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A conceptual framework to improve the reporting quality of strength training exercise descriptors in anterior cruciate ligament reconstruction rehabilitation programs

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DECLARATION

I, Arnold Vlok, declare that the PhD research thesis that I herewith submit at the University of the Free State, is my own independent work and has not previously submitted at another institution of higher education.

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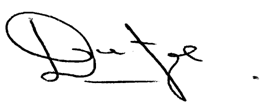

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Prof Frederik F Coetzee

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PRESENTATIONS ARISING FROM THE RESEARCH PROJECT

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ARTICLES PUBLISHED FROM THE RESEARCH PROJECT

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ABSTRACT

Introduction

Muscle weakness after anterior cruciate ligament reconstruction (ACLR) is persistent and associated with abnormal biomechanics, poor knee function, new knee injury and development of osteoarthritis. The proposed drivers of persistent muscle weakness after ACLR are changes in muscle morphology, atrophy-inducing cytokines in the knee joint, and neurological alterations on a cortical and spinal level. The most accessible approach to target muscle weakness is various types of strength training exercises. However, another explanation for persistent weakness after ACLR rehabilitation could be that programs are not following the best practice for strength training. Failure to improve muscle strength after ACLR could be caused by faulty programming of exercise descriptors (e.g., exercise type, frequency, load).

Aim

The main aim of this study was to develop a conceptual framework to improve the reporting quality of strength training exercise descriptors in ACLR rehabilitation programs.

Methodology

The study was conducted in three stages, including a Scoping Review, focussing on which strength training exercise descriptors are reported in ACLR research after ACLR surgery, and comparing the current standards of reporting ACLR strength training exercise descriptors to international best practice strength training guidelines. The modified e-Delphi survey was utilised to formulate a conceptual rehabilitation framework for ACLR. The last stage included validating the preliminary ACLR conceptual framework that included a core outcome set (COS) of strength training exercise descriptors for reporting after ACLR.

Results and discussion

We extracted data on 117 exercises from 41 studies*.* A median of *seven* of the 19 possible exercise descriptors were reported (range 3-16). Reporting of specific exercise descriptors varied across studies from 93% (name of the strength training exercise) to 5% (exercise aim). On average, 46%, 35%, and 43% of the exercise descriptors included in the ACSM, CERT, and Toigo and Boutellier guidelines were reported, respectively.

The e-Delphi results from 27 ACLR experts regarding the 21-exercise descriptor definition was 100% consensus agreement (>80% agreement), also 100% consensus agreement on a COS of strength training exercise descriptors (). However, very low consensus agreement on exercise dosages prescribed in ACLR strengthening programs.

The validation meeting consisted of four panellists that validated the preliminary ACLR conceptual framework and proposed to re-organise the 13 COS of exercise descriptors into levels of importance regarding the frequency of reporting.

Conclusion

The proposed ACLR conceptual framework for researchers and clinicians provided a platform for the reporting of strength training rehabilitation after ACLR. Improving the reporting quality of strength training exercise descriptors, definitions, and exercise dosages for ACLR rehabilitation programs can aid in the transfer of ACLR rehabilitation research towards private practice. Therefore, enabling clinicians to implement evidence-based strength training exercise configurations.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Meaning
Anterior cruciate ligament	**ACL**
Anterior cruciate ligament expert rehabilitation group	**ACLR ERG**
Anterior cruciate ligament reconstruction	**ACLR**
Arthrogenic muscle inhibition	**AMI**
American College of Sports Medicine	**ACSM**
Centre for Reviews and Dissemination	**CRD**
Clinical practice guidelines	**CPGs**
Close kinetic chain	**CKC**
Consensus on Exercise Reporting Template	**CERT**
Core outcome set	**COS**
Exercise descriptors	**EDs**
Neuromuscular control training	**NMCT**
Open kinetic chain	**OKC**
PRISMA Extension for Scoping Reviews	**PRISMA-ScR**
Randomised controlled trial	**RCT**
Repetition maximum	**RM**
Return to sport	**RTS**
Strength training	**ST**
Template for Intervention Description and Replication	**TIDieR**

DEFINITIONS

Conceptual Framework: A conceptual framework refers to a "researcher's constructed model, which explains interconnected vital concepts and relationships exploring the research problem. Conceptual frameworks are commonly seen in qualitative research in the social and behavioural sciences, for example, because often one theory cannot fully address the phenomena being studied" (Adom *et al*., 2018: 438).

Exercise Descriptors (EDs): Toigo and Boutellier, (2006) outline important mechanobiological exercise descriptors, which provide a framework to standardise the design and description of resistance exercise investigations. Examples of some descriptors 1) Repetitions; 2) Sets; 3) Load magnitude; 4) Rest between Repetitions; 5) Frequency of sessions (Toigo & Boutellier, 2006).

Strength Training (ST): Strength training was defined by Zatsiorsky *et al.,* (2020), as the practice of a certain exercise modality to improve the body's ability to overcome or counteract external resistance by specific muscular effort (concentric, eccentric, or isometric muscular contractions). Include the repetition maximum continuum from strength endurance focused to power / rate of force development focused.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION AND STUDY ORIENTATION

Chapter 1 will postulate the problem statement, rationale, research question, aim, research objectives, research design, ethical considerations, significance of the study and the chapter exposition.

This PhD study was planned and implemented as a single report but is presented in the form of chapters and an article, which includes background or additional information to the research. The research approach serves to combine the chapters and article into a cohesive entity.

It is important to note that the article should be interpreted as an independent entity with some connections and consequent overlap. This orientation to the study functions as an introduction to the research and intends to provide the reader with a holistic view of the study. The target market were researchers and clinicians working with patients after anterior cruciate ligament reconstruction (ACLR).

1.2 RATIONAL FOR THE STUDY

"When can I play again?" is the most frequently, emotionally charged, typical question asked by almost every athlete after an anterior cruciate ligament (ACL) injury. Invariably, the same question is also one of the first asked by teammates, parents, coaches, and, in the case of high-profile athletes, the media. This implies that swift surgical intervention is often selected to meet these expectations, and accelerated rehabilitation becomes a priority (Myklebust & Bahr, 2005). However, the criteria to determine a return to sport (RTS) readiness remain arbitrary, as does the optimal ACLR strength training (ST) program (Glattke *et al.,* 2022).

There may be underlying reasons why clinicians use different approaches to prepare the athlete for RTS participation. A possibility could be the poor reporting of resistance training programs that prevent accurate translation and implementation in clinical practice, considering that up to 40% of physiotherapists indicated that original research and articles were the preferred resource to learn from when treating patients with musculoskeletal pain (Holden *et al.,* 2019; Barton *et al.,* 2021). Secondly, physiotherapists lacked the ability to prescribe ST exercises for people with musculoskeletal pain. This is according to an international survey of 1,352 physiotherapists from 56 countries. Only 16% could identify an accepted ST best practice guideline, such as that of the American College of Sports Medicine (ACSM) guidelines (Barton *et al.,* 2021). Although this is a problem, it is not clear if it persists in ACLR.

Research efforts have been non-specific about the reporting, the detail of the ST exercise descriptors (EDs) in ACLR rehabilitation programs, and inadequate reporting of the resistance training intensity of these rehabilitation programs (Goff *et al.,* 2016; Augustsson, 2013; Nichols *et al.,* 2021). Consequently, there is little information available on the dose-response relationship between the volume and/or intensity of ST exercise and outcomes and what constitutes the optimal rehabilitation strategy to return patients to their preinjury level of sport and prevent reinjuries (Kotsifaki *et al.,* 2023).

Webster and Feller (2019;578) recently determined "that patients who were about to undergo a primary ACLR had high expectations for their return to preinjury level of sport, with 88% expecting to achieve this outcome". Ardern *et al*. (2011) agrees and mention that only 65% of patients after ACLR return to their preinjury level of sport. Reinjury rates can be as high as 25% (Wiggins *et al*., 2016), and only 33% of injured athletes return to competitive sports after 12 months of ACLR surgery (Ardern *et a*l., 2011). It is concerning that only 5% of ACLR athletes were managed using ACLR evidence-based guidelines (Ebert *et al*., 2017). Considering these facts, a feasible first line-treatment model that can navigate the optimal final ACLR outcomes remains debated.

Anterior cruciate ligament reconstruction is considered by many as the clinical standard to restore the mechanical stability of the joint as a prerequisite for RTS participation (Gokeler *et al.,* 2022). Conflicting evidence challenges the golden standard of ACLR surgery with exercise compared to exercise and optional delayed ACLR in 121 patients participating in the KANON trial (Frobel *et al.,* 2010). An 11-year follow-up of the KANON trial indicates no superior improvement in the $KOOS_4$ (pain, symptoms, function in sports and recreation, knee-related quality of life) outcomes when ACLR surgery with exercise was compared to exercise and optional delayed ACLR surgery (Lohmander & Roemer *et al.,* 2023). In a secondary analysis of the KANON trial, research indicates evidence of ACLR healing on MRI following ACL rupture treated with rehabilitation. Healing responses occur in 30% of patients treated within the ACLR ruptured rehabilitation group (Filbay *et al.,* 2023).

Other evidence, the COMPARE randomised control trial, which used the same objectives as the KANON trial, indicated superior knee function and ability to participate in sports after two years (Reijman *et al.,* 2021). Some consideration that should be highlighted in the COMPARE trial was that 50% of patients randomised to the rehabilitation group opted for no ACLR surgery (Reijman *et al*., 2021).

Essentially, ACLR rehabilitation should be considered as important as any golden standard treatment for ACL injury as a standalone treatment or in combination with surgery to prepare patients for successful sports participation. Therefore, the standard of rehabilitation considering the intensity, frequency, compliance, and reproducibility of a training protocol is of significance when examining the evidence and translating it into clinical practice for ST following ACL injury or reconstruction (Page *et al.,* 2016; Filbay, 2022).

Anterior cruciate strengthening programs form the cornerstone of targeting muscle weakness in collaboration with other modalities like neuromuscular/motor control training to prepare athletes for their pre-injury levels of play after surgery (Risberg *et al.,* 2007; Andrade *et al.,* 2019; Kotsifaki *et al*., 2023). Contradicting the expected positive effect of ST on muscle weakness, it is evident throughout the research that strength and power deficits persist after completing an ACLR-standardised ST rehabilitation program (Tayfur *et al.,* 2020). Arthrogenic muscle inhibition, and psychological factors can be some reasons for this continuous muscle insufficiencies (Beischer *et al.,* 2019; McPherson *et al.,* 2023). Nevertheless, reporting and implementing effective evidence-based ST exercises targeting neuromuscular strength deficits should be every clinician and researcher's responsibility.

A lack of proper reporting of ACLR EDs that determine muscle gains makes it impossible to replicate the exercise intervention with its results in clinical practice (Page *et al.,* 2017; Goff *et al.,* 2018; Poretti *et al.,* 2023). Therefore, absent EDs may leave clinicians and other researchers with the likelihood to interpolate with their own ST considerations. Consequently, the altered performance of ACLR ST programs could lead to a wide variation in individuals' physiological responses and overall clinical outcomes. A gap in the research emerges considering the reporting of ST EDs in ACLR rehabilitation programs targeting muscle weakness.

Therefore, an ACLR conceptual framework is needed to improve the quality of reporting ST EDs after ACLR surgery. Such an ACLR conceptual framework will hopefully enable researchers and clinicians to effectively micro-manage the individual EDs and progressions within the ACLR rehabilitation program. The primary reason for this focused approach is to target musculoskeletal strength deficits that develop after ACLR surgery.

1.3 PROBLEM STATEMENT

Anterior cruciate ligament reconstruction (ACLR) rehabilitation literature indicated poor reporting of strength training (ST) exercise descriptors (EDs) for research purposes (Augustsson *et al*., 2013). Such a problem is not unique to the ACLR rehabilitation field. It similarly affects the implementation of rehabilitation for other musculoskeletal conditions, like patellofemoral pain syndrome and achilles tendon ruptures (Holden *et al.,* 2018; Christensen *et al.,* 2020).

Level 1 evidence indicated that the majority (9/11) ACLR rehabilitation studies (Vlok *et a*l., 2022) lack adequate reporting of resistance training intensity to meet the demands of RTS after ACLR surgery (Nichols *et al.,* 2021). Consequently, the question remains if ACLR patients were fully prepared to manage the higher demands of power and strength components related to ST rehabilitation. However, no evidence existed regarding the possible reinjury risk of this matter.

Culvenor *et al.,* 2022, concluded in a recent systematic review with 142 randomised control trials low evidence for ACLR rehabilitation's effectiveness, including interventions like neuromuscular control exercises and open and close kinetic chain (CKC) exercises to improve symptomatic and functional outcomes. Opposingly, clinical guidelines proposed strength training, including isotonic and isokinetic, concentric, and eccentric training, as a cornerstone for the treatment of ACLR patients (Van Melick *et al.,* 2016; Kotsifaki *et al.,* 2023). Therefore, the rehabilitation of the ACLR patient should follow the clinical practice guidelines (CPGs) proposed for ACLR patients to enable them to return to their pre-injury preferred activity to prevent post-traumatic knee osteoarthritis (Van Melick *et al.,* 2016; Whittaker *et al.,* 2022).

In the systematic review, Andrade *et al*. (2020:512) ask, "How should clinicians rehabilitate patients after ACL reconstruction?" The emphasis of the review was on CPG with a focus on quality appraisal. Conclusions showed that applicability, "the ease with which clinicians can implement the CPG recommendations into clinical daily practice", was rated very poorly. Reasons for that are outside the scope of this study, but, importantly, clinicians find it difficult to implement best practice evidence-based ACLR guidelines.

Considering evidence-based practice and the implementation into clinical practice, the OPTIKNEE group indicated that the ACLR exercise intervention should be documented by utilising the Consensus on Exercise Reporting Template (CERT), a platform developed specifically for exercise trials by Slade *et al*. (2016) (Culvenor *et al.,* 2022). No research evaluated the inclusion of the CERT platform into ACLR rehabilitation until 2020. However, some earlier evidence indicates a low uptake of ST EDs included in tibiofemoral joint soft tissue injuries programs (Goff *et al.,* 2018).

Despite the perceived value of exercise rehabilitation following ACLR, some challenges exist. However, there is no clear consensus concerning specific exercise dosages or which ST EDs should be documented within ACLR strengthening programs (Augustsson, 2013; Culvenor *et al.,* 2022).

The researcher perceived the current research problem concerning ST EDs in Figure 1. An ACLR patient enters ACLR rehabilitation with the focus on being prepared for desired pre-injury levels of play. When conducting strength training, it is essential to know which ACLR ST EDs (repetitions, sets, load magnitude, frequency of sessions, etc.) were prescribed during clinical trials to replicate in clinical practice expecting the same results (Page *et al*., 2017).

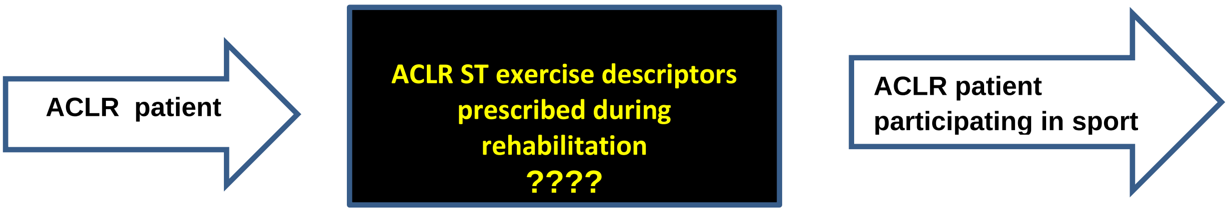

Figure 1.1: The problem regarding strength training (ST) exercise descriptors (EDs) in ACLR

The general problem was that no research exists concerning which EDs are used in rehabilitation after ACLR, and secondly, how did the literature compare to international standards of reporting strength training? A conceptual framework design was adopted to answer the research question considering the importance of such difficulty when ST encompasses an important component of rehabilitating ACLR patients (Van Melick *et al.,* 2016; Andrade *et al.,* 2019).

Several conceptual frameworks can be used to facilitate the implementation process and record increased instances of practice change and the spread of evidence (Alatawi, 2019). Casanave and Li (2015) and Parahoo (2006) distinguish between a theoretical framework and a conceptual framework as follows: "a theoretical framework is a specific framework or theory that underpins a research study, while a conceptual framework draws on various theories, frameworks, and findings to guide the research". Maxwell (2005:52) concluded and defined "the conceptual framework of a study as a system of concepts, assumptions, expectations, beliefs, and theories that supports and informs the research". The conceptual framework, in essence, describes the key factors, concepts and variables and the relationship between them. It can be regarded as the plan or model of what the researcher intends to design. Based on the lack of current evidence concerning which EDs should be included in an ACLR ST program, it was advisable to use a conceptual framework design to include different notions, traditions, and views from different stakeholders when performing ACLR strength training.

For that reason, our research question was: What ACLR framework exists for researchers and clinicians to improve the report quality regarding the specificity of ST EDs utilised while conducting ACLR rehabilitation?

1.4 RESEARCH AIM

The aim of this study was to develop an ACLR rehabilitation injury management conceptual framework for clinicians and researchers working with athletes after ACLR. While considering the aim of the study, the following research objectives were formulated in point 1.5.

1.5 RESEARCH OBJECTIVES

The objectives of this study were:

Objective 1: Review the literature to 1) determine which strength training (ST) exercise descriptors (EDs) are used in rehabilitation after ACLR surgery and 2) how the literature compares to international standards of reporting ST EDs in ACLR rehabilitation programs.

Objective 2: Develop a consensus set of ACLR ST EDs as outcomes.

Objective 3: Validate the preliminary ACLR conceptual framework through four national and international subject, clinical and framework experts.

Objective 4: Finalise the ACLR conceptual framework that includes the COS ST EDs for reporting after ACLR.

The above-mentioned objectives were achieved during the four study phases, namely (Figure 1.2):

Phase 1: Scoping review of literature on ACLR rehabilitation.

Phase 2: Modified e-Delphi survey amongst International and South African experts regarding exercise prescription descriptors and criteria for progression.

Phase 3: Validation process and the development of a conceptual framework for ACLR rehabilitation.

Phase 4: Finalisation of the ACLR conceptual framework.

1.6 RESEARCH DESIGN

A quantitative and qualitative research approach was followed to achieve the purpose and objectives of the study. A mix-method research approach was needed to collect and analyse all the relevant data for this study. The mixed-method approach enables us to "intensify and deepen the understanding and validation of the rich data collected in the study" (Almalki, 2016:291). Details regarding the specific research methods, study participants, measuring instruments and data capturing applied to answer each research objective will be included in chapters 3 to 5.

1.7 ETHICAL CONSIDERATIONS

The research protocol was presented to the Health Sciences Research and Ethical Committee (HSREC) at the University of the Free State (UFS) for approval. Ethical clearance (HSREC: UFS-HSD2019/1889/2502) was obtained before the commencement of the study. Any changes during the progress of finalising the study were approved as amendments to the protocol by the same committee (refer to Appendix A).

1.8 SIGNIFICANCE OF THE STUDY

The value of this study will provide researchers and clinicians with one common ACLR framework to report and implement strength training (ST) exercise descriptors (EDs) while conducting ACLR rehabilitation. Secondly, ACLR exercise intervention utilised during clinical trials can be directly translated to clinical practice, replicating evidence-based research results. Lastly, the ACLR framework could set the stage for further research to build on solid findings.

1.9 CHAPTER EXPOSITION

This thesis consists of an introductory chapter (Chapter 1), followed by five main chapters comprising a literature review (Chapter 2), followed by a scoping review (Chapter 3), the modified e-Delphi on the COS of strength training (ST) exercise descriptors (EDs) (Chapter 4). The following chapter concludes the validation and finalisation of the conceptual framework for ACLR rehabilitation (Chapter 5) (See Figure 2). The concluding chapter (Chapter 6) includes the strengths, weaknesses, and recommendations for further studies. The six chapters are:

1.9.1. Chapter 1: Orientation to the study

The first chapter provides a brief background on ACLR, serving as an introduction to the study. The aim was to highlight the main purpose and objectives of the study as well as the layout of the thesis.

1.9.2. Chapter 2: Literature review in ACLR

This chapter intended to give a knowledge overview of the key literature relevant to ACLR rehabilitation as first-line treatment, clinical best practice guidelines for ACLR rehabilitation, current reporting of ACLR EDs and targeted ST for ACLR patients. Research gaps open concerning the reporting of ST in ACLR rehabilitation programs. This review provides a strong foundation for the ACLR conceptual framework and confirms the methodology used for this research project.

1.9.3 Chapter 3: Scoping Review

To identify and analyse knowledge gaps concerning the reporting of ACLR ST EDs utilised in Level 1-4 studies, a scoping review (DOI: **https://doi.org/10.2519/jospt.2022.10651**) was conducted. The aim of this scoping review was to explore the extent of the literature and to map and summarise the evidence in view of the following two objectives**:**

1. Describe which ST EDs were reported in ACLR rehabilitation research.
2. Compare the current standards of reporting ACLR ST EDs to international best-practice ST guidelines.

This scoping review (Vlok *et al*., 2022) informs the following stage in the thesis, specifically the conduction of a modified e-Delphi considering the list of ACLR EDs utilised in the conclusion of the scoping review (Table 1).

1.9.4 Chapter 4: Anterior Cruciate Ligament Rehabilitation: An Expert modified e-Delphi Perspective

The purpose of this section of the research study was related to Objective 2 utilising a modified e-Delphi survey as a unique approach to formulate a rehabilitation framework for ACLR. The evidence obtained in Chapter 3 laid the foundation for the construction of the e-Delphi survey and served as a relevant connection and overlap between current evidence and the development of a new COS of ST EDs. This was accomplished by collecting qualitative opinions, supplemented with some quantitative elements, from twenty-seven (27) ACLR experts representing International and South African views on ACLR ST exercise programs. The results and subsequent discussion of these results are presented.

1.9.5 Chapter 5: A Conceptual Framework for ACLR

Chapter 5 concluded the formal validation of the new framework for ACL rehabilitation by experts. Therefore, this chapter serves as the overall summary of the findings of the study in the form of a conceptual framework for ACLR rehabilitation. The purpose of this study was to formulate a conceptual framework to improve the reporting of ST EDs within ACLR rehabilitation programs utilising both quantitative and qualitative methods of data collection. Data were processed and interpreted for the scoping review as well as the e-Delphi questionnaire and will be presented collectively to describe how the outcomes of the study were achieved.

1.9.6 Chapter 6: Conclusions and Recommendations

A holistic view of the research project as a single entity is provided in this chapter, including recommendations and other considerations regarding the strengths and limitations of the study.

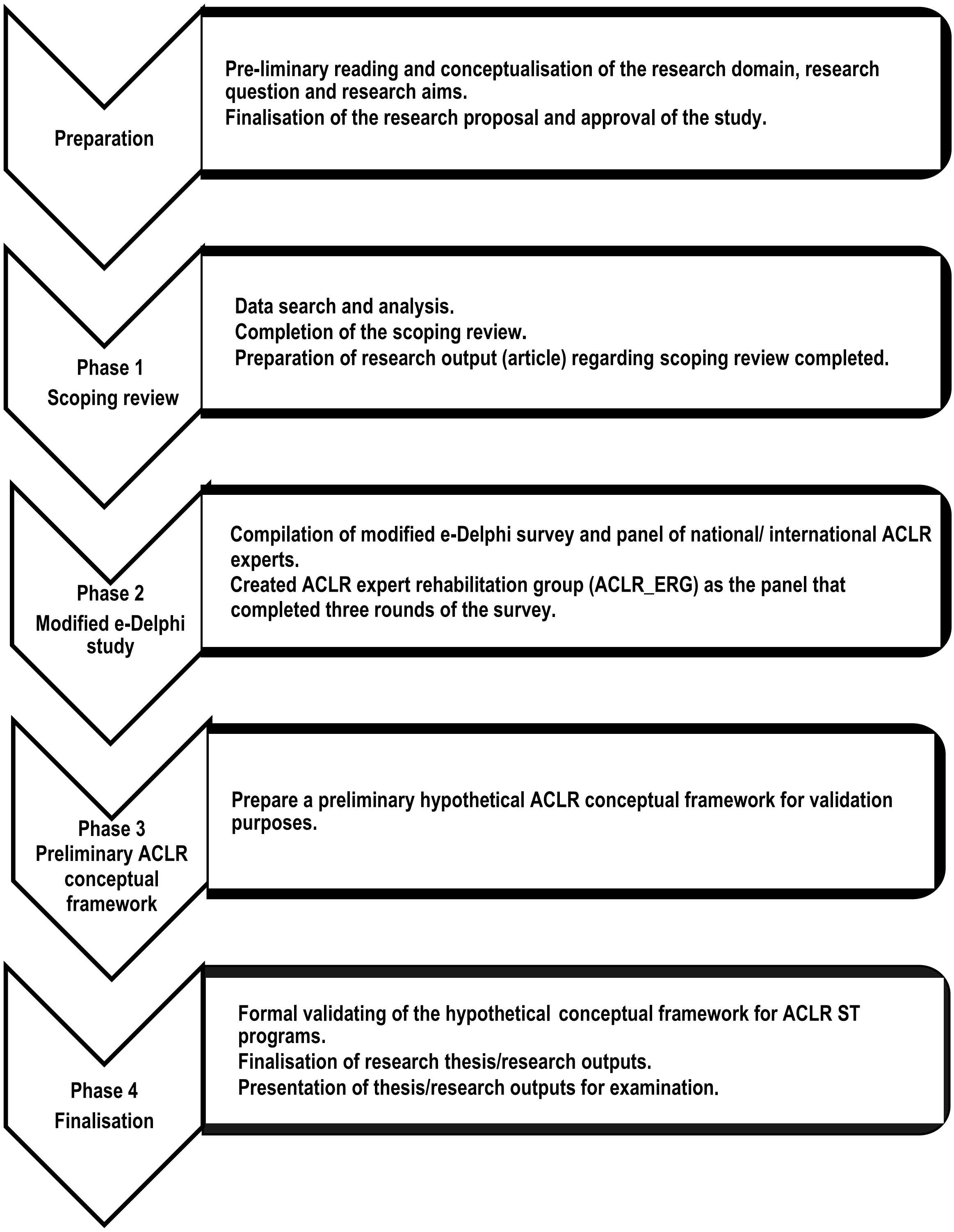

Figure 1.2: Summary of the study process

CHAPTER 2

LITERATURE OVERVIEW

2.1 INTRODUCTION

Proper reporting of the strength training (ST) exercise descriptors (EDs) (repetitions, sets, interset rest, tempo etc.) utilised during ACLR exercise rehabilitation programs is a fundamental consideration to replicate evidence-based results (Page, 2017; Goff *et al.,* 2018; Nicolas *et al.,* 2021). Unfortunately, an evidence gap exists regarding the reporting standards for ACLR ST EDs while conducting exercise rehabilitation (Augustsson, 2013). Considering the importance of exercise rehabilitation as first-line treatment, emerging Level 1 evidence compares the 11-year effect of exercise rehabilitation plus early ACLR with exercise rehabilitation plus optional delayed ACLR (when instability persists). Outcomes indicated no superior effect for surgery above exercise rehabilitation when compared with each other (Saueressig *et al.,* 2022; Lohmander & Roemer*,* 2023). Confirming the importance of ACLR and exercise rehabilitation or ACL injury in addition to rehabilitation, exercise rehabilitation can be considered as a central theme for treatment. Therefore, increasing reporting standards of the ST EDs utilised during exercise rehabilitation enables the end-user (researcher and clinicians) to replicate ACLR evidence-based programs (Slade *et al.,* 2016; Page *et al.,* 2017).

This chapter is structured as follows: In the literature review, current reporting platforms for exercise clinical trials and the applicability of ACLR clinical practice guidelines (CPGs) were discussed to present a logical flow of ideas. Best practice rehabilitation guidelines enable clinicians to distinguish between certain kinds of exercises and modes of training, which were debated concluding the literature review by reporting the necessity of exercise dosages and replicating target ST EDs for ACLR pathophysiological alterations.

2.2 ACLR EXERCISE INTERVENTIONS REQUIRE QUALITY REPORTING

The evaluation of an intervention during a clinical trial is often the primary objective of a study. Therefore, the quality of the intervention description is very important. When the trial report becomes available through journal publications, a poor description will mean that others may find the intervention difficult to implement in clinical work or replicate for research (Bandholm *et al.,* 2017). Considering that ACLR ST exercise interventions are poorly documented (Augustsson, 2013; Vlok *et al.,* 2022), it could be challenging for practitioners to implement ACLR evidence-based exercise rehabilitation programs for the lack of reporting essential exercise descriptors (EDs). Current evidence indicates the potential advantage of ACLR exercise rehabilitation as first-line treatment compared to surgical interventions for ACL-injured patients or best practice recommendations after ACLR (Reijman *et al.,* 2021; Kotsifaki *et al.,* 2023). As a result, ACLR exercise rehabilitation interventions should be reported in evidence-based reporting checklists.

2.2.1 Reporting checklist for drug and general exercise interventions

According to Hoffman *et al*. (2016: 348) "without a complete published description of the intervention, clinicians and patients cannot reliably implement interventions that are shown to be useful, and other researchers cannot replicate or build on research findings". Considering this, Slade *et al.* (2016) developed the Consensus on Exercise Reporting Template (CERT), which consists of 16 checklist elements to include in exercise intervention reporting. Only items 7a, 7b (progressions of exercises and program), and 13 (reporting of repetitions, sets, and resistance load) indicated the reporting of ST EDs utilised during clinical trials. Other generic reporting guidelines also exist. The Template for Intervention Description and Replication (TIDieR) exists to improve reporting of drug interventions in general and not specific to exercise interventions (Hoffman *et al.,* 2014). Both of these reporting checklists were not specifically developed to capture the required details of EDs used during ACLR clinical trials, but evidence should direct us towards the importance of exercise rehabilitation as a treatment for ACLR surgery.

2.2.2 Exercise rehabilitation as a first-line treatment option for ACL injury/ACLR athletes

As the literature presented here indicates that ACLR surgery should be an option to consider after an ACL injury (Rodriguez *et al.,* 2021; Reijman *et al.,* 2021). Following ACLR, surgery is no longer mandatory because of the potential long-term benefits (decrease in knee osteoarthritis) compared to other comparator treatments like exercise rehabilitation. Fifty percent (50%) of ACL-injured individuals will develop symptomatic osteoarthritis within ten years, regardless of operative or non-operative treatment (Poulsen *et al.,* 2019). “The three key treatment options for an ACL rupture are:

1. rehabilitation as first-line treatment (followed by ACLR) in patients who develop functional instability,
2. ACLR and postoperative rehabilitation as the first-line treatment, and
3. preoperative rehabilitation followed by ACLR and postoperative rehabilitation” (Filbay *et al.,* 2019; Whittaker *et al.,* 2022).

Highlighting the significance of exercise rehabilitation programs that serve as first-line treatment options for ACL injured/ACLR patients, clinicians should prescribe ACLR exercise training from well-reported best practice guidelines (Andrade *et al.,* 2019; Van Melick *et al.,* 2016; Kotsifaki *et al.,* 2023).

2.3 APPLICABILITY OF ACLR CLINICAL PRACTICE GUIDELINES (CPGS)

How should clinicians rehabilitate patients after ACLR? Level 1 evidence suggests that CPGs should be followed to improve ACLR patient outcomes during and after rehabilitation (Van Melick *et al.,* 2016; Andrade *et al.,* 2020).) Therefore, quality ACLR research must be translated and implemented in clinical practice. Unfortunately, according to Andrade *et al.* (2020), the applicability (the ease with which clinicians can implement the CPGs recommendations into daily clinical practice) domain of six different CPGs rated according to the AGREE II assessment tool is 29%. The reasons for this low applicability level were outside the study's scope. Still, the quality of reporting the ACLR exercise interventions utilised during clinical trials is a possible further obstacle in the pathway of clinical uptake and applicability that should be investigated (Augustsson, 2015; Goff *et al.,* 2018). Sixty-six percent (66%) of the international CPGs for rehabilitation after ACLR recommended different exercise types and modes of exercise training to be included in clinical practice, considering its effectiveness in targeting neuromuscular alterations (Welling *et al.,* 2019: Andrade *et al.,* 2020).

2.4 EXERCISE TYPES AND MODES TO INCLUDE IN ACLR EXERCISE REHABILITATION PROGRAMS

2.4.1 Strength training (ST) vs Neuromuscular control training (NMCT):

Both these exercise types need to be incorporated into ACLR exercise rehabilitation programs (Risberg *et al.,* 2007; Van Melick *et al.,* 2016). The final goal of an ACLR strengthening program is to target muscle weakness, restoring muscle strength and power needed for participation in the patient's sport and desired recreational activities, while the final goal of any NMCT program is to restore dynamic postural control which may be lacking after ACLR (Filbay *et al.,* 2019; Paterno *et al.,* 2010).

Contrary to previous evidence, current Level 1 evidence indicates no advantage to knee functionality in doing neuromuscular control rehabilitation exercises following the ACLR when compared with a traditional strengthening program (Cooper *et al.,* 2005; Bakowski *et al.,* 2023). Additionally, four systematic reviews identified the heterogeneity in studies utilised for the neuromuscular control intervention used, the test conducted to measure the variable. There is not enough scientific evidence to substantiate the inclusion of NMCT exercises or the effectiveness 6-24 months after ACLR (Costa *et al.,* 2020; Arumugam *et al.,* 2021; Ma *et al.,* 2021; Fleming *et al.,* 2022).

Consequently, the inclusion of the reporting of NMCT programs in our study was not validated. As a result, the main objective of our study was to consider reporting the ST exercise descriptors (EDs) utilised to improve knee functionality after ACLR surgery and, therefore, include different modes of strength training.

2.4.2 Close kinetic chain (CKC) vs Open kinetic chain (OKC) exercises

Clinical practice guidelines (CPGs) proposed that ST can be implemented immediately after ACLR, starting with CKC exercises, followed by OKC exercises in a restricted range of motion four weeks postoperatively (Van Melick *et al.,* 2016; Andrade *et al.,* 2020). The main advantage of incorporating CKC exercise is improving knee flexion after surgery, and the OKC extension exercise improved quadriceps strength after ACLR without increasing graft laxity (Mikkelsen *et al.,* 2000; Jewiss *et al.,* 2017; Forelli *et al.,* 2023).

2.4.3 Eccentric vs Concentric contractions

A combination of eccentric and concentric contractions improved quadriceps and hamstring strength during the execution of these exercises (Kotsifaki *et al.,* 2023). Eccentric OKC exercise training effectively targets quadriceps weakness after ACLR (Lepley *et al.,* 2015; Vidmar *et al.,* 2020).

