the recovery outcomes did not provide any supportive evidence for our intervention. One possibility is that intervention effects may be subject to several possible moderator variables. For example, the clinical outcomes of patients' recovery progress may vary across individuals, type of rehabilitation, type of surgery, severity of ACL rupture, and type of clinical outcomes. Systematic reviews and meta-analyses have shown that the impact of rehabilitation adherence on clinical outcomes is relatively inconsistent and indeterminate across studies. For example, recovery outcomes of patients may vary across different types of rehabilitation exercise (Zaffagnini et al., 2015), so the types of exercises that patients adopt during the rehabilitation program might have introduced additional error variance in the effects of the intervention on clinical outcomes. This is plausible because orthopedic surgeons and physiotherapists tailor the type and intensity of the rehabilitation exercises they prescribe to patients, which may have affected adherence independent of the intervention (Zaffagnini et al., 2015). On a different note, the lack of significance of the intervention effects on the clinical outcomes might be due to a relatively short follow-up (i.e., 4 months post-surgery) in our study. During the first four months post-surgery, the intensity of the rehabilitation exercises (including those in the "ACL-Well") for patients with ACL reconstruction surgery were generally relatively mild (Roi et al., 2006; Shaw, 2002), and so the variance of the clinical outcomes might be less dependent on rehabilitation adherence and other psychological factors of ACL-patients' rehabilitation. Therefore, a longer follow-up may be able to detect the growth trajectories of the recovery progress when patients are ready to pick up more intensive rehabilitation exercises, and their recovery would be more responsive to the effort and frequency of their rehabilitation.

Intervention Effects on Secondary Outcomes

According to the exploration analyses on secondary outcomes, the intervention was effective in maintaining self-reported rehabilitation adherence, but only among patients with lower rehabilitation adherence at baseline. The corresponding intervention effect on patients with higher initial rehabilitation adherence was not statistically significant. The effect of the intervention on orthopedic patients' rehabilitation adherence seems to depend on patients' initial rehabilitation adherence after ACL surgery. These findings are consistent with previous intervention research demonstrating that prior adherence is an important consideration when evaluating the effects of behavior change interventions (Evers et al., 2012). This implies that the intervention is beneficial to prevent further decline of rehabilitation adherence among patients who experience difficulties performing their rehabilitation.

Few interventions based on behavioral theory have been applied to promote behavior change in ACL-patients' recovery and adherence, and even fewer have utilized mHealth techniques to deliver the intervention to patients with ACL rupture. Consequently, the current research adds value to the literature by demonstrating the development of a theory-based intervention using a smartphone app and its efficacy in preventing the decline of adherence and motivation to rehabilitation. The mHealth intervention maintained patients' self-determined treatment motivation, characterized by high autonomous and low controlled motivation. In this study, behavioral strategies for promoting self-determined motivation included providing meaningful rationales for rehabilitation, acknowledging patients' perspectives and providing support and encouragement. The effectiveness of these behavioral strategies derived from SDT has been evidenced in other health settings (Teixeira et al., 2020), and we have now extended their applications in a clinical setting among orthopaedic patients. The results support using the "ACL-Well" app and smartphone delivery in maintaining self-determined treatment motivation among orthopaedic patients during their rehabilitation period.

Despite the supportive findings of self-determined motivation and rehabilitation adherence, the intervention effects on patients' social cognition variables were inconsistent. There were no statistically significant effects of the intervention on post-intervention social cognition constructs, and intention. One possible reason for this finding was that the behavioral strategies we applied within this mHealth intervention in relation to some of the TPB variables (e.g., provision of information about others' approval for subjective norms) were not well suited to this clinical setting. Existing interventions that have applied the concepts of TPB were shown to be effective but these interventions were primarily conducted in non-clinical settings and preventive settings (Tyson et al., 2014), which may be different from the setting and sample of our study.