2.4.4 High-intensity vs Low-intensity ST ACLR exercises

High-intensity (8RM) training from 14 weeks postoperatively was introduced to a group of ACLR patients with no adverse effect on knee joint stability and contributed to faster recovery of leg extension muscle power (Bieler *et al.,* 2014). Both High-intensity and Low-intensity do not have enough evidence to support their position.

2.5 EXERCISE DOSAGE/PRESCRIPTION OR DOSE-RESPONSE RELATIONSHIP

Exercise dosing refers to the repetitions, sets, intensity, duration, frequency, number of total exercises, and progression of each exercise while conducting an ACLR rehabilitation exercise program. The question remains how specific exercise dosage variables may influence the effectiveness of ACLR treatment (Young *et al.,* 2018). A significant variation in these variables can impact the outcomes of a specific treatment. Currently, level-one evidence indicates a lack of consensus on an optimal ACLR rehabilitation program and no clarity concerning the exercise dosage and delivery (Van Melick *et al.,* 2016; Culvenor *et al.,* 2022; Kotsifaki *et al.,* 2023). Expecting one optimal dosage is unrealistic, but with ACLR clinical trials that adequately report the critical components of exercise dosage, clinicians can make informed decisions when prescribing ACLR strengthening exercises targeting the pathophysiology of ACLR surgery (Augustsson, 2013; Goff *et al.,* 2018; Culvenor *et al.,* 2022).

2.6 TARGETED STRENGTH TRAINING (ST) TO IMPROVE PATHOPHYSIOLOGICAL ALTERATIONS AFTER ACLR

Understanding ACLR surgical impact on the knee joint's neuromuscular function should enable practitioners to target this alteration through evidence-based ACLR ST exercise configurations (Tayfur *et al.,* 2021). Quadriceps arthrogenic muscle inhibition (AMI) seems to be a challenge to treat after ACLR (Sonnery-Cottet et al*.,* 2018; Pietrosimone *et al.* (2022). AMI is a presynaptic, ongoing reflex inhibition of musculature surrounding a joint after swelling or damage to structures (Hopkins *et al.,* 2000). It is a natural response designed to protect the joint from further damage, but consequently, altered neuromuscular responses like quadriceps activation failure (QAF) are caused by this neural inhibition from central drivers (Norte *et al.,* 2021). The peripheral effect of AMI plays out in quadriceps weakness characterised by a decrease in

- voluntary muscle activation,
- rate of force development, and
- strength deficits after the ACLR participants conducted a rehabilitation program (Tayfur *et al.,* 2021).

A further extension of these peripheral morphological alterations is quadriceps Type I and Type II muscle fiber atrophy and a reduction in satellite cell activation, which are necessary to increase muscle strength after ACLR (Palmieri-Smith *et al.,* 2015; Noehren *et al.,* 2016). Working towards the optimal ST stimuli targeting ACLR pathophysiological alterations on tissue (Type I and II muscle fibers) and cellular level (satellite cell activation), one should focus on the primary objective of the strengthening exercise (Thomson *et al.,* 2015). ACLR rehabilitation programs can include a diversity of strengthening exercises targeting endurance, hypertrophy, maximum strength, or power/rate of force development deficits after ACLR (Welling *et al.,* 2019; Maestroni *et al.,* 2020; Maestroni *et al.,* 2021). These objectives can be defined by the repetitions, sets, magnitude of load, etc., that drive the adaptational process from left to right (Figure 2.1) (Spiering *et al.,* 2008; Thomson *et al.,* 2015).

Predicting the optimal molecular responses, like muscle growth or strength improvement, as the primary aim during ACLR exercise rehabilitation, clinicians should adhere to recommended ST physiological principles based on the repetition maximum (RM) continuum (Figure 2.2) to effectively prescribe ACLR exercise dosages (Beachle & Earl, 2008).

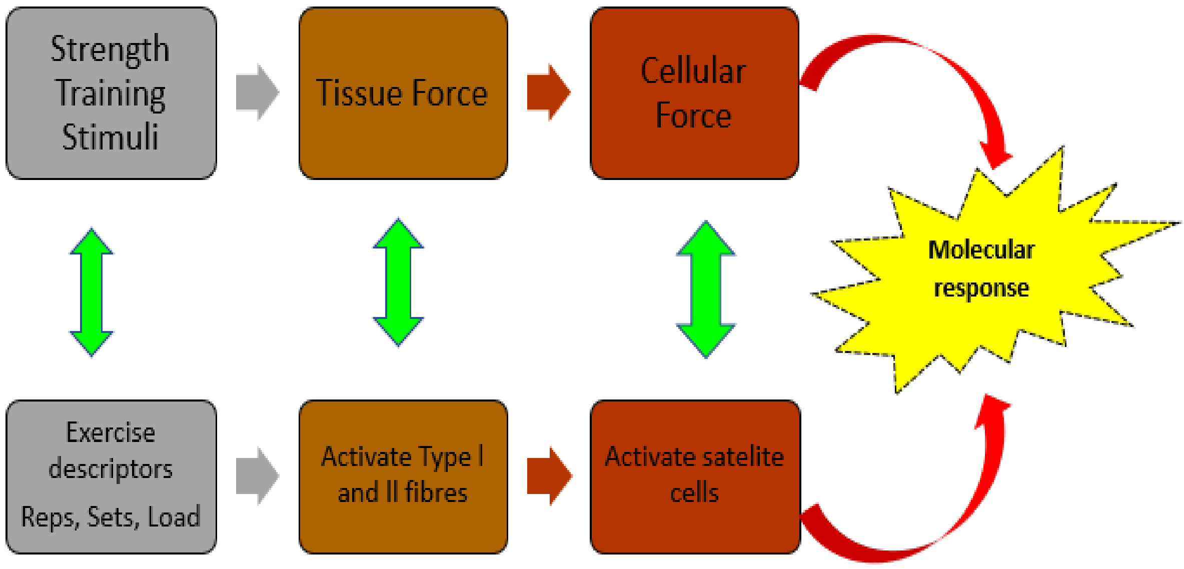

Figure 2.1: Reporting of the exercise descriptors (EDs) that drive molecular adaptational responses (developed by the researcher and adapted from Thomson et al., 2015)

Reporting of ACLR strengthening exercises descriptors (EDs) considering the repetition maximum (RM) continuum

Classifying ST EDs into the main categories of the repetition continuum (endurance, hypertrophy, maximum strength, power/rate of force development) with their individual loading parameters (repetitions, sets, tempo, rest, velocity, intensity, etc.) can emphasise a range of ST modes necessary to incorporate into ACLR rehabilitation programs. Schoenfeld *et al.* (2021: 32) are of the opinion that "repetition maximum continuum as the number of repetitions performed at a given magnitude of load, which results in specific adaptations as follows:

- A low repetition scheme with heavy loads (from one to five repetitions per set with 80% to 100% of 1-RM optimises strength increases (Figure 2.2, number 1).
- A moderate repetition scheme with moderate loads (from eight to 12 repetitions per set with 60% to 80% of 1RM) optimises hypertrophic gains (Figure 2.2, number 2).
- A high repetition scheme with light loads (15+ repetitions per set with loads below 60% of 1RM) optimises local muscular endurance improvements" (Figure 2.2, number 3).

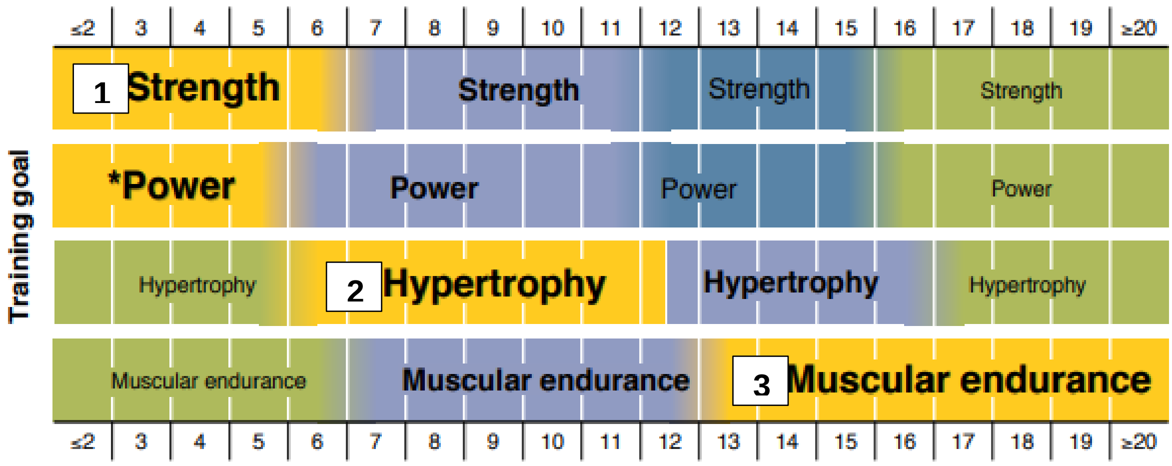

Figure 2.2: Repetition maximum (RM) continuum (Beachle & Earl, 2008)

Literature proposes that clinicians working with ACLR patients adopt targeted rehabilitation strategies that focus on lower loads initially, progressing towards maximum strength in the later phases of ACLR rehabilitation (Lorenz *et al.*, 2010; Maestroni *et al.*, 2021). Evidence of a progressive ST modal (endurance, hypertrophy, and maximum strength focused) indicates a high value for restoring quadriceps and hamstring strength deficits in ACLR amateur male and professional soccer players (Welling *et al.,* 2019; Maestroni *et al.,* 2023). Reporting the exercise dosages from high-level ACLR interventions may enable clinicians to duplicate the result of evidence-based ACLR studies.

Unfortunately, an alarming gap in ACLR rehabilitation exists due to the inadequate reporting of resistance intensity over the entire spectrum of the RM continuum

(Augustsson, 2013; Goff *et al.,* 2018). More specifically, level-one evidence indicated a dearth of reporting the intensity of power and ST exercises in the late stage (>6 months) of ACLR rehabilitation programs (Nichols *et al.,* 2021). Subsequently, a compound effect may develop between non-sporting physiotherapists that lack knowledge and skill in performing the later phases of ACLR rehabilitation, including ST exercise prescription and poor reporting of ST EDs utilised in ACLR programs (Van Melick *et al.,* 2017; Barton *et al.,* 2021: Vlok *et al.,* 2022). Therefore, research and clinical practice must follow best practice guidelines for reporting EDs and the proper execution thereof in ACLR clinical setting.

2.7 BEST PRACTICE STRENGTH TRAINING (ST) GUIDELINES TO REPORT ACLR ST DURING ACLR EXERCISE REHABILITATION PROGRAMS

ACLR rehabilitation literature recommended the usage of best practice ST guidelines like the American College of Sports Medicine (ACSM) and other supplementary literature to inform ACLR exercise programs about ST exercise dosages (Risberg *et al.,* 2007; Ratamess *et al.,* 2009). Toigo and Boutllier *et al.* (2006) reported that guidelines specific for resistance training interventions allow us to report 13 important specific ST configurations.

2.8 CORE OUTCOMES SET OF ACLR STRENGTHENING EXERCISE DESCRIPTORS (EDS)

Williamson *et al.* (2017:280) elaborated on the importance of formulating a core outcome set (COS) defined as "a list of outcomes, which experts have recommended that researchers should measure and report if they are undertaking a research study in a particular area". The COS goal in ACLR strength training (ST) is to standardise the EDs reported across studies and in clinical practice.

2.9 IMPROPER REPORTING OF ACLR STRENGTH TRAINING (ST) EXERCISE DESCRIPTORS (EDS)

Unfortunately, ACLR ST EDs (sets, tempo, repetitions, velocity, rest, intensity, etc.) are poorly reported in Levels 1-4 ACLR rehabilitation intervention studies (Nichols *et* *al.,* 2021; Vlok *et al.,* 2022). High-quality reporting is needed to improve quality appraisal, enable evidence synthesis and replication, and improve translation in clinical settings (Bartholdy *et al.,* 2019; Hansford *et al.,* 2022). We do not know whether high-quality ACLR ST programs should target these alterations by reporting the ST EDs after ACLR injury.

CHAPTER 3

SCOPING REVIEW

This chapter will focus on the scoping methodology and the scoping review article.

3.1 INTRODUCTION

In the healthcare system, we all agree that "As the drive towards evidence-based practice has gathered pace, increasing numbers of systematic reviews reporting on the effectiveness of treatments and procedures have been published by, for example, the Cochrane Collaboration, an international body supported in the UK by the UK Cochrane Centre based in Oxford, and the NHS Centre for Reviews and Dissemination (CRD) at the University of York" (Arksey & O'Malley, 2005:19). Furthermore, according to Arksey and O'Malley (2005: 19), "this rapid growth in undertaking reviews of the literature has resulted in a plethora of terminology to describe approaches. However, despite the different names used in literature reviews, all literature reviews share certain essential characteristics, namely:

- Collecting,
- Evaluating, and
- presenting the available research evidence".

More recently, the field of evidence synthesis has seen the emergence of "scoping reviews", which are very similar to "systematic reviews" in that they follow a structured process. However, it is important to note that scoping reviews are performed for different reasons and have some key methodological differences (Munn *et al*., 2018). It is also important to note that there is no universally accepted definition or purpose for a scoping review (Daudt *et al.,* 2013; Pham *et al*., 2014); however, the main characteristic of this method is that it provides an overview of a broad topic (Moher *et al*., 2015; Pham *et al.,* 2014). Moher *et al*. (2015: 4) also stated "that a scoping review allows for a more general question and exploration of the related literature rather than focusing on providing answers to a more limited question". Davis *et al*. (2009) agreed and stated that the strength of scoping reviews lies in the development and intellectual creativity process. Peterson *et al*. (2016) concluded that the "methodology for a scoping review comprised similar systematic activities completed in any review, including:

- Focus on a specific topical area,
- a well-defined research question,
- rationale regarding inclusion and exclusion criteria, and
- clearly defined procedures and responsibilities for all researchers".

According to Munn *et al*. (2018:1), "Scoping reviews are now seen as a valid approach in those circumstances where systematic reviews are unable to meet the necessary objectives or requirements of knowledge users. There now exists clear guidance regarding the definition of scoping reviews, how to conduct scoping reviews and the steps involved in the scoping review process (see Appendix B)". Munn *et al*. (2018:1) concluded that "researchers may conduct scoping reviews instead of systematic reviews where the purpose of the review is to identify knowledge gaps, scope a body of literature, clarify concepts or to investigate research conduct. While useful in their own right, scoping reviews may also be helpful precursors to systematic reviews and can be used to confirm the relevance of inclusion criteria and potential questions".

Thus, a scoping review design was used due to the exploratory nature of our research question. Therefore, the aim of this scoping review was "to determine which strength training (ST) exercise descriptors (EDs) are reported in ACLR rehabilitation research. Our secondary aim was to evaluate how the reporting in these studies compares to international standards of reporting ST Eds". From the literature, it is clear that a well-executed scoping review on ACLR rehabilitation has the potential to inform biokineticists, physios, and other clinicians in practice.

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Exercise Descriptors That Determine Muscle Strength Gains Are Missing From Reported Anterior Cruciate Ligament Reconstruction Rehabilitation Programs: A Scoping Review of 117 Exercises in 41 Studies

Muscle weakness after anterior cruciate ligament reconstruction (ACLR) is persistent and associated with abnormal biomechanics,[48,61] poor knee function,[5,14,44-46] new knee injury,[27,42] and development of osteoarthritis.[49,60]

OBJECTIVE: To (1) describe which strength training exercise descriptors are reported in anterior cruciate ligament reconstruction (ACLR) rehabilitation research, and (2) compare the current standards of reporting ACLR strength training exercise descriptors to international best-practice strength training guidelines.

DESIGN: Scoping review.

LITERATURE SEARCH: We searched the MEDLINE, PsycINFO, CINAHL, SPORTDiscus, Academic Search, ERIC, Health Source: Nursing, Health Source: Consumer, MasterFILE, and Africa-Wide Information databases.

STUDY SELECTION CRITERIA: We included level I to IV studies of ACLR rehabilitation programs with 1 or more reported strength training exercise descriptors. We used a predefined list of 19 exercise descriptors, based on the American College of Sports Medicine (ACSM) exercise recommendations, the Consensus on Exercise Reporting Template (CERT), and the Toigo and Boutellier exercise descriptor framework.

DATA SYNTHESIS: Completeness and the standard of reporting exercise descriptors in ACLR rehabilitation programs were assessed by means of international best-practice strength training standards.

RESULTS: We extracted data on 117 exercises from 41 studies. A median of 7 of the 19 possible exercise descriptors were reported (range, 3-16). Reporting of specific exercise descriptors varied across studies, from 95% (name of the strength training exercise) to 5% (exercise aim, exercise order). On average, 46%, 35%, and 43% of the exercise descriptors included in the ACSM, CERT, and Toigo and Boutellier guidelines were reported, respectively.

CONCLUSION: Key exercise descriptors for muscle strength gains are not reported in studies on ACLR rehabilitation. Only the exercise name, number of exercises, frequency, and experimental period were reported in most of the studies. *J Orthop Sports Phys Ther 2022;52(2):100-112. Epub 16 Nov 2021. doi:10.2519/jospt.2022.10651*

KEY WORDS: *anterior cruciate ligament reconstruction, CERT, exercise descriptors, intervention reporting, strength training*

Six months after ACLR, up to 40% of patients have side-to-side differences in quadriceps strength.[45] Additionally, patients had moderate side-to-side differences in isometric and concentric quadriceps strength, significant differences in eccentric quadriceps strength, and moderate differences in isometric hamstring strength 2 years after ACLR.[77] The proposed drivers of persistent muscle weakness after ACLR are changes in muscle morphology,[10,58] atrophy-inducing cytokines in the knee joint,[55,85] and neurological alterations at cortical and spinal levels.[65]

The most accessible approach to target muscle weakness is to use various types of strength training exercises.[51,63] Because muscle weakness persists after rehabilitation, standard strength training may not be sufficient, and clinicians should target the neurophysiological origins of weakness with, for example, joint aspiration, corticosteroid injection, or electromagnetic modalities.[48] However, another explanation for persistent weakness after ACLR rehabilitation could be

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The study protocol was approved by the University of the Free State Health Sciences Research Ethics Committee (reference number UFS-HSD2019/1889/2502). No funding was received for this review. Dr Grindem is an associate editor of the *JOSPT*. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.
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that programs are not following best practice for strength training.[21]

To improve muscle performance outcomes, a strength training program should follow the proposed laws of mechanotransduction,[39] exercise specificity,[40] and the specific adaptations to imposed demands principle. Failure to improve muscle strength after ACLR could, therefore, be caused by faulty programming of exercise descriptors (eg, exercise type, frequency, and load).[54] To determine whether the full potential of strength training was realized in previous literature, we need more knowledge about the exercise descriptors that are reported in ACLR rehabilitation studies.

Exercise descriptors that impact the result of strength training are well described in key exercise physiology publications. In 2006, Toigo and Boutellier[79] (T&B) reviewed mechanobiological determinants of muscle hypertrophy and presented exercise descriptors that target these determinants. Ratamess et al[66] proposed guidelines and progression models for resistance training in the position stand statement of the American College of Sports Medicine (ACSM). Slade et al[74] developed the Consensus on Exercise Reporting Template (CERT) to improve the reporting of essential exercise components across all evaluative study designs. These international standards collectively cover a comprehensive list of exercise descriptors that influence the outcomes of strength training programs. Therefore, the primary aim of this scoping review was to determine which strength training exercise descriptors are reported in ACLR rehabilitation research. Our secondary aim was to evaluate how the reporting in these studies compares to international standards of reporting strength training exercise descriptors.

METHODS

Protocol and Registration

A scoping review design was used due to the exploratory nature of the research question, where the aim was to determine which strength training exercise descriptors are reported in ACLR rehabilitation research. Study quality and risk-of-bias assessments do not influence scoping review outcomes and were therefore not performed.[1] We followed the 5-stage methodological framework proposed by Arksey and O'Malley,[1] using the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR)[80] guidelines to map the available ACLR exercise descriptors. The review was registered prospectively through the Joanna Briggs Institute web page (https://joannabriggs.org/systematic-review-register) and the Open Science Framework online platform (https://doi.org/10.17605/OSF.IO/62VYA).

Eligibility Criteria

We included randomized trials, cohort studies, cross-sectional studies, case reports, and case-control studies in the scoping review. The search was limited to studies published in the English language. Studies that reported ACLR strength training exercise descriptors between January 1990 and April 2021 as part of rehabilitation were included. We chose this time frame to limit the review to recent studies and thereby reflect current clinical practice.

Inclusion in this scoping review was based on the following eligibility criteria.

Participants Men and women (aged 16 years and older) with ACLR in isolation or in combination with meniscus repair/resection or cartilage surgery were included. The ACLR could be performed with either patellar tendon or hamstring tendon autografts. Studies that included patients who had ACLR with allografts and anterior cruciate ligament (ACL) repair were excluded, as differences in graft strength, fixation strength, and functional tension can influence rehabilitation.[28] Articles were excluded if the studied participants were nonsurgically treated after ACL injury, had other associated grade lll ligamentous knee injuries combined with ACL injury, or had significant concomitant injuries to any area other than the knee.

Exercise Intervention We included studies that described strength training exercises, defined as exercises with a fixed mass as the means of resistance (eg, ankle weights, plate-loaded resistance training machines, free weights, or resistance bands). A priori defined strength training descriptors are described in **TABLE 1**. We excluded studies that described strength training only in combination with supplementary modalities, such as neuromuscular electrical stimulation, blood flow restriction training, isokinetics, or cryotherapy.

Time At least 1 strength training exercise descriptor had to be reported in the rehabilitation program between 2 and 12 months post ACLR.

Context We included studies in which rehabilitation was performed in any setting (home-based, gym-based, or clinic-based rehabilitation).

Information Sources and Search

The librarian and first author (A.V.) compiled key phrases and words to search the different databases **(Appendix D)**. A librarian- assisted computer search of MEDLINE, PsycINFO, CINAHL, SPORTDiscus, Academic Search, ERIC, Health Source: Nursing, Health Source: Consumer, MasterFILE, and Africa-Wide Information was conducted in October 2019 and updated in April 2021. The first author (A.V.) did a hand search of all references in all included papers to identify potentially eligible articles that were missed during the electronic database search.

Study Selection

All references were downloaded into an Excel (Microsoft Corporation, Redmond, WA) spreadsheet screening tool, specifically developed by a librarian (Helena VonVille) for literature reviews. All duplicates were removed before the screening process. Two independent screeners (A.V. and D.C.) conducted the level 1 initial screening process of each article. To ensure interscreener reliability, the reviewers performed 1 training session before the screening process. Two reviewers (A.V. and D.C.) independently screened titles and abstracts for relevance. We compared and summarized the results within the customized Excel spreadsheet workbook. The remaining studies were independently screened by the same reviewers in full text to determine eligibility, and reasons for exclusion were reported **(Appendix D)**. Any disagreements between reviewers were resolved in a consensus meeting. Duplicate interventions were excluded, and we included the intervention with the most comprehensive description of exercises. The scoping review focused only on the extent to which studies reported the strength training exercise descriptors. The review did not focus on the outcome (efficiency or effectiveness) of any intervention.

Data Extraction

We reviewed full-text articles, supplementary files, and referenced articles to locate data for extraction. Data extraction was primarily performed by 1 reviewer (A.V.) and verified by a second (D.C.). To ensure that the data extraction was consistent, a random sample of the included studies (ie, 5% of the complete list of retrieved studies) was extracted in duplicate (A.V. and D.C.).

The 19 descriptors (**TABLE 1**) obtained from different sources (ACSM, T&B, and CERT) were extracted as the primary strength training descriptors. Two of these templates (T&B and CERT) have previously been used in studies evaluating exercise descriptors.[3,12,29] We composed the list of descriptors based on available guidelines on strength training recommendations (ACSM),[66] strength training exercise physiology (T&B),[79] and consensus recommendations for reporting exercise interventions (CERT).[74] The screening authors reviewed and selected 19 descriptors a priori for data extraction through a consensus approach (**TABLE 1**).

For all studies included in the review and for all strength training exercise descriptors (**TABLE 1**), the presence of a given exercise descriptor in a given study was coded as binary data (1 is present, 0 is absent). Additionally, we extracted data that described any clinical indicators that would cause adjustment to the strength training program (eg, pain or effusion).

Data Management and Analysis

The percentage of studies that reported the exercise descriptor (out of the total number of studies included) was calculated. In addition, we calculated the percentage of exercise descriptors reported in a given study (out of the total number of exercise descriptors stipulated in each of the 3 guidelines). These percentages were calculated as averages for each publication year in the period from 1992 to

TABLE 1 Definition of Strength Training Exercise Descriptors

		Checklist or Recommendation		
Descriptor	**Definition**	**ACSM**	**T&B**	**CERT**
Exercise name	The name of the exercises prescribed	x	x	
Experimental period	The duration of the entire program (eg, 12 weeks)		x	x
Number of exercises	The number of exercises prescribed per session	x		
Frequency	The number of sessions per week	x	x	x
Adherence	The extent to which the patient performed the prescribed program			x
Repetitions	The number of movements in a set	x	x	x
Exercise progress	The progression of individual exercises (eg, increase in repetitions, load, and speed)	x		x
Exercise type	The mode of exercise selected for a training program (eg, neuromuscular control exercises or strength training)	x		
Program progress	The progression of the entire program (eg, increase in the number of exercises or sessions per week)			x
Sets	The number of cycles of repetitions performed. Sets are separated by a rest interval	x	x	x
Load	The amount of resistance assigned to an exercise set	x	x	x
Range of motion	The degree of movement around a specific joint during an exercise		x	x
Rest	The duration of recovery time between sets	x	x	x
Tempo	The velocity at which an exercise is performed	x		x
Muscle action	The type of muscle action during a repetition (eg, concentric, isometric, or eccentric)	x	x	
Muscular voluntary failure	Whether exercises should be performed to the point of muscular voluntary failure (eg, repetitions performed		x	x
Training duration	The duration of each session (eg, 45 minutes)			x
Exercise order	The sequence of exercises performed in a session (eg, multijoint exercises before single-joint exercises)	x		
Exercise aim	The specific purpose of the exercise (eg, hypertrophy or maximum strength)			x

Abbreviations: ACSM, American College of Sports Medicine; CERT, Consensus on Exercise Reporting Template; T&B, Toigo and Boutellier.

2020, together with rolling averages, using a window size of 5 (**FIGURE 1**).

RESULTS

The search yielded 754 studies after 7 hand-searched articles were added. After duplicates were removed, 420 studies remained for title and abstract screening. After applying the eligibility criteria, a total of 41 studies were included in the review (**FIGURE 2**).

Baseline Study Characteristics

The demographic characteristics of the 41 studies included in the analy- sis are summarized in **TABLE 2**. In total, 28 randomized controlled trials (68%), 6 prospective cohort studies (15%), 3 cross-sectional studies (7%), 3 case reports (7%), and 1 case series (2%) were included. Collectively, the studies represent 1964 individuals who underwent rehabilitation after ACLR, 1492 (76%) men and 472 (24%) women aged 16 to 56 years. The ACLR was performed with either a patellar tendon (63%) or hamstrings tendon (37%) autograft.

Rehabilitation Setting

Experienced clinicians supervised the majority (30/41 studies, 73%) of ACLR rehabilitation programs in sports clinics, gyms, or hospital-based facilities. Fewer rehabilitation programs were entirely unsupervised: home based (9/41 studies, 22%), or home based combined with supervised booster sessions (2/41 studies, 5%).

Reported Strength Training Exercise Descriptors in ACLR Rehabilitation Research

A total of 117 ACLR strength training exercises were described in the 41 studies. The studies reported between 3 and 16 of the 19 exercise descriptors (**FIGURE 3**), with a median of 7 exercise descriptors reported. The name of the strength training exercises, number of exercises, and the experimental period were the descriptors most often documented in the included studies (**FIGURES 3** and **4**). The number of exercises used and the frequency of sessions were reported 71% to 83% of the time (**FIGURE 4**). Across the different studies, experimental periods most often lasted 3 to 6 months (24/41, 59%), and patients most often performed 2 to 3 exercise sessions per week (20/41, 49%). Supervised sessions varied from 2 (8/41 studies, 20%) to 3 sessions (17/41 studies, 41%) per week. There was, however, a considerable variation in sessions per week, from 2 to 10. The most frequently prescribed exercises to improve muscle strength were leg press (19/41 studies) and leg extension (20/41 studies).

Fewer than half of the studies reported exercise type, exercise progress, program progress, repetitions, sets, adherence, range of motion, and magnitude of load (**FIGURE 4**). Collectively, 44% to 46% of studies described number of repetitions, exercise progress, exercise type, program progress, and sets (**FIGURE 4**). Of the 117 exercises described across the studies, 53 (45%) included information on the number of repetitions. Tempo, rest, range of motion, and load magnitude were all reported in 20% to 34% of the studies. Only 34% (14/41) of the studies specified the magnitude of load, which was com-

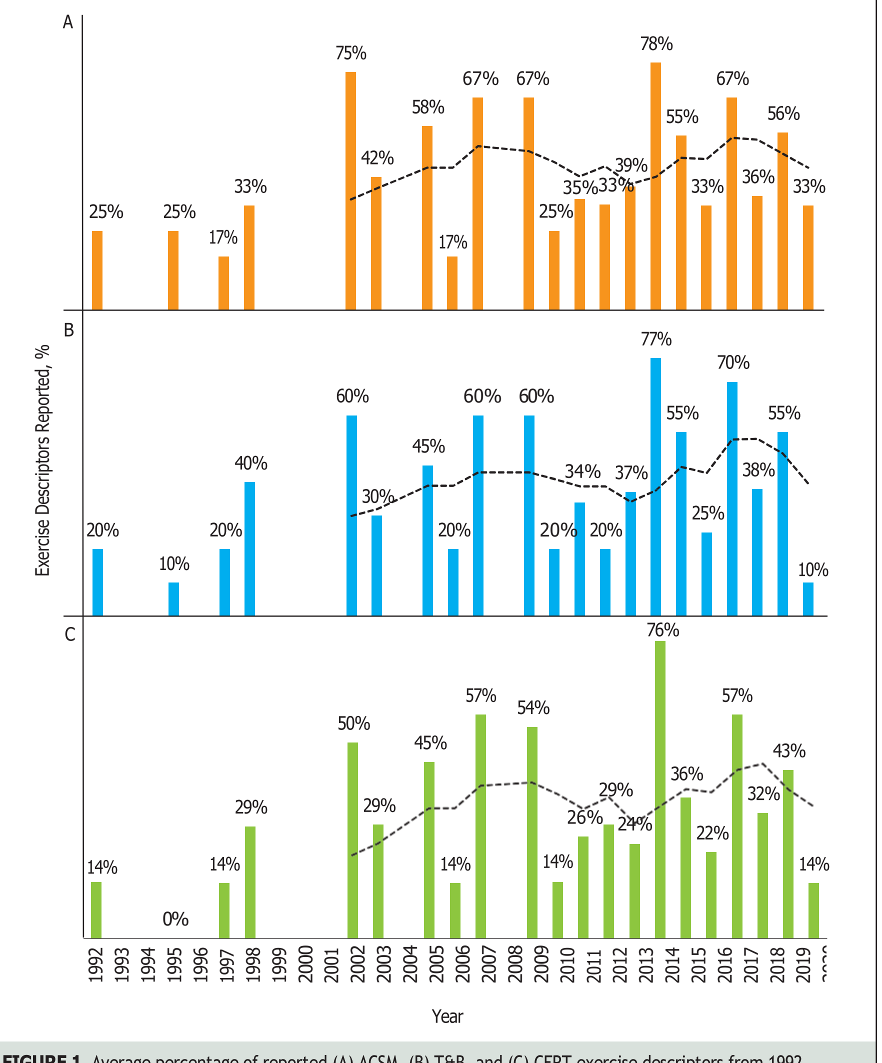

FIGURE 1. Average percentage of reported (A) ACSM, (B) T&B, and (C) CERT exercise descriptors from 1992 to 2020. Lines indicate rolling averages. Abbreviations: ACSM, American College of Sports Medicine; CERT, Consensus on Exercise Reporting Template; T&B, Toigo and Boutellier.

monly 50% to 80% of 1-repetition maximum (1RM).

Only 5% to 15% of studies reported the exercise descriptors of muscular voluntary failure, exercise aim, training duration, muscle action, and exercise order (**FIGURE 4**).

Clinical Status of ACLR Knee During the Rehabilitation

Fewer than half of the studies (18/41, 44%) reported that exercises were adjusted based on the clinical status of the knee. Pain and effusion were 2 key indicators that were noted in 16/41 (39%) studies.

Reporting of ACLR Rehabilitation Research Compared With International Strength Training Standards

The average annual reporting values of the strength training exercise descriptors for the time period of 1992 to 2020 for the ACSM (**FIGURE 1A**), T&B (**FIGURE 1B**), and CERT (**FIGURE 1C**) guidelines were summarized in **FIGURE 1**. Average annual ACLR exercise descriptor reporting varied between 17% and 78% when compared to ACSM guidelines. There was a 10% increase in the reporting of ACSM exercise descriptors from 2002 (rolling average, 35%) to 2020 (rolling average, 45%). For the T&B framework, ACLR exercise descriptor documentation varied between 10% and 77%.

The reporting of items 5, 7, 11, and 13 of the CERT guidelines (adapted for this study; **TABLE 1**) is presented in **FIGURE 1C**, with 13 descriptors to evaluate the ACLR intervention programs' reporting quality. Exercise descriptor reporting using the CERT guidelines varied between 0% and 76%. The rolling averages demonstrated large variability in the reporting of the exercise descriptors for all 3 guidelines (**FIGURE 1**). The average percentages of ACLR exercise descriptors documented (1992-2020) for each source were 46% (ACSM), 35% (CERT), and 43% (T&B).