Study Limitations and Future Directions

This research has several conceptual and methodological shortcomings. First, self-report measures were the current study's primary assessment type. Participants' responses to these measures may be influenced by self-serving bias, consistency tendency, and other methodological artifacts (Chan et al., 2020). Future studies should consider using non-self-report measures, such as patients' attendance to physiotherapy clinics, and implicit association tests to measure patients' psychological and behavioral patterns of their rehabilitation (Chan et al., 2018). Second, we did not record any data on the number of times and the total duration participants used "ACL-Well" during the intervention period. This information could provide essential information about how the usage and rehabilitation adherence are related to the effectiveness of the mHealth intervention (Vriend et al., 2015). Future research should include this quantitative information, together with qualitative data about the extent the patients study the health information and how they respond to daily supportive pop-up messages. Third, the current study did not assess some potential confounding factors (e.g., the grade of the ACL tears, the socio-economic status of the participants, and leg dominance). Future research might consider taking these factors into account when testing the mHealth intervention comprehensively. Fourth, the small sample size might account for non-significant intervention effects on the outcomes, and future research should recruit larger sample sizes to increase the likelihood of detecting significant intervention effects. In the original proposal, the sample size was first calculated based on the ANOVA. However, ANCOVA appeared to be more appropriate for this study in the later stages because the analysis would account for the essential covariates (i.e., age, sex, months for post-ACL-rupture and meniscus injury). This may have lowered the power of the current study. Finally, the high attrition rate at follow-up was notable in the current study. Although our analysis accounted for the potential confounding effects of missing data, the high attrition rate might have revealed further non-adherence to ACL reconstruction rehabilitation exercises (Chan et al., 2017). More research is warranted to investigate not only patients' adherence to rehabilitation but also their adherence to follow-up.

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Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). *Arthritis Care and Research*, 63, S208–S228.

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Table 1.

Clinical Assessments Performance

	Intervention (*n* = 26)	Control (*n* = 30)	ANCOVA	
Knee Muscle Strength	LSI% *M* [95%CI]	LSI% *M* [95%CI]	*F*	*P*
Ext PT/BW 60°/s	69.28 [59.73, 79.91]	75.14 [67.14, 81.60]	0.85	.36
Flex PT/BW 60°/s	84.51 [75.58, 93.04]	84.18 [77.23, 90.46]	0.01	.95
Ext PT/BW 180°/s	74.61 [63.15, 87.35]	81.76 [73.48, 87.83]	1.36	.25
Flex PT/BW 180°/s	90.51 [80.44, 100.96]	90.81 [83.33, 99.48]	0.01	.96
	Intervention (*n* = 16)	Control (*n* = 23)		
	M [95%CI] mm	*M* [95%CI] mm		
Knee Laxity	2.77 [1.44, 4.14]	2.72 [1.88, 3.76]	0.01	.96
	Intervention (*n* = 32)	Control (*n* = 39)		
	M scores [95%CI]	*M* scores [95%CI]		
Subjective Knee Evaluation	70.10 [65.55, 74.69]	70.09 [66.11, 74.01]	0.01	.99

Note. LSI = Limb Symmetry Index. Ext = Extension. Flex = Flexion. PT = Peak Torque. BW = Body Weight. ANCOVAs were adjusted for age, sex, months for post-ACL-rupture and meniscus injury.

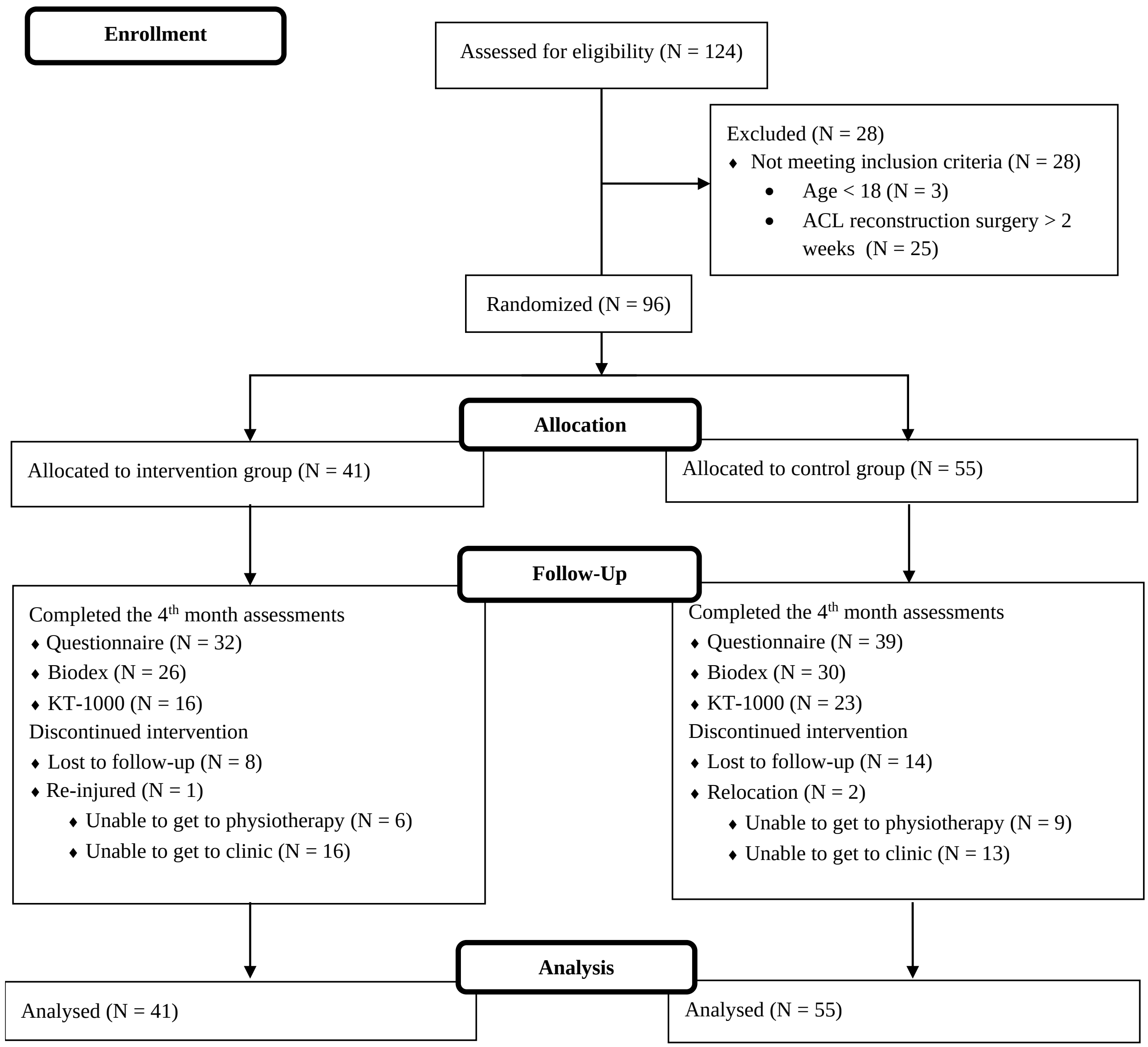

Figure 1.

CONSORT Flow Diagram

Appendix I

mHealth intervention instructions and procedures

Upon completion of the baseline questionnaire, the participants from the intervention group would be asked to search “ACL-Well” on Google Play or Apple App Store and install the smartphone app. After the installation, participants were given a login ID and password, which were only needed for first-time access. At the first login, the app would prompt a timeslot selection that the app delivers a daily notification to remind them to engage in home-based rehabilitation exercises. Then the research team member would showcase the app’s features to the participants individually, namely the knee anatomy and structure, the rehabilitation exercises, a pros and cons list of rehabilitation, and hypothetical scenarios and solutions. The rehabilitation exercises covered rehabilitation exercises that the patients with ACL rupture were recommended to perform from 1 week to 8 months post-surgery. The dosage (e.g., number of sets and repetitions) of each rehabilitation exercise is presented in the section. We encouraged participants to access the app and engage in rehabilitation exercises every day. Finally, the participants had five minutes to navigate the app and raise questions before leaving the clinic. Participants were also encouraged to contact the research team member when they encountered any issues concerning the app.