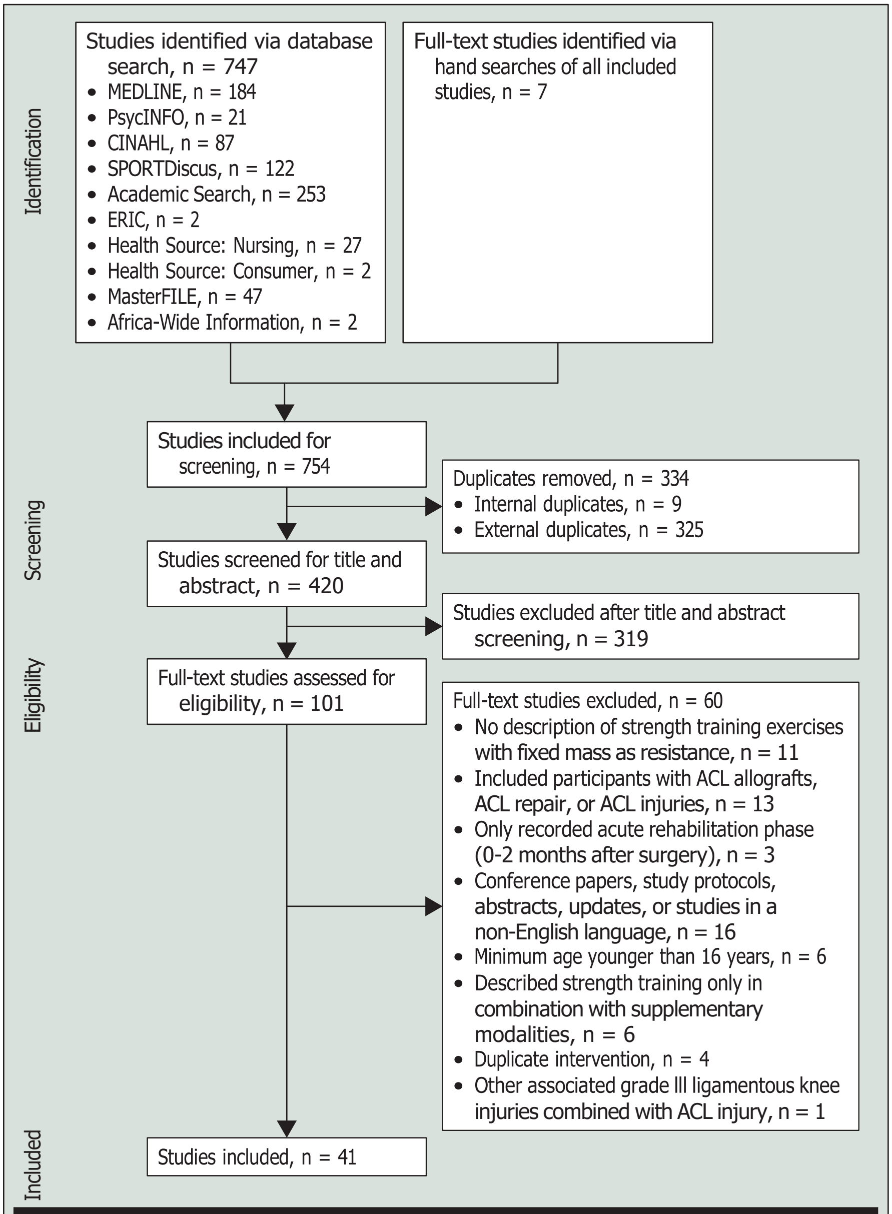

FIGURE 2. Flow chart of the study selection process according to the PRISMA extension for Scoping Reviews guidelines. Abbreviation: ACL, anterior cruciate ligament.

DISCUSSION

In studies on ACLR rehabilitation, the exercise name, the duration of the rehabilitation period, the number of exercises in the program, and the frequency of training sessions per week were frequently reported. The remaining 15 exercise descriptors included in international standards of strength training were infrequently reported (by 5% to 49% of studies).

How Is Strength Training Prescribed in ACLR Rehabilitation Studies?

Only 4 of the 19 exercise descriptors were consistently documented in our sample (**FIGURE 4**), and it is difficult to interpret or reproduce ACLR strength training programs when so few exercise descriptors are reported. The poor reporting also means that we cannot conclude that muscle weakness persists in patients who follow best practice for strength training.[21] Clinicians should therefore not discount strength training as a main factor to regain muscle strength after ACLR.

Strength Training and Muscle Weakness After ACLR

Although many factors influence successful rehabilitation and return to sport post ACLR,[59] muscle weakness after ACLR is driven by 2 main factors: a decrease in the cross-sectional area (atrophy) and arthrogenic muscle inhibition (quadriceps activation failure).[38,56,78] According to the ACSM best-practice strength training guidelines, strength training to increase the cross-sectional area should be performed with 6 to 12 repetitions, 2 to 4 sets, 60 to 120 seconds of rest between sets, and a load magnitude of 60% to 80% of 1RM. Exercises should include concentric, isometric, and eccentric muscle actions. The program's proposed duration should be 8 to 12 weeks, with a frequency of 2 to 4 sessions per week.[40] It should be noted, however, that more recent research has found that hypertrophy can be achieved with both low-load and high-load strength training.[71]

Of the studies on ACLR rehabilitation, 90% reported the experimental period's duration and 71% included frequency. However, only 44% of studies reported sets, 46% reported repetitions, 34% reported load magnitude, 20% reported rest, and 15% reported muscle action. Strength training exercise descriptors are important if we are to understand the impact of exercise selection on cross-sectional area in ACLR rehabilitation programs. Few studies report all exercise descriptors included in international standards for strength training, which impedes any interpretation of whether study participants received an adequate strength training stimulus to reduce muscle atrophy. In addition, low-intensity strength training post ACLR leads to lower muscle power response in leg extension when compared to high-intensity training.[9]

Activating the high-threshold motor units with maximal strength training is one way to target quadriceps muscle inhibition.[54] Exercise prescription for maximal strength training should involve a load magnitude of greater than 80% of 1RM, 1

TABLE 2 Demographic Characteristics of Study Participants

Study, Year, Study Design	Sample Size (Sex), Age[a]	Preinjury TAS Score[b]	Start of post-ACLR Rehabilitation	Graft Type
Wilk et al[84] 1992 CSS	n = 250 (all male) 24 ± 8	...	Day 1	Patellar, n = 250
Bynum et al[11] 1995 RCT	n = 97 (88 male, 9 female) 27	4	Day 2	Patellar, n = 97
De Carlo and Sell[17] 1997 RCT	n = 180 (130 male, 50 female) 28	...	Week 2	Patellar, n = 180
Beard and Dodd[4] 1998 RCT	n = 26 (21 male, 5 female) 28	...	Day 3	Patellar, n = 26
Tsaklis and Abatzides[81] 2002 RCT	n = 45 (all male) 25 ± 6	...	Week 1	Patellar, n = 45
Liu-Ambrose et al[51] 2003 RCT	n = 10 (4 male, 6 female) 25 ± 3	9 ± 1[c]	...	Hamstring, n =10
Beynnon et al[8] 2005 RCT	n = 22 (11 male, 11 female) 33	...	Week 1	Patellar, n = 22
Perry et al[64] 2005 RCT	n = 49 (37 male, 12 female) 33 ± 7	...	Day 1	Hamstring, n = 21; patellar, n = 28
Roi et al[70] 2005 CR	n = 1 (male) 35	...	Day 8	Hamstring, n = 1
Cooper et al[13] 2005 RCT	n = 29 (20 male, 9 female) 30 ± 7	...	Days 45-50	Hamstring, n = 26; patellar, n = 3
Gerber et al[24] 2007 RCT	n = 32 (18 male, 14 female) 30 ± 9	>4	Week 3	Hamstring, n = 20; patellar, n = 12
Risberg et al[69] 2007 RCT	n = 74 (47 male, 27 female) 28	...	Week 2	Patellar, n = 74
Morrissey et al[57] 2009 RCT	n = 24 (not reported) 31 ± 7	...	...	Hamstring, n = 6; patellar, n = 18
Revenäs et al[67] 2009 RCT	n = 38 (26 male, 12 female) 23	...	Week 1	Hamstring, n = 15; patellar, n = 23
Grant and Mohtadi[26] 2010 RCT	n = 88 (all male) 31 ± 11	...	...	Patellar, n = 88
Beynnon et al[7] 2011 RCT	n = 36 (22 male, 14 female) 30 ± 10	>5	Day 1	Patellar, n = 36
Feil et al[20] 2011 RCT	n = 96 (22 male, 74 female) 33 ± 2	...	Day 1	Hamstring, n = 96

Table continues on page 106.

TABLE 2 Demographic Characteristics of Study Participants (continued)

Study, Year, Study Design	Sample Size (Sex), Age[a]	Preinjury TAS Score[b]	Start of post-ACLR Rehabilitation	Graft Type
Hohmann et al[34] 2011 RCT	n = 40 (30 male, 10 female) 20	...	Day 10	Patellar, n = 40
Lemiesz et al[43] 2011 CSS	n = 18 (13 male, 5 female) 24	...	Week 2	Hamstring, n = 18
Souissi et al[75] 2011 RCT	n = 16 (all male) 22 ± 3	...	...	Patellar, n = 16
Silva et al[73] 2012 CS	n = 7 (6 male, 1 female) 27 ± 4	...	...	Patellar, n = 7
Ericsson et al[19] 2013 PC	n = 65 (42 male, 23 female) 26 ± 5	...	Day 1	Hamstring, n = 36; patellar, n = 25
Fukuda et al[23] 2013 RCT	n = 45 (29 male, 16 female) 25 ± 7	...	Week 2	Hamstring, n = 45
Taradaj et al[76] 2013 RCT	n = 80 (all male) 22 ± 6	...	Week 2	Hamstring, n = 80
Berschin et al[6] 2014 RCT	n = 40 (29 male, 11 female) 28 ± 6	...	Week 2	Patellar, n = 40
Bieler et al[9] 2014 RCT	n = 50 (31 male, 19 female) 29 ± 1	...	Day 1	Hamstring, n = 23; patellar, n = 27
Horschig et al[36] 2014 CR	n = 1 (male) 17	...	...	Patellar, n = 1
Harput et al[31] 2015 PC	n = 24 (all male) 28 ± 8	...	Week 1	Hamstring, n = 24
Lepley et al[47] 2015 PC	n = 36 (23 male, 13 female) Not reported	...	Week 6	Hamstring, n = 5; patellar, n = 31
Hadizadeh et al[30] 2016 PC	n = 22 (13 male, 9 female) 23 ± 4	...	Day 3	Hamstring, n = 22
Luo et al[52] 2016 RCT	n = 40 (27 male, 13 female) 43 ± 14	...	Week 1	Hamstring, n = 40
Kuenze et al[41] 2017 PC	n = 10 (1 male, 9 female) 22 ± 3	8 ± 1[c]	...	Hamstring, n = 5; patellar, n = 5
Friedmann-Bette et al[22] 2018 RCT	n = 68 (55 male, 13 female) 25 ± 5	...	...	Hamstring, n = 26; patellar, n = 32
Machado et al[53] 2018 CSS	n = 34 (26 male, 8 female) 35 ± 10	...	Week 1	Hamstring, n = 17; patellar, n = 17

Table continues on page 107.

to 6 repetitions across 3 to 5 sets, a rest period of 3 to 5 minutes, and a frequency of 2 to 3 times per week.[66] Due to Henneman's size principle, muscle contractions should be completed to the point of muscular voluntary failure to activate the high-threshold motor units.[33] However, only 15% of ACLR rehabilitation studies described whether exercises were performed to muscular voluntary failure, and 49% described the participants' adherence to the intervention program (**FIGURE 4**). Therefore, for most of these studies, we do not know whether these strength training principles were followed.

Poor Functional Outcomes and Exercise Progression Principles

The ACSM recommendations for increasing strength involve implementing basic exercise progression principles (progressive overloading), such as increases in loads, repetitions, or sets. To improve functional performance and prepare patients with ACLR for the demands of cutting and pivoting sports, ACLR rehabilitation should include progressive overload.[68] Although this strength training principle has been described in some ACLR strength training programs, many patients continue to struggle with asymmetrical knee function and muscle weakness after ACLR.[18,27,68,83] Fewer than half of the studies reported exercise descriptors for progressive overload (exercise progress and program progress) (**FIGURE 4**). Exclusion of the exercise descriptors for progressive overload could indicate a lack of emphasis on loading in the programs. It is imperative that descriptors for progressive overload are reported, as underloading in ACLR strength training programs might contribute to the persistent muscle weakness observed in the studies. Muscle weakness, and particularly quadriceps weakness, after ACLR is associated with numerous complications, such as poor patient-reported outcomes,[45] gait asymmetries,[72] and altered knee joint biomechanics.[62] Knee osteoarthritis may also develop as a long-term consequence of quadriceps muscle weakness.[60]

TABLE 2 Demographic Characteristics of Study Participants (continued)

Study, Year, Study Design	Sample Size (Sex), Age[a]	Preinjury TAS Score[b]	Start of post-ACLR Rehabilitation	Graft Type
Damian and Damian[16] 2018 CR	n = 1 (male) 18	...	Day 7	Hamstring, n = 1
Lim et al[50] 2019 RCT	n = 30 (19 male, 11 female) 32 ± 11	...	Week 2	Hamstring, n = 30
Harput et al[32] 2019 RCT	n = 48 (not reported) 30 ± 7	>5	Week 1	Hamstring, n = 48
Hughes et al[37] 2019 RCT	n = 24 (17 male, 7 female) 29 ± 7	7 ± 2[c]	...	Hamstring, n = 24
Welling et al[83] 2019 PC	n = 38 (all male) 24 ± 4	...	Week 2	Hamstring, n = 24; patellar, n = 14
Vidmar et al[82] 2020 RCT	n = 30 (all male) 24 ± 6	...	Day 45	Hamstring, n = 30
Cristiani et al[15] 2021 RCT	n = 160 (115 male, 45 female) 29 ± 6	...	Weeks 1-3	Hamstring, n = 80; patellar, n = 80

Abbreviations: CR, case report; CS, case series; CSS, cross-sectional study; PC, prospective cohort; RCT, randomized controlled trial; TAS, Tegner activity scale.
[a]*Age values are mean or mean ± SD years. The SD for age was only included if it was reported in the original study.*
[b]*Values are mean ± SD or the score defined in the inclusion criteria.*
[c]*The Cochrane formula to combine groups was used to calculate the mean ± SD.*

Is the Reporting Improving?

Despite the popularity of the ACSM guidelines for strength training purposes, these guidelines are not reflected in our findings on rehabilitation strength training exercise descriptors (**FIGURE 1A**). Similarly, descriptors included in the T&B and CERT guidelines were also inconsistently used (**FIGURES 1B** and **1C**, respectively). Rehabilitation studies published after the publication of the T&B[79] framework and the CERT[74] guidelines did not show markedly higher standards of reporting compared to studies published before these guidelines existed (**FIGURES 1B** and **1C**). These findings suggest that reporting of exercise descriptors is still not highly prioritized in this field of research. It is beyond the scope of our study to determine the reasons for poor reporting. However, we call on authors and editors to ensure that exercise descriptors in rehabilitation programs are reported along with other study details (eg, design and surgical procedures), and to make use of appendices if the level of reported detail is restricted by article word limits. Only with reported exercise descriptors can study results be fully interpreted and rehabilitation research replicated. For clinicians, reported exercise descriptors are also key to successfully transfer rehabilitation programs from research to practice.

Is the Lack of Reporting Unique to ACLR Rehabilitation?

The inadequate intervention reporting is not a phenomenon related exclusively to ACLR rehabilitation studies. None of the interventions used to develop knee osteoarthritis exercise recommendations were reported in enough detail to allow replication in clinical practice.[3] Exercise descriptors in patellofemoral pain and Achilles tendon rupture intervention studies are also poorly documented.[12,35] Our findings expand on those of 2 other reviews, which concluded that acute program variables (exercise order, tempo, rest, frequency) are inadequately described in tibiofemoral joint soft tissue injuries[25] and that the reporting of ACLR rehabilitation programs lacks specificity.[2]

Strengths and Limitations

We assessed 117 ACLR strength training exercises across 41 studies for reporting quality and compared ACLR strength training exercise reporting with international standards for strength training, a novel approach in scoping reviews on ACLR rehabilitation interventions. The search was limited to the last 30 years, and we assessed development over time, which strengthens our ability to draw conclusions on contemporary ACLR rehabilitation programs. We only included studies on rehabilitation after ACLR with autografts, and our conclusions may not apply to rehabilitation programs after ACLR with allografts and to nonsurgical ACL rehabilitation programs.

CONCLUSION

Most strength training exercise descriptors that determine muscle strength gains are inad- equately reported in studies on ACLR rehabilitation. Only the exercise name, number of exercises, frequency, and the duration of the experimental period were reported in most of the studies. U

KEY POINTS

FINDINGS: The only exercise descriptors frequently reported in studies on anterior cruciate ligament reconstruction (ACLR) rehabilitation were the exercise name, the number of exercises in the program, the duration of the rehabilitation period, and the frequency of training sessions per week. Over the past 3

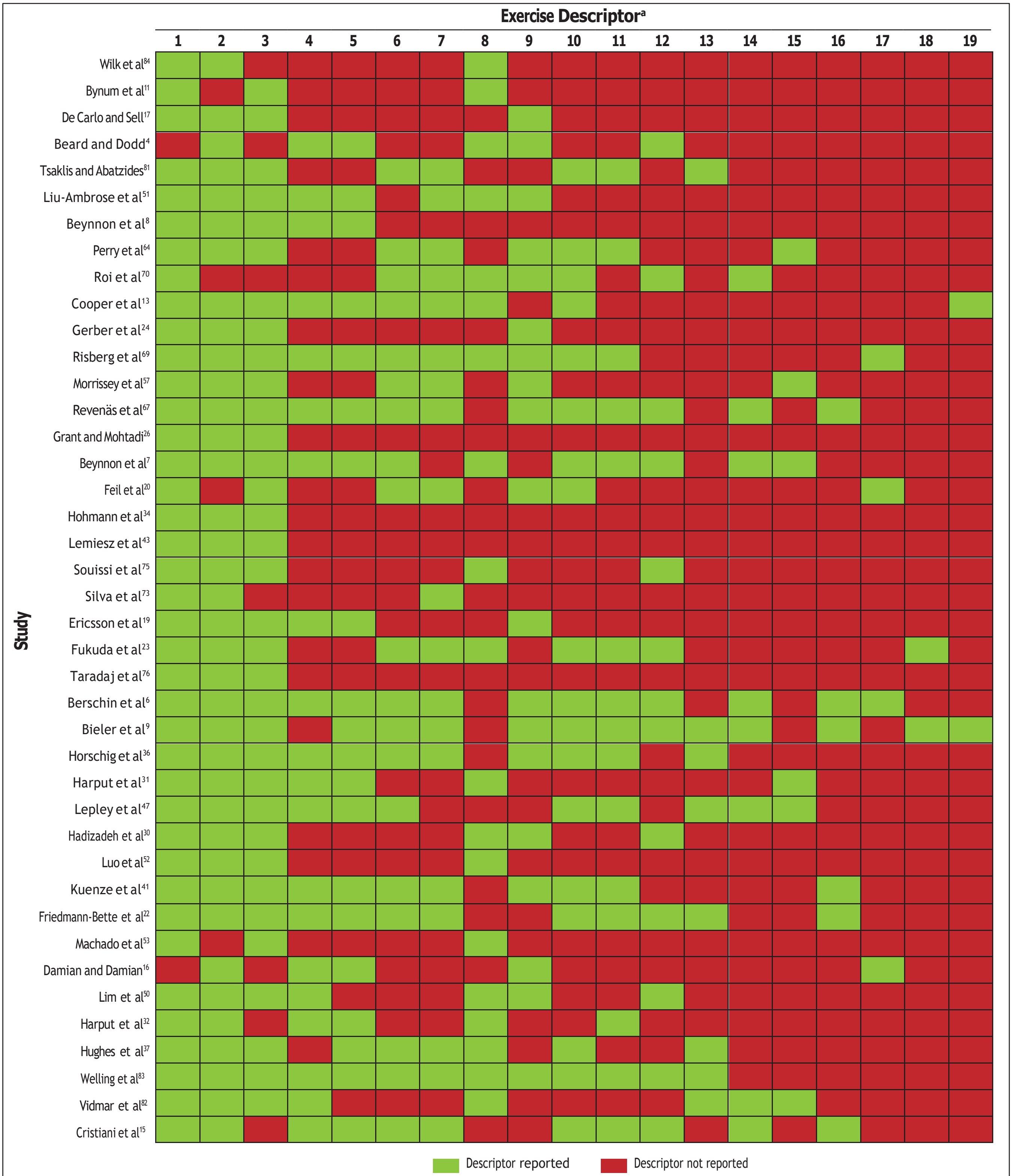

FIGURE 3. Exercise descriptors reported in studies on rehabilitation after anterior cruciate ligament reconstruction. [a]1, Exercise name; 2, Expermental period; 3, Number of exercises; 4, Frequency; 5, Adherence; 6, Repetitions; 7, Exercise progress; 8, Exercise type; 9, Program progress; 10, Sets; 11, Load; 12, Range of motion; 13, Rest; 14, Tempo; 15, Muscle action; 16, Muscular voluntary failure; 17, Training duration; 18, Exercise order; 19, Exercise aim.

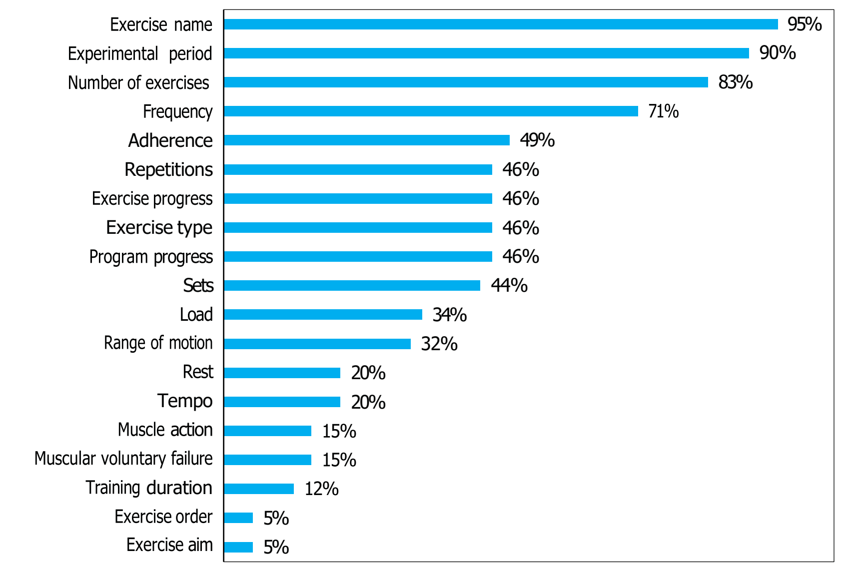

FIGURE 4. Percentage of studies that reported strength training exercise descriptors in rehabilitation programs after anterior cruciate ligament reconstruction.

decades, there has been no apparent improvement in the reporting of exercise descriptors included in the American College of Sports Medicine, Consensus on Exercise Reporting Template, and Toigo and Boutellier strength training guidelines.

IMPLICATIONS: Persistent muscle weakness is reported after ACLR rehabilitation, but how the strength training was performed is poorly reported. Clinicians should therefore not discount strength training, performed as per best-practice guidelines, as a main factor to regain muscle strength after ACLR.

CAUTION: Readers should be careful to generalize these results to other conditions and injuries.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Arnold Vlok contributed to study concept and design, data collection, data synthesis, and the outline and editing of the manuscript. Dr Grindem contributed to study concept and design and the editing of the manuscript. Dr van Dyk contributed to study concept and the outline, writing, and editing of the manuscript. Dr Coetzee contributed to data collection, data synthesis, and the outline and editing of the manuscript. All authors approved the final version.

DATA SHARING: Data are available on request.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or public involvement in this review.

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CHAPTER 4

MODIFIED e-DELPHI SURVEY

4.1 BACKGROUND AND RATIONALE:

Chapter 4 is related to Objective 2, using a modified e-Delphi survey as a unique approach to formulate a conceptual rehabilitation framework for ACLR. The evidence obtained in Chapter 2 (literature review) and Chapter 3 (scoping review article) laid the foundation for the formulation of the modified e-Delphi survey and served as a relevant connection and overlap. Therefore, the e-Delphi survey focuses on consensus agreement on standardising definitions for strength training (ST) exercise descriptors (EDs), COS ST EDs for reporting after ACLR and exercise dosage for ACLR in different phases. This was accomplished by collecting qualitative opinions, supplemented with some quantitative elements, from twenty-seven (27) ACLR rehabilitation experts representing South Africa and international views on ACLR ST rehabilitation programs. The results of the modified e-Delphi survey will be presented in the form of tables and figures, followed by a discussion of the results obtained from the modified e-Delphi questionnaires.

Strength training is highly valued in ACLR exercise rehabilitation programs to target muscle weakness after ACLR surgery. Unfortunately, ACLR ST EDs (see concept clarification) are poorly reported in ACLR rehabilitation studies (Vlok *et al*., 2022; *Welling et al*., 2021; Poretti *et al.,* 2023). So are exercise interventions and dosages across many health conditions, especially stroke, patella femoral pain, osteoarthritis, achilles tenon ruptures, and hypertension. High-quality reporting is needed to improve quality appraisal, enable evidence synthesis and replication, and improve translation in clinical rehabilitation practices (Holden *et al*., 2018; Hack *et al*., 2018; Bartholdy *et al*., 2019; Hansford *et al*., 2022).

A knowledge gap emerged that suggests a need for consensus on the specifics related to the reporting of ST EDs for ACLR exercise rehabilitation programs (Nicolas *et al.,* 2020; Vlok *et al.,* 2022). Standardising ACLR ST terminology, classifying ST EDs, and developing a COS of strengthening EDs will help fill a gap in ACLR exercise rehabilitation research and practice. Building a bridge between the rich science locked up in ACLR exercise rehabilitation intervention programs, currently underutilised (Vlok *et al.,* 2022), and clinical practice will enable practitioners to translate research effectively into practice.

Classifying ST EDs into the main categories of the strength continuum (see concept clarification) with their individual loading parameters (repetitions, sets, tempo, rest, velocity, intensity, etc.) can emphasise the range of ST modes necessary to incorporate into ACLR exercise rehabilitation programs. To compile the complete set of ACLR ST EDs, one should consider the routine practice of these descriptors by expert practitioners in ACLR exercise rehabilitation. Clinical recommendations provide practitioners with a better understanding of the ideal configuration of ACLR ST EDs. A consistent COS of ST EDs targeting ACLR muscle weakness can diminish clinical uncertainty and variability in practice (Vlok *et al*., 2022).

This study aims to provide the first step towards standardising ST EDs for effectively translating effective ACLR rehabilitation programs to clinical practice**.** Therefore, the purpose of this study is to:

- Explore what terminology of ST EDs is used in ACLR rehabilitation programs executed in private practices, sports clinics, gyms, hospital-based facilities, and research institutions,
- classify, and
- describe key ST EDs and exercise dosages to include in ACLR rehabilitation programs.

4.2 RESEARCH QUESTION

The research question in Chapter 1 to answer the problem statement (see Section 1.2) was:

- What are the perspectives and recommendations of national and international ACLR rehabilitation experts (academic and clinical practice) regarding the terminology, classification (COS), and exercise dosages prescribed in ACLR strengthening programs?

4.3 RESEARCH OBJECTIVES

The main research objectives of this study were to reach a consensus on:

- Clinical consensus on strength training (ST) terminology from international ACLR rehabilitation experts**.**
- Work towards agreement on a core outcome set (COS) of ST exercise descriptors (EDs) to classify and describe ST exercises in ACLR rehabilitation programs.
- Outline the exercise dosages of ST EDs during different phases of ACLR and how they are operationalised in clinical practice.

4.4 RESEARCH METHODOLOGY

4.4.1 Study design

A non-experimental descriptive research design utilising a modified e-Delphi survey was used.

4.4.2 Study methodology

Authentication

Jünger *et al.* (2017: 684) “acknowledged significant variation in the reporting and methodology of Delphi studies and proposed CREDES standards for reporting and conducting such studies”. Thus, this methodology has been conducted according to the guidance on conducting and reporting delphi studies (Table 4.1) and other recommended criteria (Hassan *et al*., 2000; Jünger *et al*., 2017). As no registers exist for Delphi studies, the protocol was registered on the https://osf.io/ registries with doi: https://doi.org/10.17605/OSF.IO/CD4YS.

Table 4.1: Designing an e-Delphi using CREDES (Jünger et al., 2017: 684)

• “Define the purpose and rationale of Delphi. • Prior information for establishing the knowledge base of the panel. • Unstructured (classical) or structured (modified) first round. • Required question type (qualitative or quantitative).

- Define consensus and non-consensus.
- Clear and transparent guidelines on how to proceed from round to round? What is the purpose of rounds? What if no consensus is reached after several iterations? Do items need to be deleted in the next rounds (consensus / rated irrelevant)? Do items need to be refined in the next rounds (when and how)? The number of rounds defines what determines the last round.
- Strategy for processing results between survey rounds.
- Development of materials/instruments (platform/layout /questions).
- Pilot materials/instruments.
- Selection of experts.
- Role of the research team.
- Strategy to improve the response rate.
- Validate the final report externally".

4.4.3 Overview of the modified e-Delphi study (Table 4.1 and 4.2)

To answer the following review questions:

- How do clinical experts classify and describe ACLR ST exercises used in patients after surgery?
- How do clinical experts implement ACLR ST exercises in practice?

We aimed to bridge several gaps by providing a real-world example covering methodological choices and response times in detail (Veugers *et al.,* 2020). We, therefore, used the modified e-Delphi to determine which ST exercise descriptors (EDs) are recommended according to clinical expert opinion and best practice recommendations to be included in ACLR rehabilitation programs. (Table 4.1 and Table 4.2).

Preparation (Phase 1: Table 4.2)

Study Steering Group

A steering group was established consisting of four members (Arnold Vlok, candidate; Derik Coetzee, main supervisor, Nicol van Dyk, co-study leader; Clare

Arden, expert) to answer the research question related to this study phase. The steering group opted to use a modified e-Delphi study as the scientific process to capture ACLR expert responses. The study design decisions were based on the 19 EDs already available from Phase 1 (scoping review), and we referred to the input of ACLR experts across the globe to make the electronic Delphi the best option (Powell, 2003). The expertise of the study steering group has been used to provide study oversight throughout the conduction of the study (Figure 4.1 & 4.2). The study feedback involved:

- Advice on questionnaire development.
- Structure and clarity on study methodology.
- Help with identifying experts.
- Review study results at each round and agrees on statement inclusion.

The study steering group pursued five different aspects with the primary objective of giving a quality definition of critical components in the Delphi study. See Table 4.1.

1. Research goals and research setting
2. e-Delphi format
3. e-Delphi statements and questionnaire
4. Extra questions Piloting modified e-Delphi questionnaire

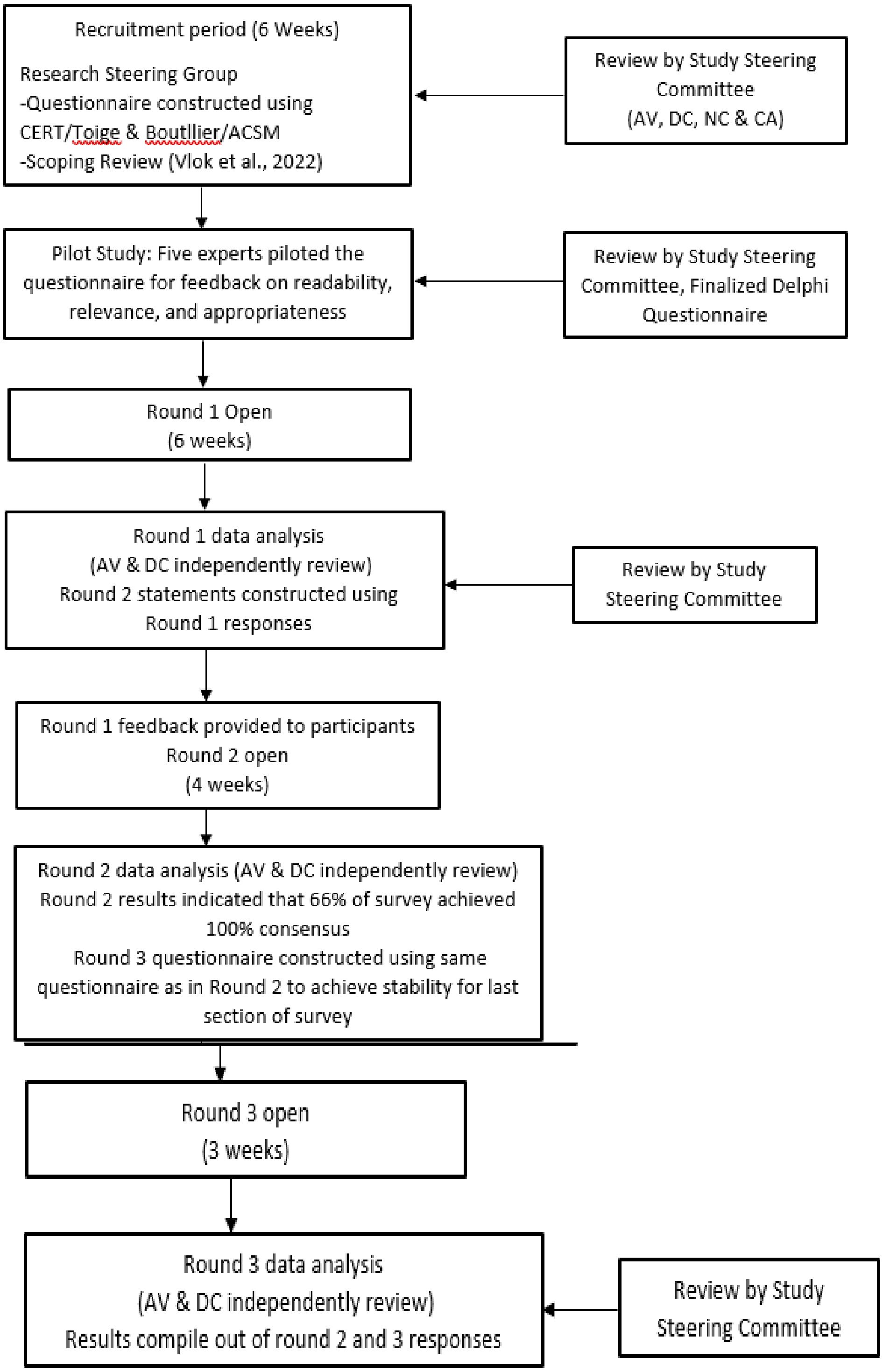


Figure 4.1: Workflow of the modified e-Delphi study process

4.4.4 Conducting (Phase 2: Table 4.2)

A survey software tool called Survey Monkey was used to circulate the e-Delphi statements in a consistent sequential order through the panel of experts selected by expert nomination identified by the steering group. No extrinsic motivation was given to the experts, and feedback was in the form of quantitative statistics presented in a table format. The survey conduction termination criteria were followed by consensus, and stability was achieved on different statements.

Table 4.2: Overview of the Delphi process (Adapted with changes from Beiderbeck et al., 2021)

	"Steps	Potential Feature	
Preparing (Phase 1)	Primary research goal	Theoretical contribution (e.g., consensus on definition, terminology)	
	Research Setting	Present-related (e.g., clinical trial, experiment, concept)	
	Delphi Format	Conventional (i.e., sequential)	
	Delphi Statements	Expert-based	Theory-/Literature Based
	Delphi Questionnaire	Statement related	Expert related
	Piloting Delphi Questionnaire	Pre-test with experts' team	Pre-test with external experts
Conducting (Phase 2)	Software selection	Survey Monkey	
	Survey flow	Constant order	
	Expert selection	Expert nomination	
	Expert motivation	Non - Extrinsic motivation	Non-monetary motivational (e.g., access to survey results)
	Feedback Format	Quantitative statistics (e.g., mean value, interquartile range)	Visual feedback (e.g., boxplot, graphs, histogram)
	Survey Conduction - Termination criteria	Consensus related	Stability related

Analysing (Phase 3)	Quantitative analysis	Descriptive statistics (e.g., mean values, mode frequency, interquartile range)”

Analysing (Phase 3: Table 4.2)

Consensus has been calculated following Rounds 1-3 for Sections 1-3. Each round used a combination of descriptive statistics. Consensus was evaluated using descriptive statistics of central tendency and dispersion. As the Likert scale is considered an ordinal scale, median and IOR were used. Expert consensus was evaluated for each statement by using percentage agreement (“defined as the percentage of responses rated agree/strongly agree”).

4.4.3 Target population

The target population for this research study entails international and national experts in the field of ACLR exercise rehabilitation (physiotherapists, biokineticist, athletic therapists/trainers, sports scientists and strength and conditioning coaches). The experts have been defined accordingly to their professional educational qualifications, years of practical experience in the field, and international and national publications on ACLR rehabilitation. However, to balance perspectives, more than one panel may have been used. Thus, in our Delphi study, the expert panel comprised of two relevant expert groups, namely professionals and academics (Cole *et al*., 2013).

The demographic information was also obtained during the recruitment period of the participants, including questions on:

- Age
- Profession
- Highest education level
- Country
- Location of work
- Publications in ACLR rehabilitation

We viewed an expert as ACLR clinicians and/or researchers with scientific expertise in academic and clinical environments and should be chosen for their work in the appropriate area and credibility with the target audience (Powell, 2003). To obtain the best answer to the research question, we purposefully selected a group of ACLR rehabilitation experts (exercise professionals and academia) with different educational backgrounds from various continents (including South Africa) with a high level of clinical experience working in various clinical locations. Our reasoning behind such a diverse group of experts practicing ACLR rehabilitation were to reflect the real world of clinicians/academia in daily practicing, reflecting a spectrum of opinions (Keeney *et al.,* 2006). Participants had to fulfil the following inclusion criterion to be viewed as international and national experts in ACLR rehabilitation (Table 4.3).

Academia (working primarily in research institutions)

- In the past five years, eligible academics with ≥2 peer-reviewed publications reviewed ISBN/ISSI journals focused on ACLR exercise rehabilitation.
- Academics who have previously worked with ACLR patients have been included based on their expertise.
- Academics in an ACLR rehabilitation supervising role that teach practitioners in the area of ACLR rehabilitation.

Exercise Professionals (working primarily in clinical practice)

- Eligible participants (e.g., physiotherapists, biokineticist, sports scientists, strength and conditioning coaches, athletic trainers) with relevant postgraduate qualifications treated ≥3 patients with ACLR per month using exercise as a rehabilitation modality.
- Clinicians with >5 years of clinical experience or who have previously worked with ACLR patients have been included.

Excluding criteria

- Unavailability
- No consent

__Table 4.3: Steps in selecting the panel of experts (Gill et al., 2013: 1324)__

Step 1	"Identify the most appropriate categories of experts or stakeholder groups for the panel.
Step 2	Populate the stakeholder groups with names derived from previous research participation, publications on the topic, professional email lists, professional organisation board and advisory panel involvement.
Step 3	Contact individuals and request to nominate other experts".

4.4.5 Survey development

The researcher with the steering group developed the first round of the Delphi survey, which included Section 1, developed out of the completed scoping review (cf. Chapter 3). Section 2 was specifically developed from previously validated and published existing survey questionnaires utilised in exercise interventions Delphi studies as an example to build reliable survey questionnaires (Boynton & Greenhalgh, 2004; Slade *et al.,* 2016) (see Section 4.4.4.1). Nineteen (19) ST EDs definitions and checklist COS descriptors were proposed during Round 1 of the questionnaires. Section 3 of the survey was developed from the American College of Sports Medicine (ACSM) best practice guidelines for strength training. Thirteen (13) exercise dosage questions were included during the Round 1 questionnaire (Ratamess *et al.,* 2009). Demographic data (Table 4.5) of the target population (Section 4.4.3) was captured on page one of the survey, while Sections 1-3 included open-ended statements to elicit the expert panel's opinions. The study steering group approved a 9-point Likert scale to rate each statement in Sections 1 and 2. (Figure 4.3). Section 3 consists of statements of exercise dosages for 0-3 months, 4-6 months and >6 months after ACLR (Arthur *et al.,* 2013).

Experts did have the option to give their expert views in the comment boxes provided during the completion of Rounds 1 and 2 for all three sections of the survey. Round 1's survey consisted of open-ended questions, formulated contextually within the three research objectives (Sections 1-3), each on a different page, followed by Round 2 (same layout as Round 1) containing opinions provided by panel members in the form of open-ended statements. Feedback during the completion of Round 1 was categorised into statements that achieved consensus, which was set at 80% agreement of the ACLR expert group (ACLR ERG), and statements which did not achieve consensus were amended based on survey expert feedback and discussions with the steering group. We summarised Round 1's result in a table format and provided it to the panellist during Round 2. We repeated the same process for Round 2 concerning Sections 1 and 2 of the survey. Saturation was achieved by Round 2 in Sections 1 and 2 with no more comments made and 80% agreement on the proposed comments in these sections. Round 3 contained only questions concerning the third objective (exercise dosages). The panellist who did not complete the survey within the allocated time was excluded after the next rounds.

The survey was divided into three sections to answer the three main objectives:

A 9-point Likert scale (strongly disagree to agree strongly) was utilised in Sections 1 and 2 of the survey (Figures 4.3) for panel members to indicate their level of agreement with each individual statement. Section 3 followed a different survey layout to capture exercise dosage responses (Figure 4.4).

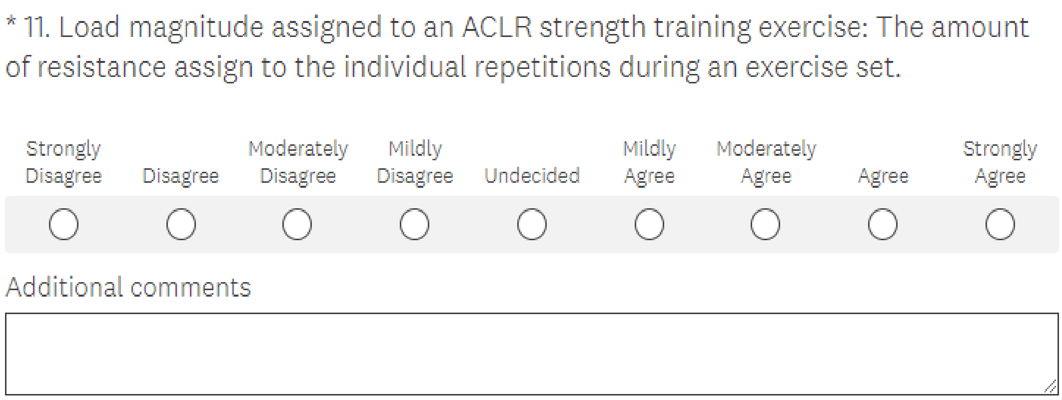
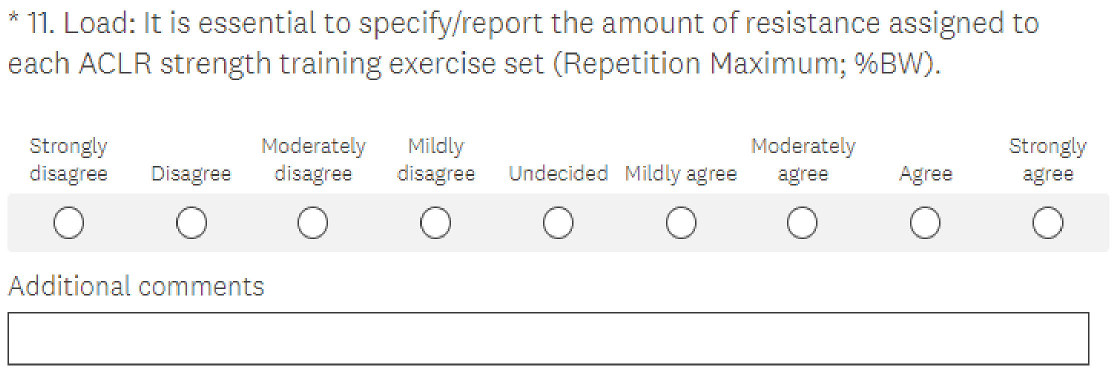


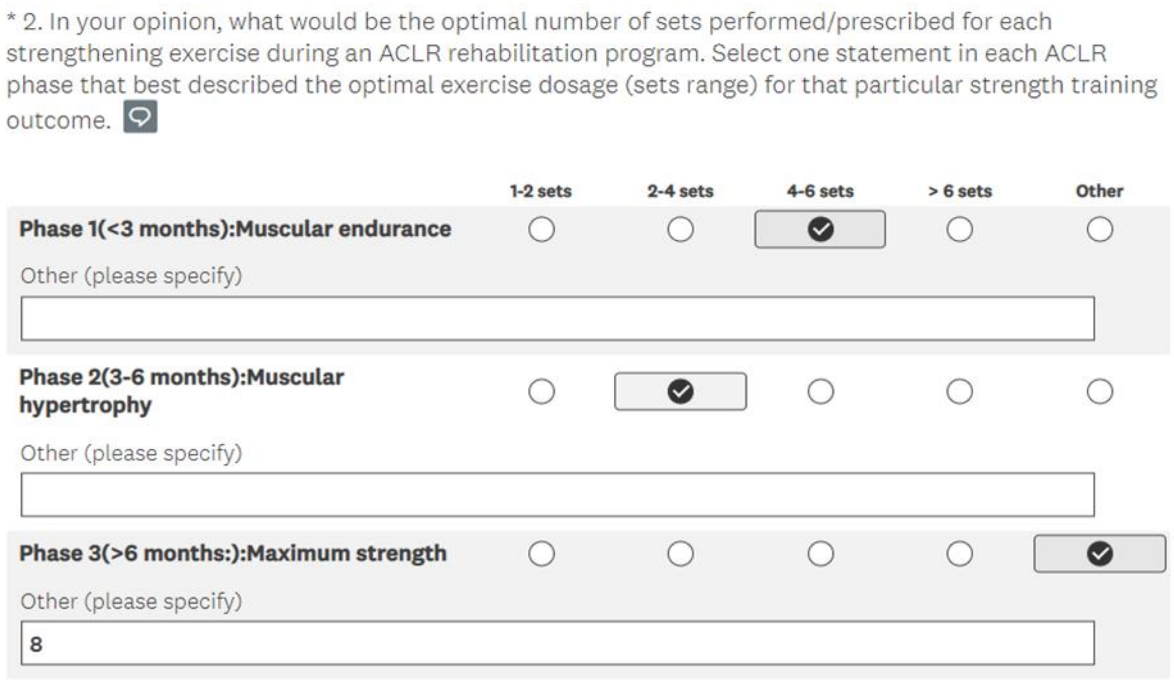
Figure 4.2: Example of 9-point Likert scale used during Round 1


* 11. Load: It is essential to specify/report the amount of resistance assigned to each ACLR strength training exercise set (Repetition Maximum; %BW).

Strongly disagree	Disagree	Moderately disagree	Mildly disagree	Undecided	Mildly agree	Moderately agree	Agree	Strongly agree
○	○	○	○	○	○	○	○	○

Additional comments

Figure 4.2: Example of 9-point Likert scale used during Round 1


* 2. In your opinion, what would be the optimal number of sets performed/prescribed for each strengthening exercise during an ACLR rehabilitation program. Select one statement in each ACLR phase that best described the optimal exercise dosage (sets range) for that particular strength training outcome.

	1-2 sets	2-4 sets	4-6 sets	> 6 sets	Other
Phase 1(<3 months):Muscular endurance	○	○	✓	○	○
Other (please specify)					
Phase 2(3-6 months):Muscular hypertrophy	○	✓	○	○	○
Other (please specify)					
Phase 3(>6 months:):Maximum strength	○	○	○	○	✓
Other (please specify): 8					

Figure 4.3: Example of ACLR exercise dosage survey layout

4.4.5.1 Survey layout

Section 1: This part of the survey was dedicated to collecting data concerning the taxonomy/definitions of ACLR ST EDs currently used by academia and clinicians treating ACLR patients.

Section 2: The ACLR Expert Rehab group was prompted to include or exclude ST EDs in a core outcome set (COS) checklist of ACLR ST exercise requirements to improve the specification and utilisation of ACLR ST EDs more efficiently during the rehabilitation period after ACLR surgery.

Section 3: The last part of the survey was dedicated to better understand the clinical utilisation/prescription of exercise dosages within an ACLR strengthening program 0-3 months, 4-6 months and > 6 months after ACLR. Proposed exercise dosages from the literature (ACSM) were formatted to be included in the survey. Experts could give their opinions based on their current or previous experience with ACLR patients.

4.4.5.2 Sample invite

Panel members were invited to the Delphi survey through an email containing a short literature review relating to the study title, context, study aims and rationale, the composition of subsequent survey rounds, and the procedure for reporting following each survey round. Attached to the mailer was a Participant Information Sheet (see Appendix E) describing e-Delphi study information to clarify study procedures, eligibility criteria, assure anonymity, and explain the withdrawal process. Participants were made aware that by following the survey link attached and providing the researcher with demographic data, they provided informed consent for study participation. Panellists were informed that an ACLR expert rehabilitation group would be created out of the survey to acknowledge each participant's involvement in publications from the survey.

Panel members were provided with the researcher's contact details if they had any inquiries. Participants were informed that they could withdraw at any time (Keeney *et al*., 2006). Panel member anonymity facilitates free and unconstrained responses (Okoli & Pawlowski, 2004; Avella, 2016) and avoids bias in the group (Boulkedid *et al*., 2011), which were ensured by panel members receiving individual emails from the researcher that did not indicate the full email recipient list. Panel members were not anonymous to the researcher. According to Okoli & Pawlowski, (2004), allowed the researcher to follow up when clarification was required.

A detailed report between rounds ensured that all panel members were well informed about the extent of consensus to provide group and individual responses to assist decision-making in subsequent Delphi rounds (Trevelyan & Robinson, 2015).

In subsequent rounds, we aimed to reduce attrition bias by including experts interested in the topic. Furthermore, experts were reminded that each round is constructed on their previous responses, indicating that they play an active role in this study's outcomes (Keeney *et al.,* 2006).

4.4.5.3 Increase response rates

Response rates are important in Delphi surveys, and therefore we intentionally maximised our response rate by focusing on the following survey checkpoints proposed by the literature (Beiderbecke *et al*., 2021).

- The questionnaire was clearly designed and had a simple layout.
- It has been piloted and tested.
- Participants were personally invited to participate in the survey.
- By creating ACLR ERG, participants felt that they were stakeholders in the study.
- The questionnaire has a clear focus and purpose and is kept concise.
- A clear aim and purpose of the study and completing the questionnaire were explained.
- Reminder emails were sent frequently during each round to prompt panellist to answer the survey within the allocated time.

4.3.5.4 Sample size

It is clear from the literature that a relatively small Delphi sample size of approximately 10-18 experts (Okoli & Pawlowski, 2004; Boulkedid *et al*., 2011) are needed. Hasson and Keeney (2011) also mentioned that it is important to minimise obtaining false consensus and to enhance data reliability. However, for this study, we invited a diverse group of experts practicing ACLR rehabilitation to reflect the real world of clinicians/academia in daily practice, reflecting a spectrum of opinions (Keeney *et al.,* 2006). Therefore, the researcher identified a purposive sample of healthcare professionals from South Africa and abroad involved in ACLR rehabilitation in collaboration with the study promoters according to the criteria listed in Section 4.4.3. Experts who were identified were invited to participate in the modified e-Delphi survey and to provide in-depth insight into the EDs considered essential for inclusion when developing a framework for the ACLR rehabilitation programme.

4.4.5.5 Pilot Study

According to Avella (2016), the Delphi survey should be well-designed and comprehensive on the chosen subject. Since the researcher made use of a self-designed survey supplemented with literature constructs (See section 4.4.4), the inclusion of a pilot study was deemed to test certain important constructs of the survey questionnaire. Therefore, the knowledge of three South African clinical experts, one expert in Delphi studies and one biostatistician was used in the pilot study. They assisted to:

- Obtain outside expertise to ensure that all statements were clear and unbiased.
- Structure the survey well to be easy to complete in electronic format.
- Establish the time required to complete the survey so the responses elicited are appropriate for analysis (Avella, 2016).

Amendments following the pilot study and changes advised:

- Concise structuring of the statements to decrease survey response time.
- Improve the logical flow of statements by moving statements up or down in the survey.
- Reconstructing the format of certain survey statements to enhance statistical analysis.
- Improve statement clarity to improve response engagement.

However, no technical problems regarding the online completion of the survey were reported, and approximately 40 minutes were needed for survey completion. The suggested amendments were made by the researcher and verified by the study leader for quality assurance purposes. As the pilot study was not analysed for subsequent rounds, no results are included in the main survey's data.

4.4.6 Data Collection

The e-Delphi survey was executed in a quantitative manner, which necessitates a discussion of reliability and validity.

4.4.6.1 Reliability

The Delphi technique is designed to obtain the most reliable consensus in a group of experts (Veugelers *et al*., 2020; Nasa *et al*., 2021; Sablatzky, 2022). It attempts to achieve this by means of a series of questionnaires interspersed with controlled feedback, including group statistical responses (Veugelers *et al.* (2020). "The anonymity among the expert groups that underpins Delphi studies promotes honesty among participants and reduces the risk of the '**halo effect'** where views from dominant or high-profile members of the group are given extra credence" (Winkler *et al*., 2016; Barret & Heale, 2020). Reliability was also achieved during the e-Delphi survey by ensuring that all the statements were clear and well-defined and that all administration and procedures were standardised. The pilot ensures reliability. The e-Delphi survey was also performed according to a specific schedule, which allowed two to four weeks for the completion of each survey round, thereby preventing or minimising participant fatigue (Creswell, 2012). The researcher reassured panel members throughout the study that they would remain anonymous and that their data would be dealt with confidentially, which resulted in the unbiased completion of the survey rounds (Slade *et al.*, 2016). Verification of data and subsequent statement adjustments by the researcher in collaboration with the study leader, as well as continuous iteration and feedback between panel members, increased study reliability (Hallowell, 2009; Avella, 2016). However, Winkler and Moore (2016: 68) highlight that "the ability of participants to amend or alter their views at each round is also a double-edged sword. It allows those taking part to reflect and reconsider their position in response to additional information, which is an important part of the practice. Conversely, there is a danger that this flexibility introduces bias, with participants altering their response to comply with what they view to be the majority view (sometimes called the **'bandwagon effect**"). To conclude, these statements are assumed to increase the reliability of consensus.

4.4.6.2 Validity

Literature indicates that reports of medical studies using the Delphi methodology often lack detailed information on how these studies are conducted (Diamond *et al.,* 2014; de Loë *et al*., 2016; Veugelers *et al.,* 2020). Medical journal word count limits detail description, therefore, it is mentioned as a possible reason for low repeatability and limited insight into external validity. However, the guideline for reporting

(CREDES) (Jünger *et al*., 2017) was followed in this study to increase the validity of the study.

Content and face validity was achieved by ensuring comprehensive coverage of the subject through a systematic review process (Hasson & Keeney, 2011). The statements posed to panel members were constructed mindfully to elicit all opinions and perspectives (Creswell, 2012; Polit & Beck, 2012; Savin-Baden & Major, 2013). Purposefully selecting a sample of experts with extensive knowledge about ACLR rehabilitation for inclusion in the survey also enhanced the validity of the data, as they were able to provide guidance and authority regarding what should be included in the framework (McMillan *et al.,* 2016). Data authenticity was ensured by verifying the adjustments made between survey rounds during a consensus meeting between the researcher and the study leader following each survey round. A proper application of the Delphi technique is essential for obtaining valid research results (Veugelers *et al*., 2020).

To conclude, most of the existing methodological literature on Delphi research will not be found by using common search strategies for medical research in databases such as PubMed and Embase, and medical researchers may, therefore, easily overlook these publications.

4.4.6.3 Ethical considerations

Before the study commenced, approval for the study was obtained from the Health Sciences Research Ethics Committee at the UFS, South Africa ((HSREC: UFS-HSD2019/1889/2502) (cf. Appendix A). The contact details of experts identified for inclusion were obtained by the researcher from their published and/or presented research. Their professional affiliations with tertiary educational institutions or involvement with international and/or national special interest groups in ACLR rehabilitation. Voluntary participation was always emphasised, and all the panel members were reminded that they could withdraw at any time during the study without repercussions.

4.4.6.4 Data collection process

The researcher and steering group used SurveyMonkey® as a data collection tool. As SurveyMonkey® is based online, it enabled easy survey adjustment as well as timely survey delivery, return and analysis of data collected from a widely distributed pool of panel members (Avella, 2016). This rapid form of distribution also enabled a speedy turnaround time between survey rounds (Okoli & Pawlowski, 2004). SurveyMonkey® depicts results on a bar graph per statement, displaying results as percentages. Data accuracy is ensured by SurveyMonkey® allowing results and panel member comments to be exported as a PDF document, which can be copied directly into the text.

Each e-Delphi round was conducted over three to six weeks, with approximately six weeks between rounds to allow for analysis and item refinement. In accordance with the standard Delphi survey procedure, panel members received a two-to-four-week period in which to complete the survey. If they did not respond, they received an electronic reminder after one week and again two days prior to the completion deadline (Boulkedid *et al*., 2011; McMillan *et al*., 2016; Slade *et al*., 2016). Feedback to the group was provided during Round 2 in the form of a table listing Sections 1 and 2's results of Round 1. We were unable to provide feedback reporting concerning Section 3 after each round because of the diversity in the answers. We opted to achieve stability (**stability** is the consistency of responses between successive rounds (Von der Gracht *et al*., 2012)) between rounds as opposed to consensus to clarify (**consensus** is the extent to which the group of panel experts share the same opinion (Von den Gracht, 2012) Section 3 exercise dosages.

The principal investigator and biostatistician developed a tailored excel spreadsheet to import the experts' responses for further statistical analysis. Two investigators (AV and DC) extracted data separately for each round to ensure feedback accuracy. Following the completion of each survey round, data was presented to the steering group, confirming that all comments and suggestions were addressed and accurately incorporated during the following round (Hallowell, 2009; Avella, 2016).

Statistical data analysis was completed during all survey rounds to establish if a consensus was reached per the statement presented to the expert panel. Data saturation is achieved when the repeated rounds yielded either convergence of panel member opinions through consensus or individual response stability per statement (Fitch *et al.,* 2001; Vázquez-Ramos *et al.,* 2007; Arthur *et al.,* 2013). Stability was therefore declared when panel member responses remained similar across survey rounds, and no further suggestions that resulted in content or contextual changes to the posed statements were elicited (Fitch *et al*., 2001; Vázquez-Ramos *et al*., 2007; Boulkedid *et al*., 2011; Slade *et al.,* 2016).

As this research study utilised a 9-point Likert scale (Figure 4.2) and 27 panellists in the study, stability was declared when panel member responses remained similar across survey rounds and no further suggestions that resulted in content or contextual changes to the posed statements were elicited (Boulkedid *et al*., 2011; Slade *et al*., 2016).

According to Felix (2011), Likert scales with five to nine response options are generally preferred for collecting information on participant attitudes and behaviours regarding proposed items and prevent a convergence around the middle point of the scale. As stated, the 9-point Likert scale (strongly disagree to agree strongly) was utilised in Sections 1 and 2 of the survey (Figures 4.2) for panel members to indicate their level of agreement with each individual statement**.**

However, during the execution of this modified e-Delphi survey, only statements achieving consensus **(≥80%**) were summarised in the detailed report to panel members completing the survey round, as no comments or justification resulted in the statement context being changed. That implies that all statements achieving consensus were removed from subsequent rounds to limit survey length and optimise participation (Trevelyan & Robinson, 2015). Statements that failed to achieve ≥80% consensus, as well as new or adjusted statements, were formulated into the subsequent survey rounds according to panel member comments and the percentage outcome of a consensus meeting between the researcher and study leader (Hallowell, 2009; Hsu & Sandford, 2010; Avella, 2016). The consensus meeting between the researcher and the study leader ensured that all suggestions were accurately incorporated into the subsequent rounds (Slade *et al*., 2016) and minimised researcher bias (Avella, 2016).

4.4.6.5 Data analysis

As mentioned, two researchers independantly (AV and DC) analysed the data during each round. A complete agreement between researchers is required to include statements, with disagreements resolved by discussions. Therefore, the two researchers review the data at each round for feedback and editing.

Round 1: Quantitative data were examined using a theoretical thematic breakdown to generate statements under themes preidentified in our scoping review, supplemented by new statements from panel experts and revision of statements that were unclear to panellists. Data were analysed for Sections 1 and 2, achieving 84% and 89.4% consensus, respectively, for the proposed statements (Table 4.4). A low level of consensus (22.2%**)** was achieved for the third section containing questions regarding exercise dosages.

Round 2: At the end of Round 2 no new statements were incorporated in the third round because 100% of statements achieved consensus (Table 4.4). Section 3 still presented a low level of consensus (Table 4.4 25.9%), and therefore the researcher and study leader decided to keep the questionnaire the same to achieve stability (see definition section) during Round 3 of the survey. Statements achieving consensus after Round 1 and 2 were used to describe the core outcomes set ST EDs that need to be implemented in ACLR rehabilitation programs after surgery.

Round 3:

Table 4.4: Summary of data analysis between Rounds 1-3

	Section 1	**Section 2**	**Section 3**
	Definitions for ACLR ST EDs	**Core outcomes set of ST EDs**	**Exercise dosages utilised by ACLR ERG during ACLR strength training**
Round 1	**Green: Consensus**		**Red: No Consensus**
	84%	89.40%	22.20%

Round 2	100%	100%	25.90%
Round 3	Achieved consensus after Round 2	Achieved consensus after Round 2	Low level of stability

4.4.6.6 Consensus, agreement, and stability

A dearth of evidence exists on the definitions and statistical measures of consensus and agreement within the Delphi literature (Von der Gracht *et al*., 2012). Some reason that consensus and agreement are interchangeable, whereas others recommend separation of definitions (Meijering *et al*., 2013). The following definitions have been used in this study:

Consensus: the extent to which the group of panel experts share the same opinion (Von den Gracht, 2012).

Agreement: a measure of inter-rater agreement where the rating of another can predict the rating of one expert (Schmidt, 1997).

Stability: the consistency of responses between successive rounds (Von der Gracht *et al*., 2012).

Since the Likert scale is considered an ordinal scale, median and IOR was used. Expert consensus was evaluated for each statement using percentage agreement (the percentage of responses rated agree/strongly agree). Response rates for all iterations of the Delphi process, including each group's response, was reported.

4.4.6.7 Data Management

The researcher ensured a transparent research process throughout the e-Delphi study by providing panel members with a comprehensive information letter relating to the procedure of the study and a detailed report following each completed round (De Vos *et al*., 2011). All personal information and data was kept secure, and only members of the steering group have access to it.

4.5 RESULTS

In this section, the results of the Delphi survey will be presented in the form of tables and figures.

4.5.1 Delphi participants: Demographics

Twenty-seven (27) ACLR experts responded. In the following, these experts are referred to as the ACLR Experts Rehabilitation Group (ACLR ERG). Demographics of the ACLR ERG who completed the survey are presented in Table 4.5. Table 4.5 shows that the median age of this group was 38 years, with clinical experience of 13 years. The expert group consisted of 20 Physiotherapists (74.1%) followed by six Biokineticists (22.2%) and one (3.7%) Sports Scientist. Forty-four percent (44%) of the participants had a doctorate degree, 29.6% had a master's, and the rest (25.9%) have a bachelor's degree. Respondents originate from 10 countries working in six different locations. Chronologically, ACLR publications vary in the groups from 0- >5 publications.

Categories	N (Median)	%
Age (years)	27 (38)	--
Clinical experience (years)	27 (13)	--
Profession		
Physiotherapist	20	74.1%
Biokineticist/Athletic Trainer	6	22.2%
Sport scientist	1	3.7%
Highest education level		
Doctorate	12	44.4%
Masters	8	29.6%
Bachelor's degree	7	25.9%
Country		
Australia	4	14.8%
Canada	3	11.1%
France	1	3.7%
Italy	1	3.7%
Netherland	2	7.4%
Norway	2	7.4%
Qatar	3	11.1%
South Africa	8	29.6%
USA	2	7.4%
Sweden	1	3.7%
Location		
Research Institutions	2	7.4%
Clinical practice	11	40.7%
Clinical Practice/Research Institution	5	18.5%
Clinical Practice/Hospital-based Facility	3	11.1%
Clinical Practice/Hospital-based Facility/ Research Institution	3	11.1%
Clinical Practice/Gym/Sport Club	3	11.1%
Publications in ACLR rehabilitation		
0	12	44.4%
1	0	0.0%
2	2	7.4%
3	1	3.7%
4	4	14.8%
>5	9	33.3%

Table 4.5: Demographics of the ACLR Expert Rehabilitation Group recruited for the modified e-Delphi survey

4.5.2 Response rate

Invitations to participate in this study were sent to 44 ACLR experts. Of these invitees, 27 (61%) accepted study participation by returning their signed informed consent forms and subsequently receiving and completing Round 1 of the survey (see Table 4.6). Table 4.6 also shows that 96% (n=26) consensus was reached in **response rate** for exercise definitions, 96% (n=25) and COS checklist in Round 3, while 92% (n=24) responded on exercise dosages.

Table 4.6: Response rate between different rounds and different sections of the survey

Delphi Rounds	Section 1 Exercise definitions	Section 2 COS checklist	Section 3 Exercise dosages
Round 1	100% (n=27)	96% (n=26)	96% (n=26)
Round 2	96% (n=26)	96% (n=25)	92% (n=24)
Round 3	Consensus*	Consensus*	92% (n=24)

Sections which achieved consensus for all presented statements were not included in subsequent rounds.

4.5.3 Content analysis of the Delphi Expert Rehabilitation group survey

4.5.3.1 Round 1: ACLR exercise descriptor definitions

The responses to the 19 questions of Section 1 of the survey in Round 1 are summarised in Table 4.7 below. During Round 1, sixteen (16) of the 19 definitions achieved consensus for inclusion (85.2%-96.3%), and only three (3) definitions did not reach consensus, which is indicated in **red**. Additionally, 61 comments were generated, of which 16 suggested a more accurate description. Specific comments provided justification for panel members' option selection. However, panel members did also propose language, terminology, and grammatical changes for ease of understanding and alignment with the purpose of Objective 1. It should be noted that certain comments were not applicable to the current research study aims and objectives, or were irrelevant to the posed statement, and did not warrant a change. However, all adjustments made to the posed statements were in accordance with the ACLR ERG comments and suggestions. The consensus meeting between the researcher and study leader ensured accurate data analysis and relevant changes to the remaining statements for Rounds 2 and 3 of the survey.

Table 4.7: ACLR exercise descriptor definitions that achieved consensus/no consensus after Round 1 survey										
Number	Exercise descriptor	Round 1 Consensus definitions	Disagreement	Undecided	Agreement	Median	Minimum	20% Percentile	80% Percentile	Maximum
1	**The name of the exercise/s:**	The name of the strength training exercises prescribed during the ACLR strength training sessions (e.g., Leg Press, Knee Extensions).	3.7%	3.7%	92.6%	8.0	4.0	8.0	9.0	9.0
2	**Number of ACLR strengthening exercises prescribed**	The number of ACLR strength training exercises reported during a single session in the ACLR strength training program.	7.4%	3.7%	88.9%	8.0	3.0	7.0	9.0	9.0
3	**Frequency of ACLR strength training sessions**	The number of ACLR strength training sessions per week prescribed.	3.7%	0.0%	96.3%	8.0	4.0	8.0	9.0	9.0
4	**Sets completed**	The number of cycles of strength training repetitions performed during a strength training exercise.	3.7%	0.0%	96.3%	8.0	2.0	8.0	9.0	9.0
5	**Adherence**	The extent (amount of ACLR strength training sessions fully completed during the course of the rehabilitation period) to which the patient performed the prescribed program	7.4%	0.0%	92.6%	8.0	1.0	8.0	9.0	9.0
6	**Repetitions prescribed**	The number of strength training movements completed during a particular exercise set.	3.7%	0.0%	96.3%	8.0	1.0	8.0	9.0	9.0
7	**Exercise progressions**	The progression of individual strengthening exercises during an ACLR strength training set (e.g., increase in repetitions, load or speed).	11.1%	3.7%	85.2%	8.0	2.0	8.0	9.0	9.0

8	**Exercise type**	The mode of exercise selected for a training program, (e.g., neuromuscular control exercises or strength training).	0.0%	11.1%	88.9%	8.0	5.0	8.0	9.0	9.0
9	**Load magnitude assigned to an ACLR strength training exercise**	The amount of resistance assign to the individual repetitions during an exercise set.	14.8%	0.0%	85.2%	8.0	1.0	7.0	9.0	9.0
10	**Range of motion**	The degree of movement around a specific joint during an ACLR strengthening exercise (e.g., leg curls at 0-90 degrees of knee flexion).	3.7%	0.0%	96.3%	8.0	4.0	8.0	9.0	9.0
11	**Interset rest prescribed between ACLR strength training sets**	The recovery time allowed between sets (e.g., 60 seconds or 5 minutes).	7.4%	3.7%	88.9%	8.0	2.0	8.0	9.0	9.0
12	**Tempo**	The velocity/speed at which an ACLR strengthening exercise is performed at.	3.7%	0.0%	96.3%	8.0	4.0	8.0	9.0	9.0
13	**Muscle contraction**	The type of muscle contraction during a specific repetition executed (e.g., concentric, isometric and eccentric).	0.0%	3.7%	96.3%	8.0	5.0	8.0	9.0	9.0
14	**Exercise order**	The sequence of exercises in a single exercise session (e.g., multi-joint exercises before single joint exercises).	0.0%	3.7%	96.3%	8.0	5.0	7.2	9.0	9.0
15	**Strength training session duration of an ACLR strengthening program**	The total duration of the strength training component of each session (e.g., 30 minutes).	7.4%	7.4%	85.2%	8.0	2.0	6.0	9.0	9.0
16	**Exercise aim**	The specific purpose/focus of the ACLR strengthening exercise (e.g., muscular hypertrophy or maximum strength).	0.0%	7.4%	92.6%	8.0	5.0	8.0	9.0	9.0

17	**The duration of the ACLR strength training program**	The total duration of the strength training component of each session (e.g., 30 minutes)	14.8%	7.4%	77.8%	8.0	2.0	5.2	9.0	9.0
18	**Program progress**	The progression of the entire program (e.g., increase the number of strengthening exercises per session or increase number of ACLR strength training sessions per week)	7.4%	14.8%	77.8%	8.0	4.0	5.0	9.0	9.0
19	**Muscular voluntary failure**	Whether exercise repetitions should be performed to the point of total muscular exhaustion during ACLR strength training programs	22.2%	0.0%	77.8%	8.0	1.0	4.0	9.0	9.0

4.5.3.2 Amendments made following Round 1 Delphi Section 1: Definitions

The ACLR ERG proposed four (4) new definitions to be included in the survey. Based on the comments of the experts, the new definitions replaced two Round 1 definition, namely

- muscular voluntary failure was changed to "set end point goal/target", and
- adherence to the prescribed sessions was replaced with "exercise completion to the prescribed sessions".