Appendix II

Screenshots of "ACL-Well"

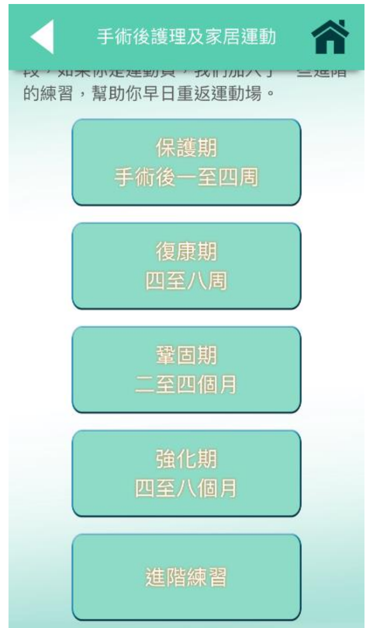

Figure 2.

The first page of ACL-well

Figure 3.

The main screen of ACL-well

Figure 4.

The rehabilitation schedules

(from post-surgery 1 week to 9 months)

Figure 5. Exercise demonstration

Figure 6. 5 Scenarios and solutions

Appendix III

Features and examples for ACL-Well

Targeted Psychological Variable	Features of ACL-Well app	Examples	Taxonomy of Behavior Change*
Self-Determined Treatment Motivation	1) Exercises demonstration	ACL rehabilitation: A list of rehabilitation exercises for patients to choose from	2. Information provision (to the individual). 22. Demonstrate behavior
	2) Notifications	ACL rehabilitation: "Many rehabilitation exercises for you to choose from"; "It is important to do home-based rehabilitation exercises"	4. Information provision (others behavior) 29. Plan social support
Attitude	1) Pros and cons list	ACL rehabilitation: Pros and cons of doing home-based rehabilitation. Then try to emphasize the pros and diminish the cons.	23. Training to use prompts. 37. Motivational interviewing
	2) Notifications	ACL rehabilitation: "Home-based rehabilitation can help you to increase the range of motion of your knee"	2. Information provision (to the individual).
Subjective Norms	1) Notifications	ACL rehabilitation: "Others' patients have also been through this, you can do it as well"	29. Plan social support 4. Information provision (others behavior)
Perceived Behavioral Control	1) Exercises demonstrations	ACL rehabilitation: Rehabilitation exercises video demonstrations with clear instructions	2. Information provision (to the individual). 22. Demonstrate behavior
	2) Scenarios	ACL rehabilitation: Provide 5 barrier scenarios that patients may encounter during their rehabilitation with suggested answers	8. Identifying barriers/Problem resolution
	3) Notifications	ACL rehabilitation: "Home-based rehabilitation is very easy"	33. Prompt self-talk.
Intention	1) Notifications	ACL rehabilitation: "Don't worry if you don't have time to do it today, you can catch up tomorrow"	38. Time management

Appendix IV

Measures of the secondary outcomes

Our psychological and behavioral outcomes included, rehabilitation adherence, and self-determined treatment motivation, social cognition, and intention. We used the Chinese version of Self-Reported Injury Rehabilitation Adherence Scale (Chan et al., 2009; Lee et al., 2020) to measure participants' frequency ("How frequent do you follow your prescribed rehabilitation program?") and effort ("How much effort do you put on completing your prescribed rehabilitation program?") in completing rehabilitation. Items on this scale were rated on seven-point Likert scales (1 = *never/minimum effort* and 7 = *often/maximum effort*). The Chinese version of the scale has demonstrated a good internal consistency (Cronbach's alpha = .87; Lee et al., 2020).

Participants' self-determined treatment motivation was measured using the 13-item injury rehabilitation version of Treatment Self-Regulation Questionnaire (TSRQ; Levesque et al., 2006). Participants responded to items of the TSRQ (e.g., "I have remained in treatment and carry out rehabilitation exercise because I feel like it's the best way to help myself") using seven-point Likert scales (0 = *not at all true* and 7 = v*ery true*). The Chinese version of the scale showed good internal consistency (α = .82) in studies (Lee et al., 2020).