  Thus, the study steering group (AV & DC) rephrased the three definitions (which did not reach a consensus during the first round).

4.5.3.3 Round 2: ACLR exercise descriptor definitions

The responses to the seven definitions of Section 1 of the survey in Round 2 (**three revised definitions from Round 1 and four new definitions included after Round 1**) are summarised in Table 4.8, indicating all seven questions that reached **consensus agreement ranging from 80.8% after Round 2.**

Table 4.8: Included ACLR exercise descriptor consensus definitions after Round 2										
Number	**Exercise descriptor**	**Round 2 Consensus definitions**	**Disagreement**	**Undecided**	**Agreement**	**Median**	**Minimum**	**20% Percentile**	**80% Percentile**	**Maximum**
1	**The description of the individual exercise/s:**	A clear description of the execution of the strengthening exercises prescribed during the ACLR rehabilitation sessions either through e.g., photographs, illustrations, video, Smartphone app, website, protocol paper, etc.	0%	0%	100%	8.0	6.0	7.0	9.0	9.0
2	**The duration of the ACLR rehabilitation phases**	The extent to which an individual patient completes the strength training objectives within an ACLR rehabilitation program (e.g., entails the time between two muscle strength evaluations).	11.5%	7.7%	80.8%	8.0	1.0	6.0	8.0	9.0
3	**Program progressions:**	Detailed description of how the entire ACLR rehabilitation program (as a whole) is progressed (e.g., increase the durations of the ACLR exercises session/s or increase number of ACLR rehabilitation training sessions per week).	3.8%	3.8%	92.3%	8.0	2.0	7.0	9.0	9.0
4	**Set end point goal/target:**	Exercise repetitions performed to the point of 1) total muscular exhaustion, 2) autoregulated like RPE or RiR)	0.0%	11.5%	88.5%	8.0	5.0	7.0	8.0	9.0
5	**Progressive overload rule of ACLR strengthening exercises:**	It is the rule that indicates the gradual increase in demand placed upon a system in response to the adaptation to previously imposed demands (e.g., increase in training volume {reps* sets*resistance}; training intensity (% 1RM,%BW,	0.0%	0.0%	100.0%	8.0	7.0	8.0	9.0	9.0

		RPE, tempo}; frequency or time trained)								
6	**ACLR strength training program:**	A tailored exercise program with the purpose towards targeting the ACLR strength deficits through specific focus on the strength training continuum (e.g., strength endurance, strength, max strength etc.).	11.5%	0.0%	88.5%	8.0	1.0	7.0	9.0	9.0
7	**Exercise completion to the prescribed sessions:**	The extent (amount of ACLR strength training sessions fully completed during the course of the rehabilitation period) to which the patient performed the prescribed program.	3.8%	11.5%	84.6%	8.0	1.0	7.0	9.0	9.0

4.5.4: Section 2: Core Outcome Strength Training (COS) checklist of ACLR Strength Training (ST) Exercise Descriptors (EDs)

4.5.4.1: Round 1: Core outcomes set of ACLR ST EDs

Consensus statements and percentage agreement, undecided and disagreement of COS ACLR ST EDs are summarised in Table 4.9. During Round 1, consensus was reached in 16 ST EDs. Only **exercise order** was again presented in Round 2 with four new EDs proposed by the ACLR ERG.

Based on the recommendations made by the ACLR ERG, we proposed four new COS ACLR ST descriptors to be included during the Round 2 survey with exercise order.

We included the following EDs in Round 2:

1. Description of the individual ST exercise.
2. Internal workload [session RPE * session time in minutes].
3. Exercise order.
4. Intra-session rest.
5. Exercise completion to the prescribed sessions.

Table 4.9: Core outcomes set of ACLR strength training exercise descriptor that achieved consensus/no consensus after Round 1									
Number	**Consensus on the core outcomes set of ACLR strength exercise descriptors to be included in ACLR rehabilitation programs**	**Disagreement**	**Undecided**	**Agreement**	**Median**	**Minimum**	**20% Percentile**	**80% Percentile**	**Maximum**
1	Name of each strength training exercise	0.0%	3.8%	96.2%	8.0	5.0	8.0	9.0	9.0
2	Experimental period	3.8%	7.7%	84.6%	8.0	4.0	6.4	9.0	9.0
3	Number of exercises	3.8%	3.8%	92.3%	8.0	2.0	7.0	9.0	9.0
4	Frequency	3.8%	7.7%	88.5%	8.5	2.0	8.0	9.0	9.0
5	Adherance	3.8%	3.8%	92.3%	9.0	1.0	7.0	9.0	9.0
6	Sets	7.7%	7.7%	84.6%	8.0	1.0	6.0	9.0	9.0
7	Repetitions	7.7%	0.0%	92.3%	8.0	2.0	7.0	9.0	9.0
8	Exercise Progressions	7.7%	3.8%	88.5%	8.0	2.0	8.0	9.0	9.0
9	Exercise Type	3.8%	7.7%	88.5%	8.0	1.0	6.4	9.0	9.0
10	Program Progress	3.8%	11.5%	84.6%	8.0	4.0	6.0	9.0	9.0
11	Load	0.0%	3.8%	96.2%	9.0	5.0	8.0	9.0	9.0
12	Range of Motion (ROM)	3.8%	7.7%	88.5%	8.0	2.0	6.0	9.0	9.0

13	Rest	11.5%	0.0%	88.5%	8.0	2.0	6.0	9.0	9.0
14	Tempo	7.7%	3.8%	88.5%	8.0	2.0	6.4	9.0	9.0
15	Muscle action	7.7%	3.8%	88.5%	8.0	2.0	6.0	9.0	9.0
16	Muscular voluntary failure	11.5%	3.8%	84.6%	8.0	2.0	6.4	9.0	9.0
17	Exercise aim	3.8%	0.0%	96.2%	8.0	4.0	7.4	9.0	9.0
18	Training Duration	11.5%	11.5%	76.9%	6.0	2.0	5.0	8.0	9.0
19	Exercise order	7.7%	15.4%	76.9%	7.0	2.0	5.0	8.0	9.0

Round 2: Core outcomes set of ACLR ST ED

Table 4.10: Core outcomes set of ACLR strength training exercise descriptor that achieved consensus after Round 2									
Number	**Consensus on the core outcomes set of ACLR strength exercise descriptors to be included in ACLR rehabilitation programs**	**Disagreement**	**Undecided**	**Agreement**	**Median**	**Minimum**	**20% Percentile**	**80% Percentile**	**Maximum**
1	The description of the individual exercise/s	0.0%	0.0%	100.0%	8,0	7.0	8.0	9.0	9.0
2	Internal Workload	12.0%	0.0%	84.0%	8.0	2.0	6.2	9.0	9.0
3	Exercise order	12.0%	4.0%	84.0%	7.0	3.0	6.0	8.0	9.0
4	Intra session rest	12.0%	4.0%	84.0%	8.0	3.0	6.2	8.8	9.0
5	Exercise completion to the prescribed sessions	8.0%	4.0%	88.0%	8.0	2.0	7.0	8.8	9.0

4.5.4.2 Round 2: COS strength exercise training descriptor consensus

Agreement (84-100%) was reached in all 21 EDs proposed to the ACLR ERG.

4.5.5 Exercise dosages prescribed during ACLR rehabilitation

Exercise dosages which reached consensus during Rounds 1-3 are listed in table 4.11[a] (**Highlighted in Green**). It is clear from Table 4.11 that ACL ERG agreement is low in the different ACL rehabilitation phases with a focus on the different strengthening components. Typical discussion points are also shown to display common responses and poor agreement from the open-ended questions (on exercise dosage (See Table 4.11).

Table 4.11: Exercise dosage configurations which achieved consensus during Round 1 (Repetitions prescribed)				
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**Percentage consensus**	**Exercise dosage according to consensus**
In your opinion, what would be the optimal number of repetitions performed/prescribed during each ACLR strengthening exercise set?	Phase 1(< 3 months): Muscular endurance	22 (25)	88.0%	13-25 Repetitions
	Phase 2(3-6 months): Muscular hypertrophy	23 (25)	92.0%	8-12 Repetitions
	Phase 3(>6 months): Maximum strength	24 (25)	96.0%	2-6 Repetitions
Exercise dosage configurations which achieved consensus during Round 3 (% RM prescribed)				
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**Percentage consensus**	**Exercise dosage according to consensus**
In your opinion, what would be the optimal set intensity (% RM range) performed/prescribed for each ACLR strengthening exercise during an exercise set?	Phase 3(>6 months): Maximum strength	19(23)	83.0%	80-95% RM
Exercise dosage configurations which achieved consensus during Round 2 (Rest between sets prescribed)				
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**Percentage consensus**	**Exercise dosage according to consensus**
In your opinion, what would be the optimal rest between sets performed/prescribed during an ACLR strengthening program?	Phase 1(< 3 months): Muscular endurance	20 (24)	83.3%	30- 60 sec
Exercise dosage configurations which achieved consensus during Round 2 and Round 3 (Sessions per week prescribed)				
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**Percentage consensus**	**Exercise dosage according to consensus**
In your opinion indicate the optimal number of ACLR rehabilitation sessions (homebased or supervised) perform/prescribed during a one week period?	Phase 2 (3-6 months): Muscular hypertrophy	22 (24)	91.6%	ACLR Sessions: 3-4
	Phase 3 (>6 months): Maximum strength	21 (23)	91.3%	ACLR Sessions: 3-4

Based on the recommendations made by the ACLR ERG, the steering group made a few amendments after Round 1 Delphi on exercise dosages prescribed during ACLR rehabilitation programs. The ACLR ERG proposed that certain **ranges need to be amended** and **new dosages** need to be included in the survey.

The study steering group decided to revise Round 1 (figure 4.4) in the following manner for Rounds 2 and 3 (figure 4.5):

- decreased the number of options to select from;
- removed the “other” block in the options;
- reorganised the options based on the ACLR ERG proposals, and
- took the extra comment block away.

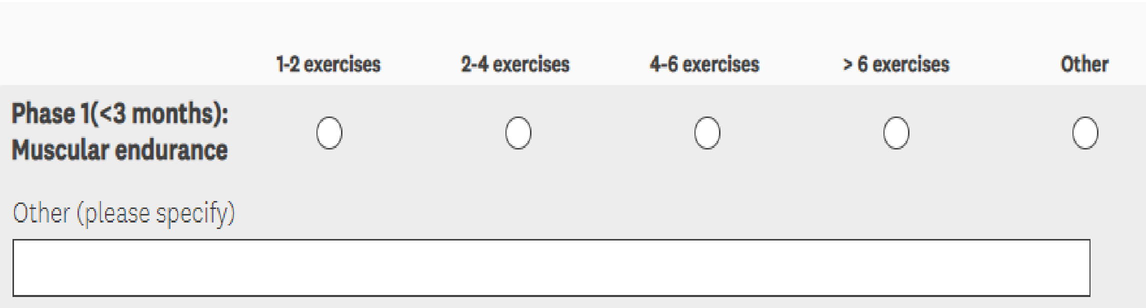


Figure 4.4: Section 3: Round 1 survey with 5 options to select from

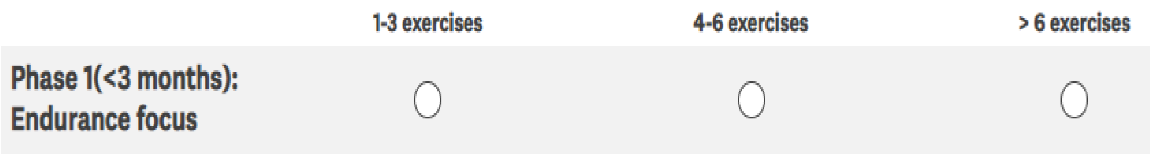


Figure 4.5: Section 3: Round 2 and 3 surveys with three options to select from

Table 4.12 shows exercise dosage configurations, which achieved no consensus from Rounds 2-3 (**title highlighted in red**). It is also clear from Tables 4.11 & 4.12 that even between rounds, the ACLR ERG were not **stable** in answering survey questions on exercise dosage configuration, which achieved no consensus from Rounds 2 and 3, ranging from **47.8% to 91.3%** in stability.

The comments by individual ACLR ERG are also summarised in Table 4.12. It is clear from the comments that the ACLR ERG found it very difficult to commit themselves to the focus of the different phases in program design.

Table 4.12: Exercise dosage configurations which achieved no consensus from Rounds 2-3 (ACLR ST exercises prescribed per session)

Survey question asked to the ACLR ERG:	Different ACLR rehabilitation phases with focus on different strengthening components	n (Total)	% Stable	% Unstable	Distribution of exercise dosage concluded in the stable group of experts			n (Total)	Extra comments by individual ACLR experts
					1-3 Exercises	4-6 Exercises	>6 Exercises		
In your opinion, what would be the optimal number of knee focused (quadriceps and hamstring) strengthening exercises performed/ prescribed per session as part of an ACLR strengthening program?	Phase 1 (<3 months): Muscular endurance focus	18 (23)	78.3%	21.7%	22.2%	66.7%	11.1%	1(23)	"Again, I am confused why we are being asked about 'muscle strengthening exercise' but again the labels are Phase 1: Endurance focus. Endurance and strength are two different forms of muscle function/performance. My answer is basically splitting the number down the middle 2 and 2 for quads and hams or 3/3 etc"
	Phase 2 (3-6 months): Muscular hypertrophy focus	14 (23)	60.9%	39.1%	14.3%	85.7%	0.0%	2 (23)	"There is no optimal number per session - it depends on whether the exercises are isolating the quad/hams or target both and on the number of sessions per week."
	Phase 3 (>6 months): Maximum strength focus	13 (23)	56.5%	43.5%	30.8%	69.2%	0.0%	1(24)	"Really depends on the number of sessions per week, the number of sets and how many muscle groups are targeted within that session. I'm pretty sure I changed my answer here, but it's too many unknowns to specify"
	Phase 3 (>6 months): Rate of force development focus	14 (23)	60.9%	39.1%	42.9%	42.9%	14.3%	1(24)	"Again, I am unsure why the phases have been provided a 'focus'?"

Table 4.12: Exercise dosage configurations which achieved no consensus from Rounds 2-3 (ACLR strengthening exercise sets per week)									
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**% Stable**	**Unstable**	**Distribution of exercise dosage concluded in the stable group of experts**			**n(Total)**	**Extra comments by individual experts**
					1-3 Sets	4-6 Sets	>6 Sets		
In your opinion, what would be the optimal number of sets performed/prescribed per exercise as part of an ACLR strengthening program?	Phase 1(<3 months): Muscular endurance focus	20 (23)	87.0%	13.0%	65.0%	30.0%	5.0%	3 (24)	Phase 1: less sets due to higher number of exercises. exposing the brain to more demands. 2) It depends how many times per week these are performed 3) It depends on the number of exercises per session. There are multiple good ways to configure the training.
	Phase 2 (3-6months): Muscular hypertrophy focus	21 (23)	91.3%	8.7%	38.1%	61.9%	0.0%	1 (24)	I don't think there is a clear-cut separation between 1-3 and 4-6. Other more important variables (e.g., load, intention to move quickly, etc.) are more important
	Phase 3 (>6 months): Maximum strength focus	18 (23)	78.3%	21.7%	38.9%	55.6%	5.6%	1 (24)	If plyometrics and maximum strength is done in the same session, probably more than 3 in total.
	Phase 3 (>6 months): Rate of force development focus	16 (23)	69.6%	30.4%	43.8%	50.0%	6.3%	n/a	**No comment**

Table 4.12: Exercise dosage configurations which achieved no consensus from Rounds 2-3 (ACLR ST repetitions prescribed)									
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**% Stable**	**% Unstable**	**Distribution of exercise dosage concluded in the stable group of experts**			**n(Total)**	**Extra comments by individual experts**
					2-6 Repetitions	**8-12 Repetitions**	**13-25 Repetitions**		
In your opinion, what would be the optimal number of repetitions performed/prescribed during each ACLR strengthening exercise set?	Phase 3(>6 months): Rate of force development focus	15 (23)	65.2%	34.8%	86.7%	13.3%	0.0%	1(23)	"4-8 reps also useful for strength/speed focus"
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**% Stable**	**% Unstable**	**Distribution of exercise dosage concluded in the stable group of experts**			**n(Total)**	**Extra comments by individual experts**
					Test @ 3-5 RM	**Test @ 6-8 RM**	**Test @ 9-10 RM**		
In your opinion, select the most appropriate multi-RM threshold range to calculate a 1 RM value during Phases 2 and 3 of an ACLR strengthening program?	Phase 2(3-6months): Muscular hypertrophy	11 (23)	47.8%	52.2%	45.5%	27.3%	27.3%	2(25)	"1) As few repetitions as possible without pain or effusion. 2) Should be the same test regardless of stage - the higher the % RM the great the inaccuracy."
	Phase 3(>6 months): Maximum strength	15 (23)	65.2%	34.8%	80.0%	20.0%	0.0%		
	Phase 3(>6 months): Rate of force development	16 (23)	65.2%	34.8%	80.0%	13.3%	6.7%		

Table 4.12: Exercise dosage configurations which achieved no consensus from Rounds 2-3 (ACLR strengthening exercises ratio prescribed)									
Survey question asked to the ACLR ERG:	**Different ACLR rehabilitation phases with focus on different strengthening components**	**n (Total)**	**% Stable**	**% Unstable**	**Distribution of exercise dosage concluded in the stable group of experts**			**n(Total)**	**Extra comments by experts**
					Inj: Un 3:1	**Inj: Un 3:2**	**Inj:Un 3:3**		
Indicate the appropriate ratio/number of ACLR strength exercises sets applied to the injured compare to uninjured side during ACLR rehabilitation programs.	Phase 1(<3 months): Muscular endurance focus	16 (23)	69.6%	30.4%	75.0%	6.3%	18.8%	2 (25)	"1) It depends on the bilateral difference as tested at the end of each phase. 2) Early on, I would encourage much more volume/work on the injured leg, but would say once they are consistently on a strength program, we encourage equal work as the uninjured leg often detrains as well. "
	Phase 2(3-6months): Muscular hypertrophy focus	16 (23)	69.6%	30.4%	31.3%	56.3%	12.5%	1 (25)	"Only until symmetry is reached"
	Phase 3(>6 months): Maximum strength focus	14 (23)	60.9%	39.1%	14.3%	35.7%	50.0%		
	Phase 3(>6 months): Rate of force development focus	17 (23)	73.9%	26.1%	11.8%	11.8%	76.5%	1(25)	"Depends on how strong the different legs are. 3:1 until symmetrical, then 3:3"

Survey question asked to the ACLR ERG:	Different ACLR rehabilitation phases with focus on different strengthening components	n (Total)	% Stable	Unstable	Distribution of exercise dosage concluded in the stable group of experts			n(Total)	Extra comments by experts
					ACLR Sessions: 1-2	ACLR Sessions: 3-4	ACLR Sessions: 5-6		
In your opinion indicate the optimal number of ACLR rehabilitation sessions (homebased or supervised) perform/prescribed during a one-week period?	Phase 1(<3 months): Muscular endurance focus	16 (23)	69.5%	30.5%	0.0%	26.7%	73.3%	1(25)	"I think it is individual and would not approach this the same with each patient."
	Phase 3(>6 months): Rate of force development focus	17 (23)	73.9%	26.1%	50.0%	50.0%	0.0%		

4.6 DISCUSSION OF RESULTS

Introduction

This modified e-Delphi aimed to answer the research question posed in Chapter 1 (see Section 1.2):

- What are the perspectives and recommendations of national and international ACLR rehabilitation experts (academic and clinical practice) regarding the terminology, classification, and exercise dosages prescribed in ACLR strengthening programs?

This modified Delphi aimed to reach experts' consensus on

- the definitions of exercise descriptors (EDs) used in ACLR rehabilitation programs;
- consistent core outcome set (COS) of strength training (ST) descriptors to be reported for better utilisation and specification of the ACLR intervention; and
- the general exercise dosages practice in ACLR rehabilitation programs.

We used three rounds, comprising two SurveyMonkey® online surveys separated by a consensus meeting by the researcher and study leader, which established a consensus statement around:

- Definitions of EDs.
- Consistent COS.
- General exercise dosage prescription in rehabilitation programmes.

Further expert voting in the final round further refined these statements, with key statements reaching a priori agreed **≥80% consensus agreement**. The following discussion is ordered around the consensus statements.

4.6.1 Strength training definitions to be used in ACLR rehabilitation programs

This study proposed 22 ST definitions in Tables 4.6 & 4.7 with **strong** consensus **agreement (≥80%)** between our ACL ERG in the second round. Furthermore, the literature and scoping review (Chapters 2 and 3) concluded that ST is an effective method to target muscle weakness after ACLR (Liu-Ambrose *et al*., 2003; Orishimo *et al*., 2010; Welling *et al.,* 2019; Vlok *et al*., 2022).

Considering the positive effect of ST as part of exercise ACLR rehabilitation, the standardisation of the ST EDs created a fundamental platform to improve the homogeneity within ACLR rehabilitation protocols, contemplating the current poor reporting in Levels 1-4 ACLR rehabilitation interventions (Goff *et al.,* 2018, Vlok *et al.,* 2022). Consequently, ACLR exercise configurations can be replicated in clinical practice, starting with the consensus definitions of the ST EDs used during clinical trials. To determine if the full potential of ST has been realised in previous literature, we need more knowledge about the EDs reported in ACLR rehabilitation studies and **standardise** these descriptors.

EDs that impact the result of ST are described in the literature. As early as 2006, Toigo and Boutellier *et al.* (2006) (T&B) reviewed mechano-biological determinants for muscle hypertrophy and presented EDs that target these determinants. Therefore, guidelines as well as progression models for resistance training were proposed in the positional stand statement of the American College of Sports Medicine (ACSM), followed by the Consensus on exercise reporting template (CERT) to improve the reporting of essential exercise components across all evaluative study designs (Slade *et al.,* 2016). These international standards collectively cover a comprehensive list of EDs that influence the outcomes of ST programs.

We consider this modified e-Delphi study as the first study to standardise **ACLR ST exercise descriptor terminology** by national and international experts in the field of ACLR rehabilitation. Vlok *et al*. (2022) developed a core outcome set (COS) of EDs to be reported during ACLR rehabilitation and started investigating the clinical utilisation of academia and clinical practitioners in the application of ACLR ST exercise dosages (see Chapter 3, Scoping Review, Table1).

The **consensus definitions agreement (≥80%)** in this study by our panel of ACLR ERG were the first step in a **three-stage process** of reporting ST EDs. Researchers and clinicians need to be familiar with the consensus terminology of ST EDs used in

ACLR rehabilitation programs to prevent research waste, simplifying the reporting of ACLR rehabilitation interventions. The continuous use of the same ACLR ST exercise descriptor definitions while performing an ACLR rehabilitation program will improve the transparency in clinical practice.

4.6.2 ACLR core outcomes set (COS) of ST EDs

Twenty-one (21) COS ST EDs were selected by the ACLR ERG to be utilised to improve the specificity of reporting in ACLR ST programs. The responses of the ACLR ERG were notably high for both Rounds 1 and 2 **(>80% consensus agreement)** of the survey. Based on the recommendations of the ACLR ERG, four new COS ACLR ST descriptors were proposed:

- Description of the individual ST exercise.
- Internal workload [session RPE * session time in minutes].
- Intra-session rest.
- Exercise completion to the prescribed sessions.

It is also clear in this e-Delphi that ACLR ERG acknowledges COS ST EDs with **strong consensus agreement (≥80%).**

Thus, the 21 COS EDs (Tables 4.8 & 4.9) are scaffolding to create an ACLR evidence-based practice infrastructure for reporting essential ST EDs and optimising the ST specification during ACLR rehabilitation programs. Including critical components like exercise frequency, intensity, volume, and exercise progressions could enable clinicians to make more informed decisions when prescribing ACLR exercise dosages (Goff *et al.,* 2018; Clark *et al.,* 2019; Welling *et al*., 2019; Culvenor *et al.,* 2022).

Vlok *et al*. (2022) also reported the percentage of studies that reported ST EDs in rehabilitation after ACLR. Interestingly, "fewer than half of the studies reported exercise type, exercise progress, programs progress, repetitions, sets, adherence, range of motion, and magnitude of load. Collectively, 44-46% of studies described a number of repetitions, exercise progress, exercise type, program progress, and sets. Of the 117 exercises described across the studies, 53 (45%) were described with the number of repetitions. Tempo, rest, range of motion and magnitude were all reported between 20%-34% of the studies. Only 34% (14/41) of the studies specified the magnitude of load, commonly 50 to 80% of one 1RM. Only five to 15% of studies reported the EDs muscular voluntary failure, exercise aim, training duration, muscle action, and exercise order". (See Chapter 3, Scoping Review, Figure 2).

However, the literature indicates the need for high-quality reporting of ACLR ST interventions (Goff *et al.,* 2018; Clark *et al.,* 2019; Vlok *et al.,* 2022). Currently, other reporting guidelines exist, e.g., the TIDieR reporting checklist, which has been developed as a generic template to report the intervention descriptions. Since the TiDieR checklist (Torgo & Boutellier, 2006) is generic, the CERT was developed as a template to report exercise interventions to supplement the specific information neglected in previous reporting of exercise-specific interventions like ACLR rehabilitation programs. Unfortunately, the CERT (Slade *et al.,* 2016) was not well supported in our scoping review, with 41 studies that were supposed to specify items 7, 8, and 13 only reporting 14%-57% of these EDs from 2016-2021 during ACLR rehabilitation programs. Furthermore, Vlok *et al.* (2022) find "that the only exercise descriptors (EDs) frequently reported in studies on ACLR rehabilitation were the:

- Exercises' names.
- The number of exercises in the programs.
- The duration of the rehabilitation period.
- The frequency of training sessions per week.

Over the past 27 years, there was no apparent improvement in the reporting of EDs included in the ACSM, CERT, and T&B ST guidelines".

To conclude, the COS of ST EDs (Table 4.9 & 4.10) may provide a consent reporting framework to be used while incorporating the RM continuum loading schemes (endurance, hypertrophy, max strength) throughout all the strengthening phases of ACLR rehabilitation. The integration of the COS of EDs with the continuum will enable practitioners to easily move sideways in any horizontal direction on the continuum when conducting an ACLR rehabilitation program. This flexibility to move between all the different ST zones, focusing on the aim of the ST exercise, considering the phase of ACLR, underline the importance of progressive overloading within ACLR rehabilitation programs (Welling *et al.,* 2019; Paton *et al*., 2022).

Replicating consistency between ACLR clinical intervention trials and improving quality reporting of ACLR ST EDs and dosages may enable clinicians in private practices, sports clinics, gyms, and hospital-based facilities to replicate publications with ACLR ST exercise programs to translate research into practice.

4.6.3 Exercise dosages proposed by the Anterior Cruciate Ligament Reconstruction Expert Rehabilitation Group (ACLR ERG)

Exercise dosages that reached consensus during Rounds 1-3 are listed in Table 4.11 **(highlighted in green)**, and exercise dosages which did not reed consensus **(highlighted in red**, Table 4.12). It is clear from Tables 4.11 & 4.12 that our ACLR ERG shows **poor consensus agreement (<80% agreement) on exercise dosages prescribed during ACLR in most of the exercise dosages** (Round 1, 22.25% and Round 2, 25.9%) and low stability in most of the questions.

Table 4.11 summarises the exercise dosage figurations, which achieved **consensus agreement (88-96%).** Therefore, only these seven exercise dosages will be discussed in detail, and a general discussion will be followed on exercise dosage configurations and the importance thereof.

4.6.3.1 Repetition prescribed (Table 4.11 & 4.12)

Literature proposed clinicians working with ACLR patients to adopt targeted rehabilitation strategies focusing on lower loads initially, progressing towards maximum strength in the later phases of ACLR rehabilitation (Lorenz *et al.*, 2010; Maestroni *et al*., 2021). Evidence of a progressive ST modal (endurance, hypertrophy, and maximum strength focused) indicates a high value for restoring quadriceps and hamstring strength deficits in ACLR amateur male and professional soccer players **(Welling *et al.,* 2019; Maestroni *et al.,* 2023).** Reporting the exercise dosages from high-level ACLR interventions may enable clinicians to duplicate the result of evidence-based ACLR studies.

Table 4.13: Strength training exercise recommendation for ACLR rehabilitation according to modified Delphi and best practice guidelines												
ACLR strength training exercise descriptors	ACLR-ERG	ACSM	Supplementary strength training and ACLR literature	ACLR-ERG	ACSM	Supplementary strength training and ACLR literature	ACLR-ERG	ACSM	Supplementary strength training and ACLR literature	ACLR-ERG	ACSM	Supplementary strength training and ACLR literature
	ACLR rehabilitation (acute <3 months; intermitted 3-6 months; late>6 months)											
	Endurance focus			Strength/Hypertrophy focus			Maximum strength focus			Rate of Force Development focus		
Knee strengthening exercises prescribed per session	(4-6)	-----	-----	(4-6)	----	3[20]	(4-6)	-----	3[25]	(1-6)	-----	-----
Strength training sets prescribed per exercise	(1-3)	2-4	3-5[7,23]	(4-6)	1-3	4-6[5,19,21]	(4-6)	2-4	3-5[17,19]	(4-6)	3-6	3-5[19]
Repetitions prescribed per set	13-25	10-25	> 15 [1,15,22,23,26]	8-12	8-12	6-12[8,15,21,23]	2-6	3-6	3-6[16]	(2-6)	1-6	3-5[19]
ACLR strength training exercise descriptors	-------	-----	-----	(3-5RM)	1RM Testing or multiple RM testing	1 RM or % RM [12,19]	(3-5RM)	1RM testing or multiple RM testing	1 RM or % RM [12,19,28]	(3-5RM)	1RM Testing or multiple RM testing	1 RM or % RM [12,19,27,28]

Sets ratio conducted during strength training sets (Injured: Uninjured)	(3:1)	Bilateral and unilateral exercises	3:0[9]	(3:2)	Bilateral and unilateral exercises	3:0[9,29]	(3:3)	Bilateral and unilateral exercises	3:3[10,14]	(3:3)	Bilateral and unilateral exercises	Bilateral and unilateral exercises[10,14,29]
Frequency of strength training sessions prescribed per week	(5-6)	2-3	2-4[8,23]	3-4	2-3	2-4[8,17,18,23]	3-4	2-3	2[16]	(1-4)	2-3	2-3[13]
Load Magnitude	(20-60%RM)	<70% RM	30-70%RM[8,15,22]	(70-85%RM)	70-85%RM	A spectrum of loading ranges (30-90%RM) can induce hypertrophy [2,3,6,15,23]	80-95%RM	80-100%RM	80-100%RM[3,15]	(70-85%RM)	0-60%RM	30-60%RM[8]
Interset rest between singular exercise sets	30-60 Sec	30-60 Sec	<60 Sec[8]	(1-2 Min)	1-2 Min	2 Min[4]	(3-5 Min)	3-5 Min	3-5Min[11]	(2-3 Min)	2-3 Min	3-5Min[11,19]

Schoenfeld *et al.* (2021:32) define the "repetition maximum continuum as the number of repetitions performed at a given magnitude of load which will result in specific adaptations as follows:

- A low repetition scheme with heavy loads (from 1 to 5 repetitions per set with 80% to 100% of 1RM optimises strength increases.
- A moderate repetition scheme with moderate loads (from 8 to 12 repetitions per set with 60% to 80% of 1RM) optimises hypertrophic gains.
- A high repetition scheme with light loads (15+ repetitions per set with loads below 60% of 1RM) optimises local muscular endurance improvements".

Level 1 evidence supports the implementation of >15 repetitions to improve local muscle endurance, while the ACSM indicates 10-25 repetitions for healthy ST beginners, and the ACLR ERG confirmed the notion with expert consensus (88%) indicating 13-25 repetitions (Risberg *et al.,* 2007; Welling *et al.,* 2019; Schoenfeld *et al.,* 2021; Hackett *et al.,* 2022). Unfortunately, low levels of strength and muscle extensor power gains occur when training at low resistance strength endurance levels between 20-30RM, 7-20 weeks after ACLR, which can compromise strength improvement (Bieler *et al.,* 2014). Strength improvement is low when training in the endurance zone of the RM continuum, but essential to prepare the injured knee for higher ST intensities later in the continuum (Campos *et al.,* 2002).

4.6.3.2 % RM prescribed (Table 4.11 & 4.12)

Load magnitude is also an essential component of maximum ST to elicit maximum strength gains after ACLR surgery (Haff *et al.,* 2012). Evidence provided indicates that maximum ST at a heavy load magnitude (>85% of 1RM) elicits higher levels of strength and rated force development compared to conventional ST at moderate loads of 60-70% of 1RM (Heggelund *et al.,* 2013). Schoenfeld *et al*. (2017) indicated that hypertrophy can be achieved with both low-load and high-load strength training. ACLR literature reported the lack of maximal strength documented in a cohort of 11 ACLR studies where only two studies reported strength intensity >%80RM (Nichols *et al.,* 2021). Altogether, the three sources proposed a load magnitude of 80-100%RM highlighting the ACLR ERG with 80-95%RM and 83% consensus agreement. However, utilizing load magnitudes >80%RM in ACLR rehabilitation can target late-phase (>6 months) quadriceps weakness and rate of force development deficits (Maestroni *et al.,* 2019; Tayfur *et al.,* 2021).