We adopted the injury rehabilitation version of TPB scale (Ajzen, 2002; Lee et al., 2020) to assess participants' social cognition (14 items; e.g., "If I want to I could follow the prescribed treatment protocols or guidelines for my rehabilitation in the forthcoming month") and intention (3 items; e.g., "I intend to carry out the prescribed rehabilitation exercise for the forthcoming month"). Participants rated the times on seven-point scales (1 = *strongly disagree* and 7 = *strongly* *agree*). The Chinese version of the scale has exhibited good internal consistency (social cognition items average α =.83, and intention α = .98; Lee et al., 2020).

Appendix V

Detailed analytical procedure for growth mixture modelling

For the secondary outcomes, we conducted seven sets of growth mixture models (Muthén & Muthén, 2017) following intent-to-treat principles, respectively for the psychological and behavioral outcomes. The growth mixture model can identify homogenous subpopulations (classes) within the intervention and control group. It is highly appropriate for rehabilitation intervention research because the data often includes heterogeneous groups of individuals who have different views and response pattern towards rehabilitation (Jung & Wickrama, 2008). The analysis determines if the respective growth trajectories of the outcome variables, align with our hypothesized intervention effects. In the growth mixture models, we determined the number of classes in a group (i.e., class solutions) by selecting the model that exhibited the lower Adjusted Bayesian information criterion (ABIC; i.e. one of the most accurate information criteria (Jung & Wickrama, 2008; Nylund et al., 2007)), with a class size larger than 5% of the group population (Nylund et al., 2007), a reliable classification as indicated by having higher entropy than other class solution (Muthén & Muthén, 2017). The classes would be categorized based on participants' baseline scores. For example, high and low class would refer to having higher and lower baseline scores of each study variables, respectively. This analytic strategy enabled us to examine our hypotheses in heterogeneous groups of individuals that varied in their psychological characteristics and behavioral patterns (Muthén & Muthén, 2017). H2 and H3 would be supported if a significant negative slopes for self-determined treatment motivation, social cognition, intention and rehabilitation adherence were observed in the control group (H2) but not in the intervention group (H3). All models were estimated using the Mplus 7.1 statistical software using the robust maximum likelihood estimator (Muthén & Muthén, 2017). Missing data were imputed using the full-information maximum likelihood method (Muthén & Muthén, 2017). Data files, analysis scripts, and outputs for this study are available online.

Appendix VI

Preliminary analyses and descriptive statistics of study variables at the baseline

No significant difference was found between intervention and control group in terms of the baseline characteristics, $t(94) = -1.46$ to 1.62, $p = .11$ to .86. Baseline characteristics of participants are presented in Table S1. Regarding the dropout analyses, we found no significant difference between the participants who complete ($n = 72$) and those who did not complete ($n = 24$) the 4th month survey in terms of gender, age, months of post-ACL-rupture, meniscus injury, or the study variables at baseline, $t(94) = -0.13$ to 1.45, $p = .15$ to .90. According to the results of Little's missing completely at random (MCAR) test (i.e., $\chi2 = 262.73$, $df = 300$, $p = .94$), our data failed to reject the null hypothesis of MCAR (Little & Rubin, 2019). The results provided some evidence that no clear pattern existed in the missing data. Descriptive statistics, zero-order correlation, reliability estimates, skewness and kurtosis are presented in Table S2.

Table S1.

Baseline characteristics

Variables		Intervention Group	Control Group	Independent *t*-test	
				t	*p*
Sex[a]	Male	25 (61%)	34 (62%)	0.18	.86
	Female	16 (39%)	21 (38%)		
Age[b]		27.56 (8.13)	28.00 (9.18)	0.24	.81
Time of ACL Injury (Months Ago)[b]		7.89 (14.02)	9.65 (16.97)	0.53	.60
Meniscus injury[b]	Yes	15 (38%)	29 (53%)	1.62	.11
	No	22 (55%)	21 (38%)		
Sporting Experience (Years)[b]		12.22 (5.68)	11.69 (7.91)	-0.35	.73
Rehabilitation Adherence[b]		12.15 (1.59)	11.62 (1.80)	-1.49	.14
Self-Determined Treatment Motivation[b]		2.06 (1.20)	1.98 (1.21)	-0.32	.75
Social Cognition Beliefs in Rehabilitation[b]		6.05 (0.73)	6.09 (0.65)	0.38	.70
Intention in Rehabilitation[b]		6.42 (0.81)	6.32 (0.75)	-0.60	.55

Note. [a]Data expressed as *N* (%); [b]Data expressed as *M* (SD).