4.6.3.3 Rest between sets prescribe (Table 4.11 & 4.12)

Proper interset rest between singular sets is essential to enhance the effectiveness of heavy maximum strength training, improve the quality/technique of the movement, and maintain the optimal tempo during execution (Spiering *et al.,* 2022). Three to five minutes rest were collectively proposed by the three stakeholders, while the ACLR ERG proposed the interset rest interval with no consensus.

The **ACSM** agreed on interset rest being 30-60 seconds or less while executing ST sets to improve strength endurance. Contrary to the majority, other ACLR rehabilitation literature used two to three minutes of rest between strength endurance exercise sets (Welling *et al.,* 2019).

4.6.3.4 Sessions per week prescribe (Table 11&12)

The ACLR ERG (91.3% consensus) agreed that three to four sessions of ST session prescribed, while the ACSM proposed two to three sessions for intermediate individuals (ST for > 6 months). Other literature indicates two sessions at 85%RM sessions would be enough to improve maximum strength gains among competitive athletes (Peterson *et al.,* 2004). ACLR soccer players followed a progressive strengthening program with the focus on maximum strength during Phases 3 and 4, seven to nine months after ACLR performing two to three sessions, five sets, and three repetitions at > 80%RM per week. Thus, it can be concluded that two to three sessions of maximum ST would be enough to recover maximum strength loss after ACLR surgery (Welling *et al.,* 2019).

The summarised comments to follow highlight why only a few of the exercise dosage configuration consensus was reached. It is clear that practicians feel that individualised prescriptions make it impossible to develop program designs according to loading principles and in phases.

Comments:

- *“I think it is individual and would not approach this the same with each patient.”*

- *“Again, I am confused why we are being asked about 'muscle strengthening exercise', but again, the labels are Phase 1: Endurance focus. Endurance and strength are two different forms of muscle function/performance. My answer is basically splitting the number down the middle 2 and 2 for quads and hams or 3/3 etc.”*
- *“Phase 1: 1) fewer sets due to a higher number of exercises, exposing the brain to more demands. 2) It depends on how many times per week these are performed 3) It depends on the number of exercises per session. There are multiple good ways to configure the training.”*
- *“I do not think there is a clear-cut separation between 1-3 and 4-6. Other more important variables (e.g., load, intention to move quickly, etc.) are more important”.*
- *“It all depends on the exercise and the task”.*

It is important to note that “to improve muscle performance outcomes, a ST program should follow the proposed laws of mechanotransduction (Khan & Scott, 2009) exercise specificity (Kraemer & Ratamess, 2004) and the SAID (Specific Adaptations to Imposed Demands) principle. Failure to improve muscle strength after ACLR could therefore be caused by faulty programming of EDs (e.g., exercise type, frequency, load) (Maestroni *et al*., 2020)”.

Thomas *et al*. (2017), Johnson *et al*. (2018), and Messer *et al*. (2020) stated that muscle weakness after ACLR is driven mainly by two main factors:

1. A decrease in the cross-sectional area (atrophy).
2. Arthrogenic muscle inhibition (AMI) (quadriceps activation failure).

Andrade *et al*. (2019) also recommended from five high-quality CPGs, that immediate knee mobilisation and strength/neuromuscular training should be used during ACL postoperative rehabilitation (Van Melick *et al.*, 2016; Logerstedt *et al*., 2017).

4.6.4 Exercise dosages proposed by ACSM, T&B and CERT as well as comparison with ACL ERG (Table 13)

As stated in the literature review (Chapter 2), “currently, Level 1 evidence indicates a lack of consensus on an optimal ACLR rehabilitation program and no clarity concerning the exercise dosage and delivery (Van Melick *et al.,* 2016; Culvenor *et al.,* 2022; Kotsifaki *et al.,* 2023). Expecting one optimal dosage is unrealistic, but with ACLR clinical trials that adequately report the critical components of exercise dosage, clinicians can make informed decisions when prescribing ACLR strengthening exercises targeting the pathophysiology of ACLR surgery (Augustsson, 2013; Goff *et al.,* 2018; Culvenor *et al.,* 2022)".

However, three main sources **(ACSM, T&B and CERT)** were used to build the ST best practice guidelines for ACLR rehabilitation programs (Ratamess *et al*., 2009; Toigo & Boutellier, 2006; Slade *et al*., 2016). **We, therefore, summarised the comparison of these three sources with our study (see Table 4.13).** The ACLR ERG consisted of 27 ACLR experts, American College of Sports Medicine (ACSM) ST guidelines for healthy individuals, and other supporting ST literature. **The reference numbers used in Table 4.13 are taken from the reference list in Chapter 3, scoping review (Vlok *et al*., 2022).**

Eight (8) ST EDs were selected to inform clinicians and researchers about exercise dosages proposed throughout the repetition maximum (RM) continuum (endurance, hypertrophy, maximum strength, rate of force development) and the ACLR rehabilitation phases (acute< 3 months; intermitted 3-6 months; late>6 months). The dashed lines indicate a free flow of the continuum elements and the function within the dissimilar ACLR rehabilitation phase/s (see Table 4.13). It is plausible to mention that no ACLR guideline/protocol can be followed as a recipe. Comparing the ACLR ERG recommendations with the ACSM positional stand, some inconsistencies were visible concerning ACLR ST dosages (see Table 4.13).

We acknowledge that patients need to be treated individually based on their unique clinical responses towards ST loading parameters and their individual physical activity preferences and goals, as stated in the comments of the ACLR ERG.

However, ACLR rehabilitation literature (Risberg *et al.,* 207; Ratamess *et al.,* 2009) also strongly recommended the usage of best practice ST guidelines like the ACSM and other supplementary literature to inform ACLR exercise programs about ST exercise dosages. Toigo and Boutllier *et al.* (2006) also report specific guidelines for resistance training interventions (Table 4.13).

The primary rehabilitation goal is to progressively load recovering tissue to promote its optimal adaptation back to full strength, elasticity, capability and function. Exercise progression also maintains ongoing adaptation to training (Pollard *et al.,* 2019). Paton *et al*. (2021: 238) also stated that "the influence of tissue healing, and the stage of healing is very important for clinicians in deciding the dosage of loading in the rehabilitation process. Components of muscle tissue (fascia, muscle cells and tendon) heal and adapt to loading at different rates after injury, and this has implications for time frames of healing, loading and recovery". Ahtiainen *et al*. (2016: 38) also mentioned that "rehabilitation should be clinically reasoned and individualised, based on the type of injured tissue, and its speed of healing and adaptation. Optimising progressive dosage of loading (volume, frequency, intensity and duration) should encompass sufficient overload to promote adaptations but not cause tissue reinjury, which may vary for each myotendinous structure (fascia/muscle/musculotendinous junction (MTJ)/tendon) the response to previous loading and strength should be prioritised to decide the dosage of exercise/load".

4.6.4.1 Strength Endurance focus

It is well known that many factors influence successful rehabilitation (O'Connor, 2020), such as the increase in the cross-sectional area (atrophy) after an injury (Thomas *et al*., 2017). Thus, we acknowledge the impact of exercise selection on cross-sectional areas in ACLR rehabilitation programs. However, according to the ACSM best practice ST guidelines, "strength training to increase the cross-sectional area should be performed with **6-12 repetitions, 2-4 sets, 60-120 seconds rest between sets and a load magnitude of 60-80% of 1RM.**

Strength training (ST) sets prescribed per session

Strength training sets vary from one to five, considering the training age of the ACLR patient and the initial healing and post-surgical responses. Training age can be categorised as either beginner (no ST done for < 2 months), intermediate (ST for two to six months), or advanced (>12 months) described by the literature (Beachle, 2008).

Commonly, ACLR patients will enter a ST program as beginners after ACLR surgery, starting with one to three sets per ACLR knee-focused exercise and progress accordingly.

Endurance focus: Repetitions prescribed per exercise set range from 13-25 shows consensus between all three sources indicated in Table 4 .13. Level 1 evidence supports the implementation of >15 repetitions to improve local muscle endurance, while the ACSM indicates 10-25 repetitions for healthy ST beginners. The ACLR ERG also confirmed the notion with **consensus agreement (88%)** (Table 4.10) indicating 13-25 repetitions (Hackett *et al.,* 2022).

Endurance focus: Knee-specific strengthening exercise prescribed per session was only indicated by the ACLR ERG as four to six exercises with **no consensus agreement** between experts and low stability (Table 4.11).

Endurance focus: Strengthening sets prescribed per exercise **varies** from one to five, considering the training age of the ACLR patient and the initial healing responses post-surgical. Training age can be categorised as either beginner (no ST done for <2 months), intermediate (ST for two to six months), or advanced (>12 months) described by the literature (Beachle, 2008). Usually, ACLR patients enter a ST program as beginners after ACLR surgery, starting with one to three sets per ACLR knee-focused exercise proposed by the ACLR ERG. American College Sports Medicine (ACSM) recommendations indicate two to four exercise sets per exercise (beginners), and other literature indicated three to five sets for healthy untrained men and three sets for ACLR patients completing a ST program (Risberg *et al.,* 2007; Radaelli *et al.,* 2015). ST to improve endurance in ACLR patients depends on sufficient exercise sets, ranging from three to five while considering the other EDs, e.g., repetitions and load magnitude prescribed.

Endurance focus: Repetitions prescribed per exercise set range from 10-25 indicates consensus between all three sources summarised in Table 4.13. Level 1 evidence supports the implementation of >15 repetitions to improve local muscle endurance. At the same time, the ACSM indicates 10-25 repetitions for healthy ST beginners, and the ACLR ERG confirmed the notion with **consensus agreement (88%) (Table 11)** indicating 13-25 repetitions (Risberg *et al.,* 2007; Welling *et al.,* 2019; Schoenfeld *et al.,* 2021; Hackett *et al.,* 2022). Unfortunately, low levels of strength and muscle extensor power gains occur when training at low resistance strength endurance levels between 20-30RM, 7-20 weeks after ACLR, which can compromise strength improvement (Bieler *et al.,* 2014). Strength improvement is low when training in the endurance zone of the RM continuum, but essential to prepare the injured knee for higher ST intensities later in the continuum (Campos *et al.,* 2002).

Endurance focus: Sets ratio conducted during ST sets (injured vs uninjured)

*S*trength deficits keep persisting after ACLR surgery, which underlined the unreciprocated question of increasing the volume of exercise dosage on the injured side compared to the uninjured side (Turpeinen *et al.,* 2020). Accordingly, the ACSM recommends an equal set ratio of 3:3 in healthy individuals that should be followed when prescribing ST, but it can differ when one introduces ST rehabilitation to an ACLR patient. Considering the trauma after ACLR surgery, which influenced muscle strength around the injured knee, a different approach is validated regarding an unequal loading ratio of 3:1 and 3:0, respectively, proposed by the ACLR ERG and other research (Kuenze *et al.,* 2017; Oliveira *et al.,* 2022;). Only two ACLR studies utilised a 3:0 ratio to improve quadriceps strength (Table 4.13). Moreover, a lack of research exists regarding the ST ratio recommendations during ACLR rehabilitation.

Another consideration that has been explored is the phenomena of cross-education which can be defined as focusing initial exercise training on the uninjured limb to improve the strength of the injured, considering the cross-over effect. Level 1 research indicates no increase in strength benefits when one includes a cross-education program in a standard ACLR rehabilitation program (Zult *et al.,* 2019). Contrary, Minshull *et al.* (2021) concluded no decay in quadriceps peak force after 24 sessions of 3-5RM cross-education ST on the uninjured knee. In conclusion, Aspetar clinical practice guideline on rehabilitation after ACLR does not include the practice of cross-education in ACLR patients to improve the strength of the injured leg (Kotsifaki *et al.,* 2023).

Endurance focus: Frequency of ST sessions prescribed per week

The ACLR ERG concluded with **no consensus agreement and low stability** (Table 4.11) a high frequency of ACLR ST sessions (five to six) prescribed during the initial phases of ACLR rehabilitation. The ACSM recommends two to three sessions for beginners of a strength endurance program, while other ST literature proposes two to four sessions (Kraemer *et al.,* 2004). Additional Level 1 ACLR literature indicates two to three sessions per week within a cohort of 11 studies and a randomised control trial evaluating neuromuscular training vs ST in ACLR patients (Risberg *et al.,* 2007; Nichols *et al.,* 2021). Currently, we do not have the exact number of sessions prescribed, but two to four sessions per week seems feasible based on current literature.

Endurance focus: Load magnitude **prescribed per exercise set** can differ in several ways, considering the objective of the specific exercise and program. When the aim of the exercise is to improve strength and muscle endurance, the ACLR ERG with **no consensus agreement and low stability** (Table 4.12) concluded a load magnitude intensity between 20-60%RM, while the ACSM and Schoenfeld *et al*. (2021 proposed <70%RM and other research confirms it with 30-70%RM (Kraemer *et al.,* 2004). Welling *et al.* (2019) introduced a load magnitude of <%50RM for ACLR amateur soccer players to improve muscle strength endurance, although not the main purpose of the study. Therefore, a load magnitude range between 30-70%RM is viable to use in ACLR rehabilitation programs to target endurance deficits. Maximum strength deficits can be targeted when training at 60% RM, two sets, >20 repetitions (Campos *et al.,* 2002).

Endurance focus: Interset rest between singular exercise sets

All three resources (Table 4.13) agreed on interset rest being 30-60 seconds or less while executing ST sets to improve strength endurance. Contrary to the majority, other ACLR rehabilitation literature used two to three minutes of rest between strength endurance exercise sets (Welling *et al.,* 2019).

4.6.4.2 Strength/hypertrophy focus:

Restoring muscle mass after ACLR is essential to improve muscle strength (Fukunaga *et al.,* 2019). A decrease in quadriceps muscle fiber force production and cross-sectional area (CSA) of the Type l and llA vastus lateralis muscle fibres six months after ACLR and rehabilitation, reflecting the need for a proper ACLR ST intervention targeting these morphological alterations (Noehren *et al.,* 2016; Gumucio *et al.,* 2018).

Targeting atrophying CSA in the affected quadriceps and hamstring muscle groups after ACLR through the activation of Type l and Type ll muscle fibres could be essential to improve contractile fiber force production. Campos *et al.* (2002) concluded that muscle hypertrophic changes occur primarily at muscle fibre Type l, llA, and llB levels with 12.5%, 19.5%, and 26.5%, respectively, in untrained individuals training with loads between 9-11RM; three sets; two to three session per week performing three exercises per session, reflecting the RM continuum prescription for hypertrophic changes.

Strength/Hypertrophy focus**: **Knee strengthening exercises can be prescribed per session

The ACLR ERG proposed four to six knee strengthening exercises prescribed per session (Table 4.13), while literature conducted on healthy individuals included three knee-focused exercises for hypertrophic muscle-induced changes (Campos *et al.,* 2002).

Strength/Hypertrophy focus: Strengthening sets prescribed per exercise

The ACLR ERG indicates four to six sets per exercise with **no consensus agreement and low stability** (Table 11), while the ACSM put forth one to three sets for beginners, and other literature proposed four to six sets per exercise (Beacle, 2008; Krieger, 2010). Focussing on ACLR ST targeting quadriceps weakness using the leg press exercise as a conventional ST modality, a set frequency of six at 8RM was prescribed to the ACLR control group. Quadriceps muscle CSA improved by 4%, and quadriceps peak torque improvement was clinically significant (Friedmann-Bette *et al.,* 2018).
Sets prescribed should be viewed within the context of other EDs, e.g., repetitions and load magnitude that make up the dose-response to exercise training.

Strength/Hypertrophy focus: Repetitions prescribed per set

All three sources (Table 4.12) unanimously recommended a six/8-12 repetitions range when prescribing repetitions per set for strength/hypertrophy focus exercises.

Strength/Hypertrophy focus: RM test conducted

The ACSM concluded that 1RM or multiple repetitions (multiple-RM) tests could be conducted on healthy individuals with more training experience prior to testing. Other ST literature consented with 1RM, %RM or multiple-RM testing utilised to measure accurately load applied during ST for healthy individuals and ACLR patients (Risberg *et al.,* 2007; Beachel, 2008; Thomson *et al.,* 2020; Nichols *et al.,* 2021). Thus, it has been suggested that a 3RM test could be used instead of a maximal 1RM test. Ignoring an athlete's training status and exercise technique experience will diminish the safety and accuracy of 1RM test results (Beachel, 2008). Maximum strength testing is commonly applied for the first time 12-24 weeks after ACLR surgery (Risberg *et al.,* 1999; Angelozzi *et al.,* 2012). More precise ACLR ST exercise prescriptions coincide with the measurement of ST intensities during the ACLR rehabilitation period. This can enable clinicians to carefully select the proper load intensities to target contractile fibre force deficits and atrophying Type I and llA muscle fibers after ACLR surgery.

Strength/hypertrophy focus: Sets ratio conducted during ST sets (Injured vs Uninjured)

The ACLR ERG indicates a 3:2 injured vs uninjured ratio to utilised in targeting muscle weakness after ACLR surgery during the consequently following ACLR ST phases. Although there is **no consensus agreement**, some experts indicate that a difference in ratio will be followed until the asymmetry between injured and uninjured is corrected. ACSM proposed unilateral and bilateral exercises following hypertrophic training. A Level 1 randomised control trial was conducted by Oliveira *et al.* (2022) to assess the effect of unilateral versus bilateral resistance exercise in postoperative rehabilitation after ACLR with bone-patellar tendon-bone graft. The main aim of this study was to verify whether unilateral isotonic resistance exercise is more effective than bilateral exercise for obtaining postoperative functional and muscular strength symmetry between the donor limb and reconstructed limb for patients who received a BPTB graft. The unilateral ST ratio was 3:0 donor vs the reconstructed side for the intervention group, while the control group executed the exercise bilaterally. Results indicated a bilateral strength improvement for both groups but more so for the intervention group (donor side). Therefore, although surgical producers differ from the norm, we can see the effect of unilateral strength training. Increasing the total exercise volume by increasing the number of sets performed on the injured side targeting muscle weakness seems promising, but a lack of research exists.

Strength/hypertrophy focus: Frequency of ST sessions prescribed per week

Exercise frequency differs from three to four sessions (ACLR ERG with **91.6% consensus agreement Table 4.11**), two to three sessions (ACSM), and two to four sessions (other literature) (Table 4.13). The variance between the different sources are low, which indicates a high level of agreement. Targeting muscle weakness and improving muscle CSA and strength after ACLR surgery required two to four sessions per week. Level 1 systematic indicates a frequency of twice compared to once a week would be enough to induce hypertrophic chance in healthy untrained individuals (Schoenfeld *et al.,* 2016).

Strength/hypertrophy focus: Load magnitude

A spectrum of loading ranges from 30-90%RM can induce hypertrophic changes according to other ST literature (Table 4.13). Opposingly, the ACLR ERG and ACSM suggested a hypertrophic range of 70-85%RM (Table 4.13). The reason for such a difference in hypertrophic ranges between the different sources is uncertain.

The impact of load magnitude considering the other EDs, e.g., sets, repetitions etc., on the muscle CSA and weakness of the ACLR limb is essential. ACLR quadriceps strength deficits and atrophy can be targeted through ST exercises ranging from 30-90%RM, which activates Type I and IIA muscle fibers considering that exercise has been executed <70%RM should be done until failure, while exercise between 70-90%RM should be executed in a controlled with good technique.

ACLR ST exercises executed between 8-12RM (65-80%RM) effort over an eight-week period increase maximum muscle power with 16% (Bieler *et al.,* 2014).

Strength/hypertrophy focus: Interset rest between singular exercise sets

The collective agreement between the three resources (Table 4.13) indicates a rest period of one to two minutes while doing strength/hypertrophy exercise sets.

4.6.4.3 Maximum strength focus:

Strength and power are reduced in dynamic movement patterns, e.g., single leg countermovement jumps and isolated muscle groups like quadriceps and hamstrings after ACLR (Maestroni *et al.,* 2021). Improved maximum strength can target muscle weakness and functional deficits and enhance the force-time characteristics (e.g., RFD and external mechanical power) of an individual, which can be translated to their athletic performance (Suchomel *et al.,* 2016). Therefore, ACLR rehabilitation should prepare athletic populations to tolerate loads and velocities across the full spectrum of the force–velocity curve and the RM continuum (Maestroni *et al.,* 2019). This is essential for returning injured athletes to high-performance levels. Activating high threshold motor units through Type llA muscle fibers is essential to improve maximum strength force production.

Maximum strength focus: Knee strengthening exercises prescribed per session

The ACLR ERG proposed four to six exercises for maximum strength gains, and supplementary ACLR literature indicated three knee focus exercises (Table 4.13) (Maestroni *et al.,* 2020).

Maximum strength focus: ST sets prescribed per exercise

Sets prescribed by the ACLR ERG entailed four to six (**no consensus agreement** and low stability (Table 4.12), ACSM recommends two to four sets, and the supplementary literature support three to five sets (Table 4.13) while executing exercises with the intent of maximum strength gains during ACLR rehabilitation.

Level 3 cohort ST study investigated ACLR amateur soccer players implementing the RM continuum from four to nine months ending with five sets of three repetitions at >80%1RM during their last phase to improve knee extension and flexion muscle strength. Strength improvement of the quadriceps group was clinically significant with <10% difference at nine months post-operative ACLR (Welling *et al.,* 2019). Additionally, ACLR literature considering strength and power training specifies four sets at 6RM to improve quadriceps strength (Maestroni *et al.,* 2020). It appears that performing multiple exercise sets, to a certain extent, is advantageous in developing maximal strength (Suchomel *et al.,* 2018). Maximum ST sets ranging between three to six are necessary to target high threshold motor units' activation in ACLR patients, and so diminish quadriceps weakness.

Maximum strength focus: Repetitions prescribed per set

For maximum ST gains after ACLR surgery, the repetition prescribed forms an important foundation of the ACLR ST program. The ACLR ERG proposed a repetition range of two to six (**96% consensus agreement Table 4.11**), and the ASCM and supplementary ST literature indicates three to six repetitions per set (Table 4.13). Activating the high-threshold motor units with maximal ST is one way to target quadriceps muscle inhibition (Maestroni *et al*., 2020). However, exercise prescription for maximal ST should involve a load magnitude of >80% 1RM, one to six repetitions across three to five sets, a rest period of three to five minutes, and a frequency of two to three times per week (Ratamess *et al*., 2009).

Maximum strength focus: RM test conducted

The ACLR ERG indicated that 3-5RM **(no consensus agreement Table 4.12)** testing should be done during this rehabilitation phase, while ACSM recommends 1RM testing or multiple RM testing for healthy individuals. Supplementary literature indicates that 1RM or %RM testing can be feasibly implemented when measuring maximum strength intensity (Suchomel *et al.,* 2021). Additionally, power, and maximum strength exercises do not lend themselves well to multiple-RM testing above five repetitions for repeated testing sets because the technique can deteriorate rapidly (Beachle & Earle, 2008).

Maximum strength focus: Sets ratio conducted during ST sets (Injured vs Uninjured)

The ACLR ERG indicates a 3:3 ratio which agrees with the supplementary ST ACLR literature. ASCM proposed bilateral and unilateral exercises can be used during this phase of strengthening healthy individuals.

Maximum strength focus: Frequency of ST sessions prescribed per week

The ACLR ERG (91.3% consensus) agreed that three to four sessions of ST session prescribed, while the ACSM proposed two to three sessions for intermediate individuals (ST for >6 months). Other literature indicates two sessions at 85%RM sessions would be enough to improve maximum strength gains among competitive athletes (Peterson *et al.,* 2004). ACLR soccer players followed a progressive strengthening program focusing on maximum strength during Phases 3 and 4, seven to nine months after ACLR performing two to three sessions, five sets, and three repetitions at > 80%RM per week. Thus, it can be concluded that two to three sessions of maximum ST would be enough to recover maximum strength loss after ACLR surgery (Welling *et al.,* 2019).

Maximum strength focus: Load magnitude

Load magnitude is an essential component of maximum ST to elicit maximum strength gains after ACLR surgery (Haff *et al.,* 2012). Evidence provided suggests that maximum ST at a heavy load magnitude (>85% of 1RM) elicits higher levels of strength and rated force development compared to conventional ST at moderate loads of 60-70% of 1RM (Heggelund *et al.,* 2013). ACLR literature reported the lack of maximal strength documented in a cohort of 11 ACLR studies where only two studies reported strength intensity >%80RM. Altogether, the three sources proposed a load magnitude of 80-100%RM highlighting the ACLR_ERG with 80-95%RM and 83% consensus agreement. Utilising load magnitudes >80%RM in ACLR rehabilitation can target late phase (>6 months) quadriceps weakness and rate of force development deficits (Maestroni *et al.,* 2019; Tayfur *et al.,* 2021).

Maximum strength focus: Interset rest between singular exercise sets

Proper interset rest between singular sets is essential to enhance the effectiveness of heavy maximum strength training, improve the quality/technique of the movement, and maintain the optimal tempo during execution (Spiering *et al.,* 2022). Therefore, all three stakeholders collectively proposed three to five minutes rest, while the ACLR ERG proposed the interset rest interval with no consensus (Table 12 & 13).

4.6.4.4 Rate of force development (RFD) focus:

The rate of force development (RFD) is one of the most important variables affecting performance in sports activities that require great acceleration (Marques *et al.,* 2007). Unfortunately, RFD deficits persists in quadriceps and hamstring muscle groups beyond 12 months after ACLR (Tayfur *et al*., 2021; Angelozzi *et al.,* 2012; Turpeinen *et al.,* 2020; Nielsen *et al.,* 2020). Thus, the time has come to incorporate RFD exercise into ACLR rehabilitation ST programs (Buckthorpe & Roi, 2018). However, it is essential to consider which dosage components can be incorporated according to ACLR experts, ACSM and other ST literature. Wellinget *et al*. (2019: 13) stated, "Besides strength training, other aspects (i.e., balance, running technique, jump-landing technique, etc.) were trained during the fourth phase of the rehabilitation. After that, the focus was on on-field rehabilitation and RTS".

Filbay and Grindem (2019: 42) indicate that "late phase rehabilitation should be individualised based on the patient's specific goals and athletic demands. The type of sport and physical activity that patients with an ACL rupture wish to participate in can vary widely; assessment of these athletic demands is key to tailoring a rehabilitation plan that leads to a successful return to sport (RTS) or activity. Typically, this phase includes impairment-specific heavy strength training, power, and agility drills, and sport-specific exercises. After passing the criteria of a performance-based RTS test battery, the athlete gradually resumes participation in unrestricted sports practice. This is achieved with a staged progression from modified training (e.g., noncontact only), to full training (unrestricted), to restricted participation in competition (by the number of minutes), to unrestricted participation in competition".

Rate of force development (RFD) focus: Knee strengthening exercises prescribed per session

ACLR ERG concluded with four to six exercises. Still, with **no consensus agreement** (Table 12) and no recommendations from ACSM, other ACLR clinical commentary indicated four exercises as examples to improve RFD (Maestroni *et al.,* 2019).

Rate of force development (RFD) focus: ST sets prescribed per exercise

There was a slight disagreement on the number of sets prescribed between the three sources with the ACLR ERG **(no consensus agreement)** putting forth four to six sets, the ACSM three to six sets, and other ST literature proposed three to five sets (Baechle & Earle, 2008) (see Table 4.13). Peak power and RFD six months after ACLR can be developed following three sets of split squads (three reps at >85%RM), squad jumps, countermovement jumps and single leg hops (Maestroni *et al.,* 2019).

Rate of force development (RFD) focus: ST repetitions prescribed per exercise set

Repetitions prescribed vary between two to six indicated by the ACLR ERG, following one to six proposed by the ACSM and three to five for the other literature (Table 4.13). Depending on the aim of the exercise, RFD exercise can be divided into targeting late RFD improvement (>300ms) like squatting at 85%RM between three to six repetitions and early RFD (< 300ms) executing single leg hops body weight between three to six repetitions (Beachle & Earle, 2008; Oliveira *et al.,* 2013). Either way, repetitions ranging from three to six will imply similar objectives in the improvement of RFD after ACLR surgery.

Rate of force development (RFD) focus: RM test conducted

During the intermitted ACLR phase (three to six months) and late ACLR phase (>6 months), the ACLR ERG suggested that a 3-5RM testing should be conducted. At the same time, ACSM indicated a 1RM or multiple RM test can be performed on healthy individuals with weight training experience (Table 4.12). Other ST literature determined that %RM and 1RM can be utilised to estimate the load magnitude for RFD development (Beachle & Earle, 2008; Cormie *et al.,* 2011) (Table 4.12). Testing maximum strength and power through the recommended best practice guidelines was essential for measuring improvement or adjusting RFD load during ACLR rehabilitation programs (Suchomel *et al.,* 2016).

Rate of force development (RFD) focus: Sets ratio conducted during RFD sets (Injured: Uninjured)

ACLR ERG encouraged a symmetrical loading ratio when conducting RFD strengthening exercises. The ASCM and other literature suggest bilateral exercise execution, defined as exercises executed with both limbs and unilateral loading, defined as training with one limb, should be done to improve maximum strength and RFD (Ogborn *et al*., 2021; Suchomel *et al.,* 2018) Table 4.13). Furthermore, varying exercise selection to include split-stance positions, such as the split-squad and lunge positions, can target interlimb asymmetries after ACLR (Ogborn *et al.,* 2021). To conclude, a dearth of evidence exists that should inform us about loading ratios for specific RFD interlimb asymmetries after ACLR surgery.

Rate of force development (RFD) focus: Frequency of RFD training sessions prescribed per week

The ACLR ERG (no consensus agreement) (Table 4.12) proposed a 1-4 RFD-focused exercise sessions per week, while the ACSM and other literature indicate two to three sessions.

Rate of force development (RFD) focus: Load Magnitude

Rate of force development (RFD) is a neuromuscular quality that lacks in the majority of ACLR patients between six and 24 months after surgery (Turpeinen *et al.,* 2020; Tayfur *et al.,* 2021; Maestroni *et al.,* 2021). Some literature indicated that intensities above 80%1RM, necessary to improve RFD and maximum strength, were not adequately reported in ACLR exercise interventions (Nichols *et al.,* 2021). Consequently, load magnitude prescribed for the improvement of RFD in ACLR patients is an essential exercise descriptor and an important neuromuscular quality for the RTS performance that should be targeted through effective exercise prescriptions (Buckthorpe & Roi, 2017; Maestroni *et al.,* 2021).

The ACLR ERG proposed a load magnitude ranging from 70-85%RM for RFD exercise, while ACSM recommended 0-60%RM, and other literature indicated 30-60%RM (Table 4.13). It is clear that a single relative intensity cannot be broadly applied to all exercises as an optimal training load for power and RFD. Heavier loads lifted (>70% RM) resulted in a greater increase in late RFD (300-800ms), while lighter loads lifted (< 30%RM) led to improved activation of early RFD (50-300ms) (Oliveira *et al.,* 2013). Thus, the aim of the RFD exercise within an ACLR rehabilitation program would define the load magnitude selected.

Rate of force development (RFD) focus: Interset rest between singular exercise sets

ACLR rehabilitation programs should include a maximum ST phase when considering a sport with cutting and pivoting manoeuvres as a RTS goal. For maximal strength and RFD, rest periods of two to three minutes are proposed (Garber *et al*., 2011). As discussed in the literature review (Chapter 2), there is an “alarming gap in ACLR rehabilitation exists due to the inadequate reporting of resistance intensity over the entire spectrum of the RM continuum (Augustsson, 2013; Goff *et al.,* 2018). More specifically, Level 1 evidence indicated a dearth in reporting the intensity of power and ST exercises in the late stage (>6 months) of ACLR rehabilitation programs (Nichols *et al.,* 2021)".

Maestroni *et al.* (2021: 98) concluded that "sports and healthcare professionals should be encouraged to adopt targeted rehabilitation strategies focusing on maximal strength, that include specific exercise selection, dosage, and progressions. Briefly, current evidence indicates single joint (e.g., leg extension/curl) and multi-joint exercises (e.g., split squat, front/back squat, deadlift) involving a load (or intensity) of 80-100% of the participant's one RM, utilising approximately one to six repetitions, across three to five sets, with rest periods of three to five minutes, and a frequency of two to three times per week". Kyritsis *et al*. (2016) proposed isokinetic quadriceps strength testing (≥90% of the opposite leg), three single-legged hop tests (≥ 90% of the opposite leg), and an agility test (11 seconds). Additionally, athletes had to complete on-field sport-specific rehabilitation.

Maestroni *et al.* (2021) further stated that because of the paucity of studies investigating RFD and reactive strength, we could not draw conclusions between these fundamental physical determinants and rehabilitation status, which warrants further research.

4.6.5 The lack of consensus agreement on exercise dosage in ACLR rehabilitation programs

It is a fact that only with reported EDs can study results be fully interpreted and rehabilitation research replicated (Nichols *et al*., 2021). For clinicians, reported EDs are also key to successfully transferring rehabilitation programs from research to practice (Williams *et al*., 2017). Our findings in our scoping review (Vlok *et al*., 2022) expand on those of two other reviews, which concluded that acute program variables (PVs) (exercise order, tempo, rest, frequency) are inadequately described in tibiofemoral joint soft tissue injuries (Goff *et al*., 2018), and the reporting of ACLR rehabilitation programs lack specificity (Augustsson, 2013). Vlok *et al*. (2022) concluded that "the only exercise descriptors frequently reported in studies on ACLR rehabilitation were the exercises' name, the number of exercises in the programs, the duration of the rehabilitation period, and the frequency of training sessions per week. Over the past 27 years, there was no apparent improvement in reporting exercise descriptors (EDs) included in the ACSM, CERT, and T&B strength training (ST) guidelines".

Vlok *et al*. (2022) also indicate that "persistent muscle weakness is reported after ACLR rehabilitation, but how the strength training was performed is poorly reported. Clinicians should, therefore, not discount strength training performed after best practice guidelines as a main factor to regain muscle strength after ACLR".

The question arises if persistent weakness after ACLR rehabilitation is still relevant, it could be that programs are not following best practices for ST (Filbay & Grindhem, 2019; Maestronie *et al*., 2020). It is also well documented that to improve muscle performance outcomes, a ST program should follow the proposed laws of mechanotransduction (Khan & Scott, 2009), exercise specificity (Kraemer & Ratamess, 2004) and the SAID (specific adaptations to imposed demands) principle (Vlok *et al*., 2022). Maestronie *et al*. (2020) stated in this regard that failure to improve muscle strength after ACLR could therefore be caused by faulty programming of EDs (e.g., exercise type, frequency, load).

Therefore, Vlok *et al*. (2022) concluded that to determine if the full potential of ST has been realised in previous literature, we need more knowledge about the EDs and, very importantly, the exercise dosages reported in ACLR rehabilitation studies. Unfortunately, our e-Delphi study on the general exercise dosages practice in ACLR rehabilitation indicates very low consensus agreement between our ACLR ERG on exercise dosages prescription. Alarmingly, Barton *et al.* (2021) indicates in their large multi-national survey that many physiotherapists lack guideline knowledge, awareness and perceived competence to promote physical activity for people with musculoskeletal pain. **It must be noted that 74.1% (20/27) of our ACLR ERG were physiotherapists**. Sixty percent (60%) of Physiotherapists were able to correctly state the WHO physical activity guidelines for adults, reflecting findings from similar national-level studies (50-60%). Barton *et al*. (2021: 1011) further stated, "Despite acknowledging their role, only 38% and 50% of physiotherapists believed they had been trained to prescribe and progress aerobic exercise and resistance training following **accepted guidelines**, irrespectively.

Additionally, very few stated that they were aware of accepted aerobic exercise and resistance training guidelines (20-31%), and fewer were able to name accepted guidelines (11-21%)". In conclusion, it is clear that these findings indicate professional development initiatives that may benefit all physiotherapists, and an urgent need exists for professional development initiatives related to exercise prescription. Therefore, physiotherapists and other clinicians in the field (biokineticist) need to improve their knowledge in resistance training, regardless of postgraduate training. Curriculum development is sorely needed in this field. Welling *et al*. (2021) concluded that physiotherapists should focus on improving the quality of rehabilitation after ACLR by implementing more progressive strength training.

4.6.6 Strength and Limitations of the study

According to the literature, there are many potential weaknesses of the e-Delphi and consensus research methodology (Veugelers *et al*., 2020; Paton *et al*., 2023). Paton *et al*. (2023) speculate that bias is possible with inadequate expert inclusion and exclusion criteria in a study with inadequate design (Barret & Heale, 2020). Despite our invitation to national and international experts involved in ACLR rehabilitation, 27 experts responded. The median age of our ACLR ERG group was 38 years, with good clinical experience of 13 years. The expert group consisted of 20 physiotherapists (74.1%), followed by six biokineticists (22.2%) and one (3.7%) sports scientist. Our ACL ERG are well qualified, with forty-four percent (44%) of the participants having a doctorate degree, 29.6% a master's, and the rest (25.9%) having a bachelor's degree. Respondents originate from 10 countries working in six different mixtures of locations from 10 different countries. Therefore, our ACLR ERG was not heterogenous in profession, with 74% (20/27) physiotherapists and only 16% (biokineticist) and one athletic trainer. This could result in inclusion bias for one profession (Cole *et al*., 2013). Academic criteria were thought to be important, and clinical experience was deemed to be important.

Unfortunately, choosing criteria for expertise is difficult for any Delphi study and represents one weakness of this methodology (Paton *et al*., 2021). While we trusted the survey respondents (our ACLR ERG) to have excellent knowledge of ACLR with excellent academic qualifications, it may be possible that ST prescriptions were outside their domain and level of expertise or scope of practice (Welling *et al.,* 2019; Barton *et al*., 2021). The perspectives of some of the groups may be under-represented in this study, with biokineticists and athletic trainers comprising a smaller proportion (6%) of our expert panel, and their view specifically in the final phase of ACL rehabilitation is vital (Belton *et al*., 2019). In the later stages of rehabilitation of ACLR, experts advocate the prescription of cutting and pivoting manoeuvres (Garber *et al*., 2011), agility, pivot movement, rate of force development as key components and progression criteria to full return to performance (RTP$^{erf.}$) (Suchomel *et al.,* 2018; Filbay & Grindem, 2019; Maestronie *et al*., 2020; Ogborn *et al.,* 2021). This also needs experts to continuously monitor and test athletes through rehabilitation and using modalities such as isokinetic dynamometers, GPS, photocells and force plates (Filbay & Grindem, 2019; Maestroni *et al.,* 2019; Paton *et al*., 2023).

4.6.7 Conclusion and Recommendations for future research

Our ACLR ERG proposed 22 ACLR exercise descriptor definitions which clinicians should use in ACLR programs and core outcome EDs. However, exercise dosages prescribed during ACLR rehabilitation during different phases focusing on the different strengthening components needs further research. We concluded that to determine if the full potential of ST has been realised in previous literature, we need more knowledge about the EDs and, very importantly, the exercise dosages that are reported in ACLR rehabilitation studies (Grindem *et al.,* 2016; Filbay & Grindhem, 2019; Maestronie *et al*. 2020). Unfortunately, our e-Delphi study on the general exercise dosages practice in ACLR rehabilitation shows very low consensus agreement between our ACLR ERG on exercise dosages prescription. Physiotherapists should focus on improving the quality of the rehabilitation after ACLR by implementing more **progressive ST** (Welling *et al*., 2021).

It is also clear from the literature that physiotherapists and other clinicians (biokineticists/athletic trainers) in the field of ACLR needed to improve their knowledge in resistance training, regardless of postgraduate training, and curriculum development is sorely needed in this field (Barton *et al*., 2021).

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CHAPTER 5

VALIDATION OF ACLR CONCEPTUAL FRAMEWORK

5.1 INTRODUCTION

In this chapter, the methodology of the validation meeting will be described, and the results obtained using qualitative content analysis will be presented with a discussion concerning the elements to be included and/or excluded in the final framework.

It is advised that researchers position their problem statements within a conceptual or theoretical framework (Chalmers, 1982, as cited in McGaghie *et al.*, 2001). A theoretical framework provides the theory that contextualises and justify the study, whereas a conceptual framework draws on various theories, findings, and frameworks that guide the research process (Adom *et al.*, 2018; McGaghie *et al.*, 2001). A conceptual framework refers to a researcher's constructed model, which explains interconnected vital concepts and relationships exploring the research problem (Adom *et al.*, 2018). During Phase 3 of this research study, the researcher developed an ACLR conceptual framework for integrating a consensus core outcome set (COS) of strength training (ST) exercise descriptors (EDs) into ACLR rehabilitation programs following the completion of a scoping review and the resultant completion of a modified Delphi survey.

The proposed ACLR conceptual framework was subjected to a validation meeting consisting of area experts to enhance its legitimacy. An in-depth consensus-seeking discussion of the content from various views of expertise was necessary to improve the ACLR conceptual framework's credibility. This purposefully selected panel consisted of one national and three international experts. There were two ACLR subject experts, one musculoskeletal clinician/researcher, and one panellist specialising in ST and conditioning.

The primary purpose was to validate and finalise the presented draft ACLR conceptual framework regarding the definitions used and the 18 core outcomes set of EDs (ACLR strengthening exercises) proposed to be reported on by the ACLR ERG. The second objective was to explore expert views concerning the practicality, context, and concepts used (Creswell, 2012). Various obstacles can be encountered when working towards better reporting ACLR ST EDs in both research and clinical settings. These data-driven research designs through which the ACLR conceptual framework was designed can comprise of qualitative research.

As part of the exploratory process, a validation meeting was held. The nature of the meeting was flexible and included questions related to the study objectives to facilitate a critical review of the ACLR conceptual framework (Tastle *et al.,* 2005; Cohen & Crabtree, 2006; Botma *et al*., 2015; Van der Merwe, 2020). The selection process and nature of the meeting are discussed below in detail. The data obtained during the validation meeting was applied to finalise, contextualise, and enhance the ACLR conceptual framework's credibility.

The chapter will conclude with a description of the ACLR conceptual framework finalisation process and a presentation of the framework.

5.2 RESEARCH QUESTION

The following research question was addressed.

- What are the opinions of national and international experts from various fields (research and clinical practice) interacting with ACLR patients regarding the draft ACLR conceptual framework for the reporting of strength training (ST) exercise descriptors (EDs)?

5.3 OBJECTIVES OF THE FOURTH PHASE

The objectives of the fourth phase of the study were:

- To discuss, critically review, and validate the construct of the ACLR conceptual framework for reporting strength training (ST) exercise descriptors (EDs) to be included in research and clinical practice settings.
- To finalise the ACLR conceptual framework for reporting ST EDs to be included in research and clinical practice settings.

5.4 RESEARCH METHODOLOGY

5.4.1 Study design

A qualitative descriptive research design was utilised within the constructivist research paradigm. The semi-structured group interview process, comprising the validation meeting, enabled collaborative construction, and meaningful negotiation (Mojtahed *et al*., 2014, Van der Merwe, 2020) of the framework.

5.4.2 Study methodology

5.4.2.1 Target population

Subject experts in ACLR rehabilitation, both in the clinical and research spheres, musculoskeletal rehabilitation and ACLR strength and condition constructs were recruited to discuss the presented core outcomes set of strengthening exercise descriptors (EDs) to be included in ACLR reporting rehabilitation programs (Slocumb & Cole, 1991). The researcher aimed to purposefully include a combination of experts in the validation meeting to create a more generic conceptual framework situated equally in both clinical and research practice by ensuring a balanced meeting composition where various experts' voices are heard (Figure 5.1). Reflecting on the e-Delphi survey experts' distribution, the researcher aimed to include again the same unbiased distribution of panellists in the validation meeting, mirroring both the clinical and research-based views of the effective utilisation of an ACLR intervention. When the e-Delphi survey was completed, panellists, representation was almost equal, with 44% of the panellists being clinicians and 56% being within a research-based environment. Therefore, the researcher aimed to include 50% clinically based panellists and 50% research-based panellists in the validation meeting. Ensuring an equal distribution of ACLR, experts enabled the collection of input from a broader community concerning strength training (ST) exercise descriptor utilisation for a balanced viewpoint to a wider ACLR rehabilitation community.

5.4.2.2 Validation panel expert setting

Due to the population required to ensure the credibility of the ACLR conceptual framework content, a purposive sampling method was used with the following inclusion criteria.

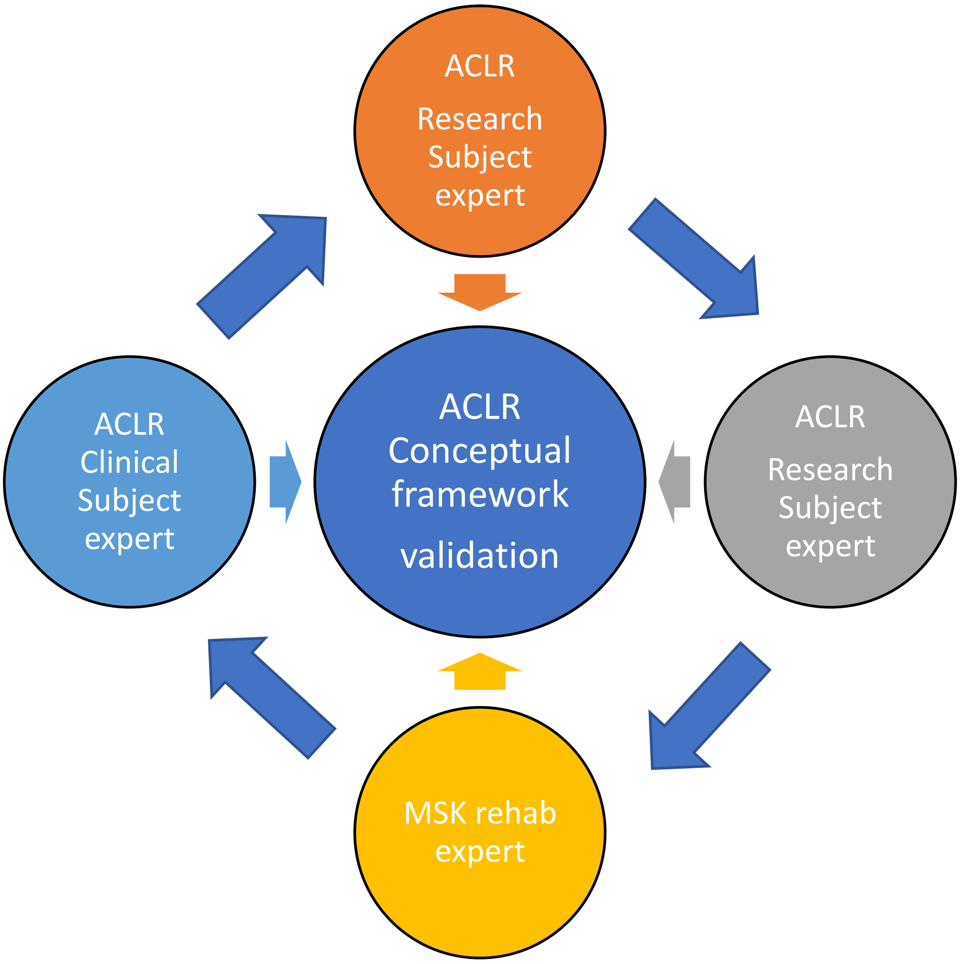

Figure 5.1: Classifying of validation panel

Inclusion criteria:

- Panellists had to be classified as having research and/or clinical experience in ACLR rehabilitation programs or musculoskeletal skeletal rehabilitation, which is defined as the following:
    - Panellists considered to be subject experts were required to have published at least ten scientific articles in the field of ACLR rehabilitation.
    - Panellists considered to be clinical experts should either be the head of an institute or regularly work with high-level sports rehabilitation, including ACLR patients.
- Panellists need to have a working history of 10 years and more or currently working with ACLR patients in research or a clinical setting.

In the context of this study, a research setting was defined as an institution where ACLR patients are rehabilitated with the primary focus of performing research, with a clinical setting referring to an environment within the community or a private sector where patients are treated on a one-on-one or group basis.

5.4.3 Unit of analysis

According to Creswell (2012) and Devadas (2016), a small sample size is preferable for discussions aiming to elicit a large amount of information from participants through questioning (Polit & Beck, 2012). The researcher identified four suitable candidates.

Panellists were identified through their publications and work profiles available in the public domain. The participants were emailed an information leaflet outlining what the study and study participation entails (Appendix F). Panellists could decline or accept the invitation via feedback on the invitation mailer. All participants indicated their willingness to participate. A summary of consenting panellists is available in Table 5.1.

The validation meeting was structured according to a meeting guide, which assisted the facilitator with the format and sequencing of the questions posed to panellists (Creswell, 2012; Devadas, 2016). The meeting guide (Appendix H) comprised open-ended questions in keeping with the current study's objectives developed by the researcher based on previous research studies following a similar design.

Prior to the exploratory study, the researcher presented and discussed the initial ACLR conceptual framework draft with the study promotors to ensure a clear representation of the conceptual framework. Points of discussion during the researcher-study promotor discussion were:

- Concept design and clarification.
- Specification for whom the ACLR conceptual framework is designed.
- Processing of conceptual data.

Table 5 1: Demographics of validation meeting panellists

Panellists Number	Profession	Highest Qualification	Area of expertise	Articles published	Affiliations
1	Physiotherapy	Professor	ACLR subject expert	103	1. NHMRC Fellow 2. Senior Research Associate, Department of Physiotherapy, International university 3. Honorary Senior Research Associate in Orthopaedics, Rheumatology & Musculoskeletal Sciences, International university
2	Physiotherapy	Doctorate	ACLR subject expert	14	1. Postdoctoral Research Fellow at an international university
3	Physiotherapy	Doctorate	MSK Rehabilitation expert	41	1. Senior Lecturer at two national universities in the field of MSK rehabilitation
4	Biokinetics, Strength and Conditioning coach	MSc Sport & Exercise Medicine	Clinical expert working with ACLR patients	0	1.Senior physical performance coach of Premiership rugby team; Head of Performance, UK

Amendments following the online study promotors discussion included the following:

- The title of the ACLR conceptual framework should be more explicit and align with the approved research title and objectives.
- Visual representation of the framework should change to depict only obtained data from Phases 1 and 2 (scoping review and Delphi).
- Improve the description of the target market of the proposed ACLR conceptual framework.

5.5 Exploratory study

Following the adjustment of the ACLR conceptual framework draft, an exploratory study was held to enhance the study's trustworthiness (Devedas, 2016). The exploratory study aimed to ensure that the validation meeting is facilitated in line with the approved research protocol to familiarise the facilitator with the meeting process and to ensure optimal question design to elicit the desired responses to answer the posed research question and objectives (Devedas, 2016).

Amendments after exploratory study

- After the exploratory study, procedural changes were made to improve the flow of the meeting. These changes included providing more detailed information and background regarding the aims of the study, preceding study phases, and a draft framework to elicit more directed and goal-oriented input during the validation meeting. Two questions were combined as they were very similar.
- Adjustment of question order allowing a logical flow of discussion; wording changed to mirror open questions (Table 5.2, questions 1, 4 and 5 changed positions).
- New questions were generated to align with the meeting with the research question and objectives (Table 5.2, questions 4 and 6).

Table 5.2: Questionnaire changes after exploratory study

Original	New	Reason for change
1. Please provide your opinion on the exercise descriptors and their definitions included in the framework (Table 1 in the provided document).	1. Please provide your opinion on the core outcomes set (COS) of strength training exercise descriptors and their definitions included in the framework (Table 1 in the provided document)	Introducing the term COS as part of the main objective of the study.
2. In your opinion, how do you perceive the framework as supporting more detailed and/or accurate reporting of ACLR strength training?	2. In your opinion, how do you perceive the framework as supporting more detailed and/or accurate/complete reporting of ACLR strength training?	No changes
3. What is your view regarding the practicality of the proposed framework?	3. What is your view regarding the practicality of the proposed framework?	No changes
4. What would the impact of the proposed framework be on the various stakeholders involved in the ACLR strength training rehabilitation process, where stakeholders refer to all healthcare professionals involved in the rehabilitation process?	4. Would you consider this framework a value proposition to existing CERT and TiDIER frameworks for reporting exercise interventions	New questions based on current exercise reporting frameworks in literature.
5. Do you have any suggestions and/or comments regarding the visual presentation of the framework? Please provide your reasoning for your suggestions.	5. Do you have any suggestions and/or comments regarding the visual presentation of the framework? Please provide your reasoning for your suggestions.	No changes
6. New question	6. In your opinion, can this framework be used for targeted strength training for muscle weakness after ACLR surgery, although not the primary purpose of it?	Develop new question based on the morphological alterations after ACLR and strength training.

5.6 Data collection and construction process

Ethical approval was obtained for all study phases before the commencement of the research study (HSREC number: UFS-HSD2019/1889/2502).

Considering the varied geographical locations of participants, the validation meeting was scheduled online utilising the Microsoft Teams platform. Each participant received the following documentation via email two weeks prior to the scheduled meeting in preparation for the discussion (Mojtahed *et al.,* 2014):

- Participants' information leaflet detailing the study aims, objectives, and validation procedures (Annexture F)
- The draft ACLR conceptual framework document consisting of Section 1: Consensus core outcome set (COS) of exercise descriptors EDs table; Section 2: Draft ACLR conceptual framework; Section 3: Excel spreadsheet illustrating possible clinical implementations of the conceptual framework (Annexture G).

The validation meeting was facilitated by a personnel member at the University of the Free State (UFS) who is trained and skilled in facilitating group discussions using semi-structured interviews and focus groups. The researcher and facilitator met before the validation meeting to brief the facilitator on the research aims, objectives, and procedure of the validation meeting, to ensure the accuracy of the data collected.

Before the commencement of the meeting, the facilitator introduced each panellist and provided a short overview of the validation meeting process, including the audio recording of the session. Panellists were made aware that they would be known to the researcher on the audio recordings but that all references to names and locations would be removed from the transcripts.

The researcher also took the opportunity prior to the commencement of the meeting to provide an overview of the research study and the subsequent need for the validation meeting. The opportunity was provided to participants to ask any clarifying questions prior to the start of the validation meeting.

The meeting guide (Annexture H), with its open-ended questions, was used to facilitate the validation meeting. Participants were encouraged to voice their opinions and recommendations (Creswell, 2012; Van der Merwe, 2020). The facilitator explored only participant opinions and comments linked to the research topic, which put participants at ease and minimised participant fatigue (Creswell, 2012).

This study used a convergent process to arrive at the best possible answers regarding the ACLR framework, and the core outcomes set of strength training (ST) exercise descriptors (EDs) were presented for discussion (Tastle *et al.,* 2005; Botma *et al*., 2015; Van der Merwe, 2020). Consensus was achieved when all participants agreed on the value of reporting an individual exercise descriptor. If no agreement could be reached, the discussion was facilitated until data saturation was achieved. Data saturation was defined when no new comments, recommendations, or opinions were raised by participants regarding the value of a particular core outcome exercise descriptor (Tastle *et al*., 2005).

The researcher was present during the online meeting and made field notes of the participants' reactions and suggestions. Conjunctively, the audio recordings together with subsequent transcription, allowed for a dependability and/or confirmability audit to ensure data accuracy (Polit & Beck, 2012; Savin-Baden & Major, 2013). Although the researcher was available to provide clarity, if required by participants, the researcher in no way engaged during the data-gathering process. During the discussion, an environment free of coercion, bias, or rehearsed answers was created by not providing the meeting guide to participants before the meeting and the researcher refraining from answering unrelated questions or presenting his perspectives (Creswell, 2012). Therefore, data reliability was enhanced. When a participant expressed recommendations regarding a specific informing statement or question, the facilitator discussed the proposed change and confirmed that the group's opinion was portrayed in the final statement or answer and did not reflect only one individual's opinion.

5.7 Content Analysis

Table 5.3: Content analysis summary following validation meeting		
Theme	**Category**	**Code**
COS 1: Evidence of reporting exercise dosages	Exercise volume	Sets
		Reps
		Load Magnitude
	Progressive overloading	Rule for exercise progressions
	Exercise completion	Prescribed sessions completed
COS 2: Neuromuscular adaptational responses	Exercise program variables	Aim of the exercise
		Exercise order
		Set endpoint goal
		Interset rest (Rest between sets)
COS 3: Evidence-based considerations	Strength training literature	Muscle contraction type
		Frequency of sessions
		ROM
Contextual factors	Mode of delivery	Home vs Supervised
	Individual patient factors	Elite vs Novice
		Psychological factors
		Criteria for progression
	Feasibility or Practicality	Target Audience
Reporting Framework	Implementation	Repeating components
		Visual illustration of the level of importance
		Terminology used
	Other reporting frameworks	CERT and TIDieR reporting framework

After the validation meeting, Microsoft Teams generated a transcript of the recorded meeting. The researcher reviewed the transcript and compared it to the audio-recording to ensure that the transcribed data was correct and removed any reference to names. The structural coding process described by Saldana (2018) was utilised for the content analysis process as the meeting followed a structured interview format.

The researcher read and re-read the transcript and identified codes that the participants mentioned. Saldanha (*2018: 120*) defines codes as *"a word or short phrase that symbolically assigns a summative, essence-capturing, or evocative attribute for a portion of language-based or visual data."* Following code identification, the researcher grouped similar codes into categories and similar categories into themes. "*A category is a label in the form of a word or short phrase applied to a grouped pattern of comparable codes and coded data, while themes can be defined as an extended phrase or sentence that identifies and functions as a way to categorise a set of data into a topic that emerges from a pattern of ideas*" (Saldana, 2018: 226). While keeping this in mind, the researcher populated Table 5.3, which summarised the qualitative analyses of the validation meeting. An independent coding process was followed to enhance the trustworthiness of the study further. An experienced qualitative researcher independently coded the transcript, and a consensus meeting was held with the researcher and independent coder to identify any discrepancies in the codes, categories and themes identified.

During the validation meeting, the following adjustments were made:

- The discussion was held to position contextual factors on the outer surface (Figure 5.4) of the picture to include some contextual considerations that can impact the quality of reporting during ACLR program interventions.
- **Four** of the 18 exercise descriptors (EDs) were excluded from the initial list of core outcomes set of EDs as not necessarily part of reporting in ACLR rehabilitation programmes.
- Muscle action and tempo were combined into one descriptor named muscle contraction type.
- A suggestion was made to adjust the ACLR conceptual framework's visual representation to a comprehensive picture reflecting the frequency of what strength training (ST) EDs should be reported at what time points. Although panellists alluded to the fact that the reporting between research and clinical settings would look different and include different essential reporting elements, the research team did not deem it appropriate to segregate the ACLR conceptual framework. Reporting of ST following ACLR should be uniform in nature and evidence-based. Therefore, the ACLR conceptual framework remained generic in nature to indicate the elements essential to report on during the execution of an ACLR ST rehabilitation programme.

5.8 Content Analysis

The researcher reviewed the transcript numerous times and similar ideas and codes were identified. Subsequently, codes were grouped into similar categories where applicable and, after that, into themes. The content analysis process identified five themes, ten categories, and a total of 21 codes (Table 5.3). The themes emerging from the data were as follows: Evidence of reporting exercise dosage; Neuromuscular adaptational responses; Evidence-based considerations; Contextual factors; Reporting Framework. The themes were organised into levels of importance, referring based on the feedback received from the validation panellists?

Each theme with the relevant emerging categories and/or codes will be presented and discussed individually for ease of reference. Emerging categories are underlined in the text with verbatim participant quotations indicated in italics, and codes bolded.

5.9 RESULTS AND DISCUSSION

5.9.1 Theme 1: Evidence of reporting exercise dosages

Evidence of reporting exercise dosages was identified as Theme 1, consisting of three categories and five codes. These five codes were chosen to be displayed within the first red circle named COS 1, indicating the high importance of being required to be reported during each session (Figure 5.1). Linking current research and reporting exercise descriptors (EDs) together, we see that reporting exercise dosage and reporting strength training (ST) EDs in clinical trials seem to be the missing puzzle piece in the literature (Augusston, 2013; Vlok *et al.,* 2022). According to Culvenor *et al. (*2022: 8), "*reporting critical components of exercise dosage and delivery, clinicians would be able to make a more informed decision when prescribing (ACLR) exercises*".

Data obtained from panellists indicated the importance of reporting exercise volume (category) consisting of **sets, repetitions, and load magnitude prescribed**. One participant noted [P1]*"…repetitions, sets, and load magnitude definitely are high on the list*", while P[2] confirmed it with "…*absolutely essential. I say load magnitude, repetitions, frequency, and sets…*". Contrary to this, research tends to indicate a low percentage of the reporting of exercise sets (18/41 studies; 44%), exercise repetitions (19/41 studies; 46%), and load magnitude (15/41 studies; 34%) in Level 1-4 ACLR ST interventions (Vlok *et al.,* 2022).

Importantly, session reporting, including the top three codes (repetitions, sets and load magnitude) of ST EDs throughout the ACLR rehabilitation period should be mandatory in any ACLR ST intervention to inform all stakeholders about the individual prescribed dosage during each session.

Furthermore, exercise sets, repetitions, and load magnitude depend on each other to determine the total exercise volume per session. Total exercise volume per session equals sets multiplied by repetitions multiplied by load magnitude (Ratamess *et al.,* 2009), which are closely related to the progressive overloading principle targeting higher levels of strength. The ability to improve strength is closely related to manipulating the exercise volume via these three variables, individually or in combination with each other (Ratamess *et al.,* 2009). Exercise progressions via exercise volume are essential to report and should be included as part of exercise prescription when implementing ACLR exercise rehabilitation programs.

Panellists deemed it essential to include rules for progression when reporting ST EDs in ACLR rehabilitation. The second category within Theme 1 was identified as <u>progressive overloading</u>, referring to the increased intensity accompanying the progression of an ACLR strengthening exercise program. One panellist [P2] mentioned*, "I think documenting what you're using to progress people is really important*"*.* While another participant [P1] proposed that it should be renamed "…*criteria for progression*". It was suggested that the renamed category of criteria for progression instead be situated within the outer part of the ACLR conceptual framework referring to the contextual factors influencing the ST portion of the ACLR rehabilitation process, emphasising that it "...*encompasses both the programs as well as the exercise progressions*". According to the definitions proposed in the COS table the rule for exercise and program progressions differ from the criteria for progression. The first two codes (exercise sets and exercise repetitions) (Table 5.3) indicate session-based progressive overloading while continuing with rehabilitation. According to [P1], criteria for progression indicate "...*goal orientated, time orientated whether you know that they meet certain criteria and then it's progressed...*". Criteria for progression indicate a goal-based assessment intending to measure if patients can move to the next ALCR rehabilitation phase (Meyer *et al.,* 2006). Subsequently, criteria for progression were established and positioned within contextual factors (Figure 5.1).

Panellist number three mentioned that all exercise and program progressions should encompass all the other exercise descriptors. However, contrary to this, research does not share the same view through two scoping reviews, indicating that only 46% and 50% of the cohort of studies reported on exercise and program progressions (Goff *et al.,* 2018; Vlok *et al.,* 2022).

Literature has reported an alarmingly low level of evidence supporting ACL or meniscal rehabilitation interventions to improve symptomatic and functional outcomes during 142 randomised clinical trials. One of the challenges reported was the lack of reporting exercise dosages consisting of exercise intensity, volume, and exercise progressions (Culvenor *et al.,* 2022). Therefore, the ACLR conceptual framework aims to be well-positioned to improve reporting by capturing these EDs more frequently during ACLR rehabilitation programs. The panel referred to the importance of including <u>exercise completion</u> with the specific code of prescribed sessions completed while reporting the ACLR exercise intervention. Emphasising the reporting of it was mentioned by [P2] noting, "...*if they're not performing the prescribed exercises then nothing else in terms of their effectiveness is that relevant*". Literature indicates that increased exercise completion, also referred to as exercise compliance rate, to the prescribed sessions with a well-designed progressive overloading physical therapy program improves knee function and correlates with greater chances of a RTS after ACLR in recreational athletes (Han *et al.,* 2015).

Therefore, although not all panel members entered the discussion supporting or negating the suggestion, the researcher, following a consensus-seeking discussion with the independent coder and study promotor, opted to include exercise completion rates within them as essential to report. As rightly stated by Culvenor *et al. (2018),* the exercise, which is done by the patient, is the best ACLR exercise.

5.9.2 Theme 2: Neuromuscular adaptational responses

The second theme emerging from content analysis was that of neuromuscular adaptational responses, which consisted of one category (exercise program variables) and four codes. Panellists specified that **exercise aim, exercise order, set endpoint goal and interset rest** to be reported. The colour orange was selected to indicate a lower level of importance than red, indicating that the codes forming part of this theme should, according to panellists, only be reported once (Figure 5.1). Considering the standard propensity of these four exercise codes, the level of session-based changes towards it will most likely be low. Once-off reporting by researchers of these codes may improve the practicality for clinicians to incorporate these descriptors in private practice.

The magnitude of adaptation to strengthening exercises depends mainly on the strengthening exercises' **purpose/aim,** namely endurance, hypertrophy, max strength, or power (Bird *et al.,* 2005). Purpose-driven or targeted strength training (ST) for ACLR patients should be based on the specific muscle strength deficits that persist on various levels after ACLR (Tayfur *et al.,* 2021). Indeed, the effectiveness of any strengthening exercise implemented after ACLR rests in the optimisation of the mechanical exercise stimuli targeting muscle strength deficits on morphological, neural, and central levels (Tayfur *et al*., 2021) (Figure 5.1).

The researcher noted some confusion among panellists when considering the code, exercise aims, and its meaning within the context of strength or strengthening exercises. P[4] noted, "*You have to go into your session with the goal and ensure that you get the most out of your patient, which will tie exactly with the load magnitude and the exercise you prescribed based on the goal*", while P[3] mentioned "*I think the aim of the exercise is probably a nice to have if we're just talking about strength, particularly in this context, I think that would be more important if we were including a lot of different types of interventions…".* P[2] concludes with *"I'd say that most of these (exercise aims) are less important than some of the other elements".* P[2] and P[3] seemed to generalise the term "strength" as an all-inclusive theme for ACLR rehabilitation programs, while the definition specifies that the exercise aim should reflect the specific component of the ST repetition maximum (RM) continuum (Figure 2.2), targeting either the endurance, hypertrophy, maximum strength, or power zone. Literature indicates that progressive strength training, focusing on the different zones of strength training, restores quadriceps and hamstring muscle strength within seven months after ACLR in amateur male soccer players (Welling *et al.*, 2019).

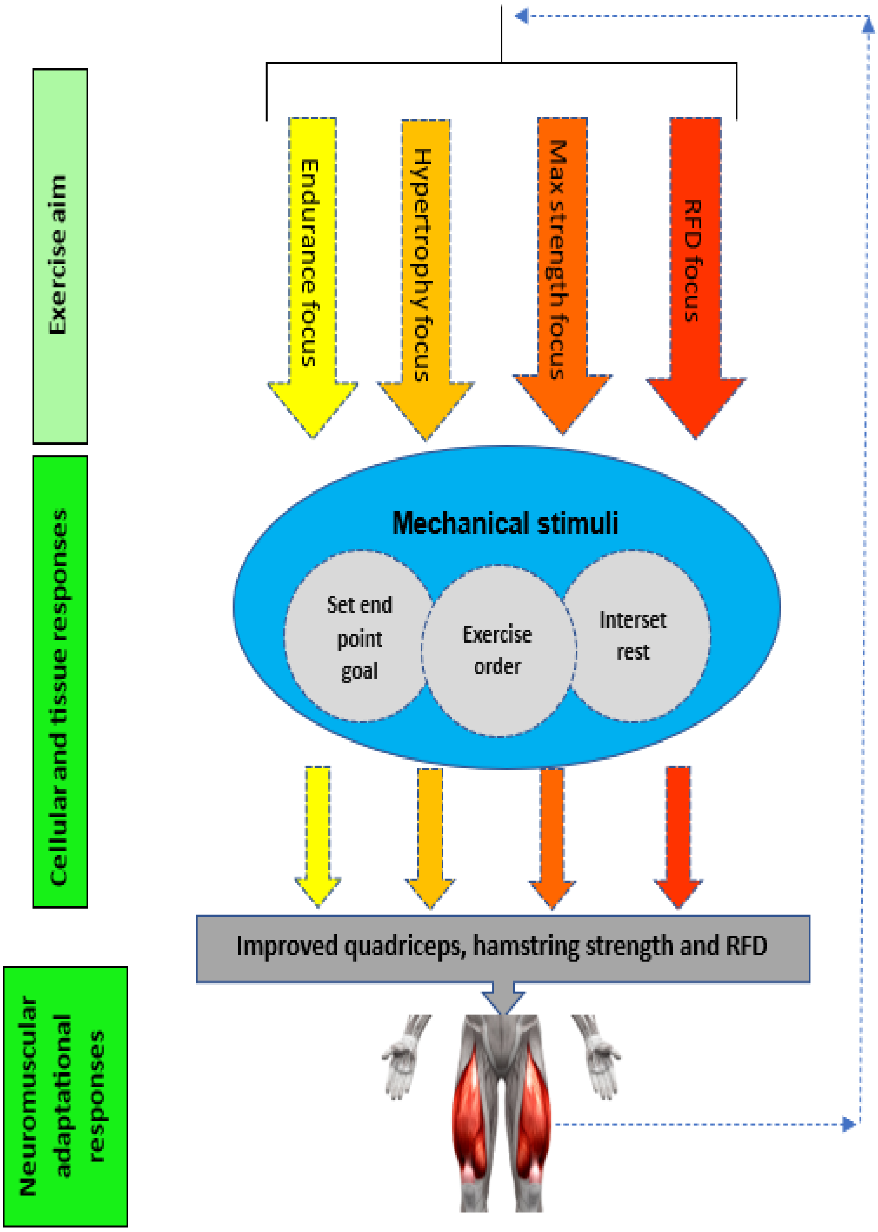

Figure 5.2: Target ACLR strengthening exercises to improve quadriceps and hamstring weakness Compiled by the researcher, Vlok, 2023, as part of thesis

Welling *et al.* (2019) and Smith *et al*. (2020) described the effect of a 12-week twice a week progressive resistance exercise program with a cohort of ACLR participants who underwent ACLR via a hamstring autograft focusing on improving hamstring strength via a progressive supervised ST program compared to a traditional home-based low intensity exercise program for ACLR patients. Results indicate that supervised progressive ST was superior to low-intensity home-based programing in the improvement of knee flexor strength. This home-based intervention appears to lack proper ST intensity by emphasising the endurance-focused ST zone alone (Fig 5.1) (Bregenhof *et al.,* 2023). In support of this, research has also reported a lack of explosive hamstring strength, although maximal isometric hamstring strength recovered after ACLR surgery 7-12 months post-operative (Knezevic *et al.,* 2014; Buckthrope *et al.,* 2020). Thus, it is visible that the law of exercise should specificity be adhered to when one wants to improve the specifics of strength deficits after ACLR.