Table S2.

Descriptive statistics of secondary outcomes

	1	2	3	4
1. Rehabilitation Adherence	1			
2. Self-Determined Treatment Motivation	.271**	1		
3. Social Cognition in Rehabilitation	.57***	.15	1	
4. Intention in Rehabilitation	.62***	.22*	.75***	1
Mean	11.83	2.01	6.04	6.35
SD	1.72	1.20	0.67	0.78
McDonald’s Omega	.78	.83	.91	.98
Skewness	-0.51	0.71	-0.88	-1.21
Kurtosis	-0.45	0.51	0.89	1.11

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Appendix VII

Sensitivity analyses

Sensitivity analyses involved repeating the analysis after removing the four covariates (i.e., age, sex, months for post-ACL-rupture and meniscus injury). There were still no significant differences between intervention and control group in primary outcomes ($F(1, 37 \text{ to } 69) = 0.19$ to 2.29, $p = .21$ to .89). In relation to the treatment of missing data, we conducted another set of sensitivity analysis. In particular, five imputed data sets were combined to generate a final imputed dataset. No significant differences between the intervention and control group were found in the primary outcomes ($F(1, 37 \text{ to } 69) = 0.01$ to 1.01, $p = .32$ to .98). Therefore, the main findings of our intervention (i.e., ANCOVAs) was shown to be robust against patients' background and patterns of missing data.

Appendix VIII

Fit indices and estimates of the growth trajectories in each class

	Classes solution fit indices			Growth factors for each class					
	n	ABIC	ENT	Group	Class	*n* (%)	*M* Intercept [95% CI]	*M* Slope [95% CI]	Hypotheses
Adherence									
	2	1077.45	.82	Intervention	low	14 (34%)	10.50 [9.54, 11.46]	.04 [-.17, .24]	H2 supported; H3 partially supported
					high	27 (66%)	12.99 [12.41, 13.60]	-.50 [-.79, -.21]	
				Control	low	22 (40%)	9.90 [9.02, 10.78]	-.25 [-.44, -.06]	
					high	33 (60%)	12.68 [12.03, 13.32]	-.15 [-.28, -.03]	
Self-Determined Treatment Motivation									
	2	867.82	.88	Intervention	low	34 (83%)	3.70 [3.17, 4.22]	-.08 [-.14, -.01]	H2 supported; H3 partially supported
					high	7 (17%)	5.59 [4.65, 6.53]	-.11 [-.31, .09]	
				Control	low	49 (89%)	3.68 [3.44, 3.93]	-.12 [-.21, -.03]	
					high	6 (11%)	6.15 [5.06, 7.23]	-.39 [-.56, -.21]	
Social Cognition									
	1	619.27	1.00	Intervention		41 (100%)	6.04 [5.85, 6.23]	-.12 [-.17, -.08]	H2 supported; H3 not supported
				Control		55 (100%)	6.07 [5.93, 6.22]	-.07 [-.12, -.01]	
Intention									
	2	715.79	.97	Intervention	low	5 (12%)	4.60 [4.20, 4.99]	.26 [.07, .44]	H2 and H3 partially supported
					high	36 (88%)	6.62 [6.48, 6.75]	-.19 [-.25, -.13]	
				Control	low	8 (15%)	4.98 [4.66, 5.29]	.12 [-.03, .26]	
					high	47 (85%)	6.56 [6.43, 6.68]	-.16 [-.23, -.09]	

Note. ABIC= Adjusted-Bayesian Information Criterion. ENT = Entropy. CI = Confidence Interval.