Exercise order in a single session**,** referring to exercise sequence as well as if the exercise includes a multi-joint or single joint approach, is considered essential in ST exercise programs, particularly when targeting neuromuscular responses like strength, power, velocity (Bird *et al.,* 2005). Based on the exercise aim, exercise order can influence the effectiveness of the exercise stimuli via the level of fatigue induced through the specific exercise configuration (Simao *et al.,* 2012)**.** One should recognise the relevance of exercise order configurations within an ACLR strengthening program to obtain the best neuromuscular adaptational responses depending on the primary objective or aim of the ACLR strengthening exercise (Marshall *et al.,* 2021).

Panellists considered exercise order a less important exercise descriptor to report on in a clinical setting but more important in a research setting. A possible explanation for that would be the panellist's background as two panellists work in a more clinical research-orientated environment where one practises in a sports conditioning environment. P[4] indicated the importance of including it in clinical practice considering rehabilitation ACLR patients by noting, "*So I am for me, exercise order is quite important because they are the things that are going to take the most time to prepare and to perform and would be the most taxing on one or more levels, they are going to hurt the most."*

The ACLR conceptual framework did not differentiate between clinical practice and research institutions but rather proposed a generic universal evidence-based approach towards reporting ST exercise descriptors (EDs) targeting muscle weakness after ACLR surgery.

As illustrated in Figure 5.2, exercise order can, in conjunction with other exercise descriptors can improve the efficiency of the exercise stimuli while regulating the fatigue components between exercises (Simao *et al.,* 2012). Reporting of a fatigue measurement scale while executing exercise sets, also called **set endpoint goals,** should be included in the reporting of EDs according to P[2] noting, *"…agree with the set endpoint goal being included".* Literature indicates that strengthening exercises should be performed within a certain level of fatigue or set endpoint goal, which drives morphological, metabolic, and neural adaptational response according to the exercise objective; strength endurance, maximum strength, or peak power (Suchomel *et al.,* 2018).

Although the definition of set endpoint goal was provided in the preliminary draft of the ACLR conceptual framework (Section A, Appendix G) for panellists, it seemed that one panel member still misinterpreted the definition thereof as they commented, "*I think in clinical practice to set an endpoint goal is quite important to set it with the athlete to agree on the endpoint goal*" P[3].

According to ST literature, one should understand the application of **interset rest or rest between sets** to optimise the preservation of exercise intensity while performing ST exercises. The aim of interset rest while performing multiple exercise sets is to increase the strengthening exercises' efficiency, safety, and effectiveness (De Salles *et al.,* 2009). Consequently, the interset rest interval is commonly prescribed based on the training goal or exercise aim, e.g., endurance, hypertrophy, maximum strength, or power, which will be linked with other EDs like exercise order and set endpoint goal (Figure 5.1).

Panellists believed interset rest may be documented once-off and depend on other external factors, "*I guess for me like the interset rest might be a nice to have just because that inherently might be variable depending on the patient and the time that's in the clinic"* P[2]. P[1] concluded, *"Implicit interset rest, I think less important. I don't think there's any evidence to show that, you know, variation and interset rest effects effectiveness".*

The literature indicates that interset rest significantly affects acute and chronic muscle responses, which can dictate the program's overall effectiveness (Grgi *et al.,* 2017). Acute muscle responses like muscular exhaustion after executing a set of maximum strength repetitions (>80%RM) will differ from performing a set of strength endurance-focused repetitions (40%-70%RM) performed with 60-90 second rest. Interset rest will target replenishing the anaerobic energy system when working in the maximum strength zone to complete another set at the same priority intensity and velocity of %RM. Considering the endurance-focused zone of the RM continuum, interset rest can be shorter to drive a metabolic response within the muscle trained to improve the proposed endurance component (Bird *et al.,* 2005; Ratamess *et al.,* 2009; Jukic *et al.,* 2021).

Finally, a deep understanding of the exercise program variables, including exercise aim, set endpoint goal, interset rest and exercise order targeting muscle strength after ACLR, will enable the ACLR rehabilitation therapist to target resistant ALCR neuromuscular alterations effectively.

5.9.3 Theme 3: Evidence base considerations

Theme 3 was identified as **evidence-based considerations,** including one category and four codes (Table 5.3). The panellist indicated the level of importance, green, which suggests that these codes should be reported when they deviate from the norm. P[1] confirmed this point by mentioning, *"...if it deviates from the normal for that exercise, report it. So, if you're recommending that they only do it through half range or you're recommending that they do it isometric hold or an eccentric that you report it, but it's not something that's needed to report every time with every exercise*".

The four codes, **muscle contraction type/tempo, frequency of sessions, range of motion, and exercise type**, were grouped under the strength training (ST) literature category. Strength training literature communicates the importance of these four codes to improve the effectiveness of ST exercises executed (Rametass *et al.,* 2009). More specifically, the contraction type may be defined as the concentric, isometric, or eccentric component when completing a repetition. Eccentric exercise after ACLR surgery positively improved quadriceps activation and strength, indicating its importance in ACLR rehabilitation programs (Gokeler *et al.,* 2013; Lepley *et al.,* 2015; Kotsifaki *et al.,* 2023).

At the same time, panellists did not reach a consensus on the inclusion of muscle action in reporting ACLR ST descriptors, considering various contextual factors like home-based programs and elite vs novice. P[1] further described the contextual environment, like home-based programing or elite Olympic athletes vs novices, will hamper reporting details based on the practicality of reporting such detail. P[4] indicated muscle action should be reported based on the essence it has in strength and conditioning practice. This conflicting view highlighted important reflections on how ST EDs should be reported following ACLR exercises rehabilitation, provided that ST adaptational response remains the main purpose. If the ACLR exercise intervention aims to utilise muscle action as a potential modifier targeting altered muscle strength deficits after ACLR, reporting of the muscle contraction mode may be vital in replicating the intervention.

One panellist suggested that tempo and muscle action should be grouped as muscle contraction types. Therefore, muscle contraction type/tempo was evaluated and noted by panellist [P1] as a low-level of reporting status, *"I don't think tempo again really dependent on the setting"…"not that critical"*, while P[1] concluded "...*tie together muscle action and the purpose of the session…".* P[1] further mentioned to incorporate muscle contraction type as redundant with every session in clinical and research reports and not in home-based settings. One can speculate that the reason for that could be that patients do not execute exercise that includes that amount of detail. [P1] also noted, *"Can you track the tempo and whether they maintaining that and if something is prescribed in a home base? Probably not. So, I think not that critical..."*. Panellists in sports environment settings seemed to disagree when discussing the importance of muscle contraction type/tempo compared to participants in clinical research settings. Still, the researcher categorised it as green, indicating that it should be reported independent of the clinical or sports environment settings. Reporting muscle contractions type/tempo is essential to improve the transferability of the intervention description and target strength deficits during the ACLR rehabilitation period by optimising the mechanical stimuli induced (Maestroni *et al.,* 2019).

Frequency of prescribed sessions can be defined as the number of prescribed ACLR ST sessions per week (Vlok *et al.,* 2022 unpublished data). Training frequency depends on the type of training session, the training status, and the recovery ability of the individual (Bird *et al.,* 2005). Training frequency can vary depending on contextual factors like performance vs recreational athletes and time constraints to execute the program. Important to note that the exposure to the ST stimuli should be done within a realistic number of sessions per week for neuromuscular adaptational responses to occur (Ramatess *et al.,* 2009). The frequency of sessions cannot be viewed as a separate exercise descriptor. Still, it should be considered in the context of other ST exercises descriptors like muscle contraction type, exercise type, exercise order, and interset rest (Bird *et al.,* 2005).

One panellist indicated the importance of reporting the frequency of ACLR exercise sessions prescribed per week. P[1] confirmed, "…*personally I think it's absolutely essential. I say load magnitude, repetitions, frequency and sets as the obvious ones that stand out".* Quality reporting within the ACLR conceptual framework the ACLR may improve clinical usefulness.

Range of motion (ROM) indicates the degree of movement around a specific joint during an ACLR strengthening exercise (e.g., leg curls at 0-90° of knee flexion) (Vlok *et al.,* 2022 unpublished). The literature presents the importance of including ROM considerations when performing ACLR ST exercises (Van Melick *et al.,* 2016; Kotsifaki *et al.,* 2023). From a clinical viewpoint, ROM should be prioritised concerning the physiological healing response early (0-3 months) after ACLR surgery (Kotsifaki *et al.,* 2023). After that (>3 months after ACLR), ROM should be regarded as an essential exercise descriptor for targeting ACLR muscle strength deficits. Toigo *et al*. (2006) elaborated on the molecular and cellular muscle adaptations when including ROM as part of their proposed set of EDs to improve the effectiveness of ST stimuli.

Validation panellists favoured ROM as an exercise descriptor that should be reported in the ACLR conceptual framework during ACLR rehabilitation by P[3], "*Yeah, I think for certain to know in which range this strengthening exercise was done, it is important".* P[1] noted that *"…so if it's just a standard range of motion or full range, I don't think people need to report that, but something like that could be if it deviates from the normal for that exercise, report it. So, if you're recommending that they only do it through half range*..." P[1] viewpoint concludes that if ROM deviates from the norm, it should be reported. P[4] concludes *" ...and my last point about range of motion*

– *I think that's absolutely imperative for definitely your first. Your first 12-14 weeks of any ACLR?"*.

ROM was included to be reported in the ACLR conceptual framework as a green circle when it deviates from the norm (Figure 5.1) to improve reporting quality standards in the ACLR strength rehabilitation program.

5.9.4 Theme 4: Contextual factors

The fourth theme identified following content analysis consisted of three categories and three codes in total. The overarching definition further explained that the contextual environment relates to the setting (gyms, homes, clinics, etc.) in which ACLR rehabilitation can take place, the patient's physical activity preferences (recreational or elite) and the athletes' psychological status after ACLR. All these contextual factors can contribute to the effectiveness of reporting and implementing the ACLR strength training (ST) exercise descriptors (EDs). Therefore, the researcher identified the axiom, "Start with an end in mind", to link the ACLR conceptual framework with the main aim of any ST program after ACLR.

The final objective of any ACLR rehabilitation program is to prevent re-injury risk when the athlete returns to preferred playing sports after rehabilitation (Rambaud *et al.,* 2022). Consequently, identifying the neuromuscular modifiable risk factors which could lead to re-injury risk would be the highest priority to target in any ACLR ST rehabilitation program (Grindem *et al.,* 2016; Filbay & Grindem, 2019). Quadriceps muscle weakness after ACLR was detected as a risk factor that could hamper the athlete's ability to play sports (Grindem *et al.,* 2016). Such weakness should be targeted with high-quality reporting (ACLR conceptual framework) and execution of ST EDs despite impeding contextual factors that can influence the quality of delivering the exercise program, for instance, a home-based vs a gym-based supervised program. The researcher is of the opinion that quality reporting and quality delivery of ST EDs is a function of the final objective of any ACLR rehabilitation program, codependent on contextual factors.

Contextual factors are positioned in three main categories, namely **delivery mode, individual patient factors, and feasibility.** Delivery mode highlights in which context the program was delivered, home vs supervised or target audience. Although not the central theme of the ACLR conceptual framework, the panellist proposed that the rehabilitation setting can influence the level of what should be reported. As P[4] noted that a home-based environment can be challenging to report or prescribe certain elements in a ACLR rehabilitation program, *"…setting or you dealing with a Pilates clinic, your clinic or you're dealing with a home-based environment, and that will obviously dictate both the patient you're dealing with, the equipment that's available…".* P[4] elaborates more on the challenges of a home-based program incorporating other factors that could influence the amount of detail captured in an ACLR rehabilitation program by mentioning *"Working mom. And they have got to find their own space. And there are the day-to-day domestics under one roof with four to five people together.* P[1] questions the feasibility of tracking muscle contraction mode/tempo as a descriptor to be reported in a home-based environment, *"Can you track the contraction mode and whether they are maintaining that prescribed in a home-base? Probably not."*

Literature reports conflicting results in the success of a home program vs a supervised program where a supervised program was defined as a certified clinician facilitating the execution of the program in a specific environment (Kotsifaki *et al.,* 2023). Supervised rehabilitation led to better outcomes than home-based rehabilitation one year after ACLR (Rhim *et al.,* 2021). Kotsifaki *et al*. (2023) concluded in the Aspetar clinical practice guideline that there was no difference between home-based (unsupervised) and supervised programs for knee laxity, strength, and functional outcomes. Therefore, concluding that ACLR patients should have their programs individualised based on their specific contextual environment regarding the execution of the rehabilitation protocol.

Individual patient factors are the next discussion category with three codes that can affect the reporting of ST EDs. Firstly, panellists mentioned elite athletes as a contextual factor that can influence the reporting of ST EDs. P[1] mentioned the incorporation of muscle contraction type within the context of elite athletes *"…even maybe if you set a particular tempo, especially at an elite athlete level, could be* *important. But do you need to measure that and write that down?*" P[4] agrees with the importance of understanding the contextual factors that can influence reporting standards mentioning, "*Are you dealing with a Premiership elite performance setting or a Pilates clinic".* No literature could be retrieved detailing the inclusion or exclusion of reporting ST EDs within the context of individual patient factors.

Secondly, P[3] mentioned the athletes' psychological status referring to the fear of re-injury, which might significantly impact the execution of the ACLR exercise program, *"I really think that any non-exercise components of fear after an injury, fear after the operation, is very important. You will not get the max out of your athlete if you are not at least measured or looked at that and talked*". Fundamentally, the psychological status of the athlete should not impede the basic building blocks, which are the ST EDs of the ACLR conceptual framework. However, what it captures (exercise dosage) can be influenced by an athlete's emotional status.

Lastly, criteria for progression were proposed to be included in the ACLR conceptual framework underneath contextual factors. P[1] mentioned*, "I think that criteria for progression are essential, but I'd probably phrase it like that criterion for progression*. Supported by P[2], "*I think criteria for progression is essential to include in some capacity for this, like whether that be soreness rules or looking at joint effusion or response to exercise. I think documenting what you are using to progress people is important*"*.* The researcher opted to include another contextual factor in the ACLR conceptual framework, criteria for progression, which developed from the validation conversation when "exercise progressions" and "program progressions" were discussed. Consecutive testing after each ACLR rehabilitation phase is of utmost importance to inform the athlete and clinician about the success of the current rehabilitation program executed (Meyer *et al.,* 2006; Joreitz *et al.,* 2020). Strength testing information can provide muscle adaptational responses towards the ACLR strengthening program performed. Reporting the newly adjusted ST EDs during the follow-up ACLR rehabilitation phase is a vital aspect of strengthening ACLR patients.

<u>Feasibility or Practicality</u> was identified as the last category under the theme contextual factors, with one code**, target audience.** During the validation meeting, panellists kept trying to distinguish what should be reported in the two different contexts; however,

the splitting of the framework was not the aim. The researcher aimed to develop the ACLR conceptual framework within an evidence-based practice context, irrespective of the setting.

All four panellists agreed that the target audience should influence the level of importance of which exercise descriptors (EDs) are essential to reporting on and which EDs would be deemed less important. Considering time constraints, reporting on 18 EDs would be too extensive and not viable in either research or clinical practice. P[1] noted having too much to report on in a private clinical setting would not be feasible, but in a clinical trial, you have to write all details of the intervention. P[2] mentioned, "…*extensive reporting in the context of research will keep constancy between trials, but it may differ in a clinical setting based on the added value for every day practicing clinicians*. Panellists P[1] and [4] mentioned the lack of feasibility considering the number of items that should be reported currently. P[1] stated that *"I think it also has some advantages to be so thorough and extensive to look to think about these different elements when we're people prescribing rehabilitation, either in research or clinical practice*". One panellist proposed splitting the target audience for the ACLR conceptual framework in research and clinical practice because they differ. All these details can be captured and uploaded into an appendix when conducting a clinical trial where ST is the intervention.

Quality reporting of ST EDs for research purposes should be a function of replication with the intent to duplicate the ACLR rehabilitation program in clinical practice to achieve the same result (Page *et al.,* 2017). At the same time, clinical practice should focus on implementing evidence-based reported EDs (from ACLR research interventions) to achieve similar results to research. Adequate reporting in practice can identify new gaps or areas for more focused and detailed research. Therefore, a mutually symbiotic relationship can exist between the two groups sharing the same primary objective: utilising the same ST EDs targeting muscle weakness after ACLR while preparing ACLR patients to participate in their preferred pre-injury levels of play.

All panellists unanimously agreed to develop a shorter version of the 18 COS descriptors extracted from the Delphi study to increase its feasibility for adoption in clinical and research settings. P[1] confirmed, *"What are the most important or the* *core elements... So, I think about having a core list and then an additional list of recommended outcomes which can be longer". P[3] concluded, Well, isn't it possible to have a corset to say what must be recorded".*

Therefore, the validation meeting concluding the Delphi consensus experts meeting indicates a continuation toward improving the ACLR conceptual framework's credibility and feasibility. The adoption into both research and clinical practice of such an ACLR conceptual framework with its components requests for the next step, according to P[1] commenting*, "...but yeah, I think piloting"*, which is outside this research's scope.

5.9.5 Theme 5: Reporting framework

The last theme consists of four codes and two categories embedded in the reporting framework theme (Table 5.3). Implementation and other reporting frameworks were considered as the categories which will be used to discuss the four codes. Implementing the current reporting framework was directly linked to the three codes: **repeating components**, **visual illustration of the level of importance, and terminology used.**

Panellists indicated redundant elements that can either be grouped under a new heading or removed from the list of core exercise descriptors. Capturing or implementing strength training (ST) exercise descriptors (EDs) that do not add value to ST stimuli will impede the optimal usage of the ACLR conceptual framework. Therefore, two core outcomes set EDs that were deleted because they were recorded without prompting someone to do it – exercise name and the number of exercises. P[1] comments, *"I think it's essential, but wouldn't people do that anyway? I don't know who wouldn't put the name of the exercise if they're going into all this detail about describing the exercise*. P[2] commented on a number of exercises with *"I don't know if the number of exercises to me would be as important.*

The description of exercises was debated between panellists in terms of the setting it provided – home-based or via an electronic platform such as telemedicine. It was noted that "…*it is important when you're dealing a home-based, or you're dealing with a telemedicine case. If you are dealing with someone in person, that's not really important. But then, if you bring up the description of exercise and mode, it opens up* *the quality of execution, cueing, and the interaction of that descriptor or that exercise to your patient or athlete"* P[4]. Panellists tended to view the detail of the exercise description as not essential if the clinician supervises the programme as they are there to ensure correct execution. Contrary to the validation meeting, the CERT (Item 8) and TIDieR (Item 8) indicate that a clear description of the exercise prescribed during rehabilitation is essential, regardless of the setting, either via illustrations or pictures. (Slade *et al.,* 2016). The researcher concludes that a detailed exercise description might be redundant in a clinical practice setting but essential when conducting research regarding exercise efficacy. However, considering that the framework presented is aimed to be generic in nature and not be viewed differently in the various settings, the researcher opted to remove the description of the individual exercises.

Exercise progress and program progress were combined into an encompassing code of **rule for exercise progressions** as a new code in Theme 1, and criteria for progression was developed considering the validation panel to measure strength improvement of ACLR patients on a regular basis during the different phases of ACLR rehabilitation. The researcher, therefore, included the new code of **criteria for progressions** as part of the contextual factors theme to assist in designing a new ST program based on the assessment information. Concluding, criteria for progressions as part of contextual factors will not change the format of the ACLR conceptual framework, but ACLR therapist would still be able to utilise the consensus ST EDs to report their follow-up program targeting muscle weakness that keep persisting after ACLR (Tayfur *et al.,* 2021).

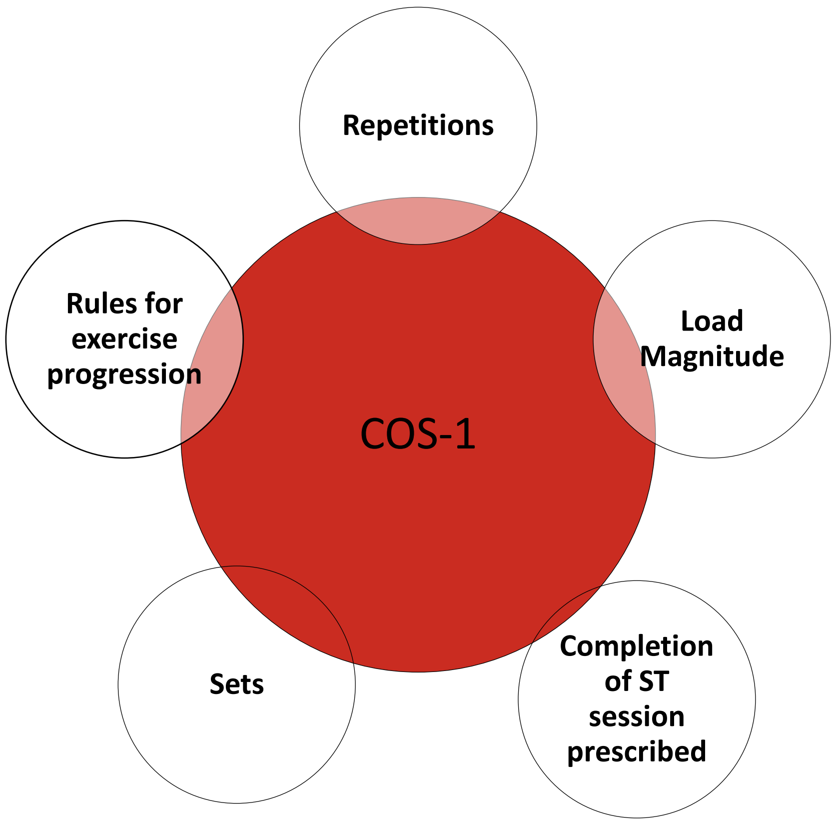

Figure 5.3: COS-1 exercise descriptors that should be reported within each ACLR exercise rehabilitation session

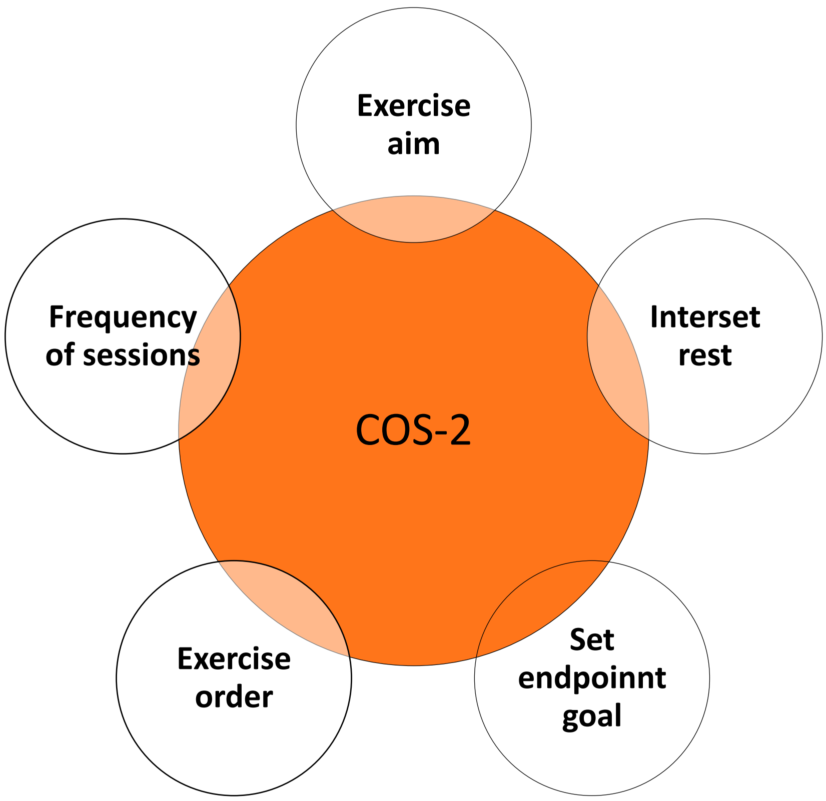

Figure 5.4: COS-2 exercise descriptors that should be reported once

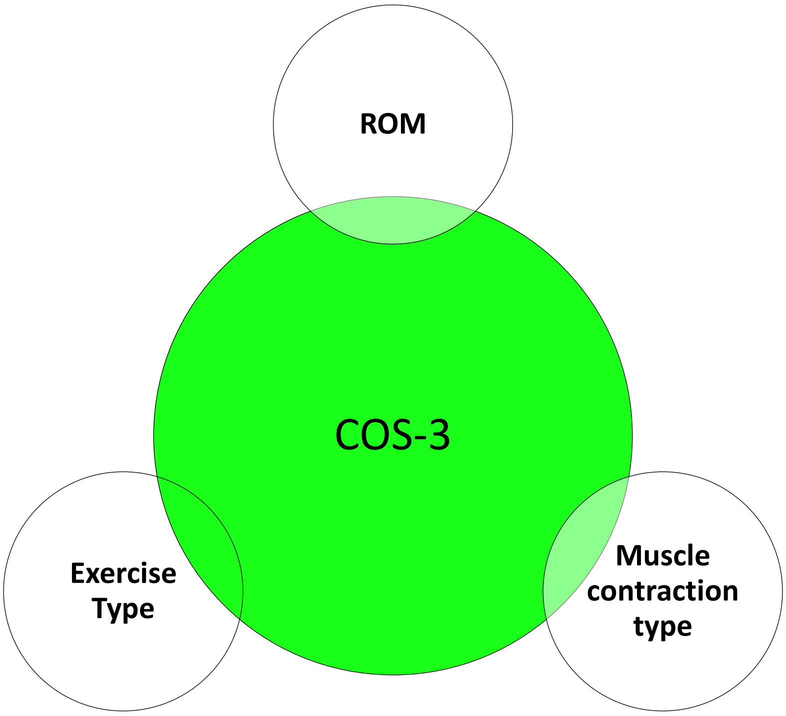

Figure 5.5: COS-3 exercise descriptors that should be reported when deviated from the norm

5.9.6 Visual illustration of the level of importance

Visual illustration of the level of importance indicating strength training (ST) exercise descriptors (EDs) reporting in terms of reporting frequency to improve the feasibility and decrease time efficacy (Figures 5.3, 5.4, 5.5). Panellists unanimously agreed that the 18 descriptors (Section A, Appendix G) should be categorised into levels of importance describing the reporting frequency to improve feasibility in practice. Therefore, the remaining 13 descriptors were categorised according to the feedback from panellists into three main categories, namely core outcomes set one (COS-1: Figure 5.3) indicate descriptors that should be reported sessional, core outcomes set two (COS-2: Figure 5.4) reflecting EDs that should be reported once, and core outcomes set three (COS-3: Figure 5.5) considering EDs that should be reported only when it deviates from the norm.

<u>The practicality and feasibility</u> of the ACLR conceptual framework will be challenged based on time constrains for rehabilitation professionals lacking the time to complete the detailed reporting. The researcher, therefore, takes this critical factor into consideration by grouping the reporting of ST EDs into COS 1-3 (Figures 5.3, 5.4, 5.5) level of importance in terms of the frequency of what should be reported and how

frequently. COS 1-3 compliments the reporting of ST EDs through the lens of current evidence-based practice.

The ACLR conceptual framework has the potential to improve the replication of the ACLR intervention or execution of the intervention in ACLR rehabilitation programing while considering its feasibility.

Terminology used: "Reporting" of EDs vs "strength training elements to increase ACLR rehabilitation effectiveness" were proposed by a panel member (P1) as a slight change in terminology used between researchers or clinicians. P[1] indicates that the word "reporting" of ST EDs is more inclined to attract researchers who aim to improve the quality of documenting the clinical intervention, while the everyday clinician would be more inclined to improve their effectiveness in terms of utilising the well-reported ST EDs. The researcher considered the main research question asking about the reporting of ST EDs in ACLR exercise rehabilitation programs and concluded to keep "reporting of exercise descriptors" as the appropriate terminology for this study.

Theme 5 concludes with the last category of other reporting frameworks that exists, namely the **TIDieR,** which was initially developed as an extension from the minimal recommendation of CONSORT and SPIRIT to improve the completeness of reporting and, ultimately, the replicability of exercise-based rehabilitation interventions. It is important to note that the TIDieR checklist is not specific to exercise interventions, making it globally applicable for any clinical intervention study (Page *et al.,* 2019). Consequently, Slade *et al.* (2016) developed the **CERT** (Consensus on Exercise Reporting Template), a 16-item checklist aiming to increase clinical uptake of effective exercise programs, enable research replication, reduce research waste, and improve patient outcomes. Unfortunately, the CERT reporting checklist did not achieve a substantial uptake within the ACL research community. Only 14%-57% of CERT Items 7 and 13 (ST descriptors) were reported in a cohort of 41 ACLR studies between 2016 and 2021 (Vlok *et al.,* 2022). The reason for this low uptake is currently unknown. Therefore, the researcher developed the ACLR conceptual framework, including an Excel tool to improve the utility of EDs in reporting ACLR ST exercise interventions.

Comparing the ACLR conceptual framework with two other reporting checklists, the researcher developed Table 6.2. COS-1, where items were marked in red, indicating session-to-session-based reporting. The reason for marking it red is because these descriptors would have the highest probability of changing between sessions and can influence the supreme effectiveness and transferability to the clinical practice of the ACLR ST program.

Strength training literature confirms that in designing resistance training programs, one should acknowledge the exercise program variables (load magnitude, frequency, sets, and repetitions prescribed) to improve the acute and chronic musculoskeletal response toward ST (Bird *et al.,* 2005). While Augustsson *et al.* (2013) supported the documentation of ST during ACLR interventions, identifying the main criteria for reporting as training frequency (per week), intensity (load magnitude), volume (sets *repetitions* load) and progression rule. All this evidence directs the effective reporting of ST EDs while implementing an ACLR ST intervention.

Exercise dosage per session can be derived from the ACLR conceptual framework, reporting on these COS-1 (Table 5.3) exercise descriptors. This may significantly impact future research concerning the documentation of crucial therapeutic dosage and delivery to prevent the "one size fits all delivery" of ACLR programs considering the CERT and TIDieR checklist. Adequate reporting of COS-1 exercises descriptors utilised during ACLR research intervention sessions will enable clinicians to include/replicate EDs that can improve the effectiveness of their ACLR ST programs. Remarkably, all three reporting frameworks agree on the COS-1 ST EDs that need to be reported during ACLR rehabilitation programing (Table 5.3: Red).

Secondly, COS-2 EDs marked in orange signify that these are only to be reported once within the ACLR conceptual framework (Table 5.3). The CERT and TIDieR reporting framework did not consider these EDs within their reporting guidelines. The possible reason for excluding these details in the TIDieR reporting framework was that the TIDieR was developed for drug interventions and not specifically tailored to exercise interventions (Hoffman *et al.,* 2014). Consequently, the CERT developed from the TIDieR reporting checklist as an extension for reporting exercise interventions in general but still did not include all the ST EDs necessary to reproduce ST intervention details regarding targeting muscle weakness after ACLR surgery (Page *et al*., 2017; Vlok *et al.,* 2022).

Lastly, COS-3 EDs were neither reported in the CERT nor TIDieR reporting guidelines, probably for the reasons mentioned in the COS-2 EDs section.

The ACLR conceptual framework should enable ACLR researchers and practitioners to document ACLR ST exercises descriptors either to improve the quality of the clinical trials or for clinical note-taking purposes to transfer ACLR ST interventions to clinical practice research effectively.

5.9.7 Conclusion

This chapter presented the methodology and results of the final study phase, namely a validation meeting seeking the opinions of national and international experts regarding the reporting of strength training (ST) exercise descriptors (EDs) in the ACLR conceptual framework presented.

Panel members believed elements related to exercise volume, exercise completion, and progressive overloading are essential to report on for each rehabilitation session. Consequently, aspects regarding the exercise program variables, namely exercise aim, order, set endpoint goal, and interest rest, were deemed less important and should be reported on a once-off basis. Muscle contraction type/tempo, range of motion, and exercise type should be reported when it deviates from the norm.

Table 5.4: Strength training exercise descriptors comparison with other intervention reporting frameworks

Exercise Reporting guidelines	Sets	Repetitions	Load Magnitude	Rule for exercise progressions	Completion to prescribed sessions	Exercise aim	Interset rest	Set endpoint goal	Frequency of sessions	Exercise order	ROM	Muscle contraction type/Tempo	Exercise type	Reason for exclusion
ACLR Conceptual Framework	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A
CERT	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	Generic exercise reporting framework
TIDieR	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	Generic drug intervention reporting framework

Comments from panel members assisted in identifying relevant contextual factors influencing the framework implementation as well as the identification of redundant and/or repeating elements.

Considering other frameworks, TIDieR and CERT, the ACLR conceptual framework will add value to the current existing body of evidence regarding the detailed reporting of ST exercise descriptor specifications. The main difference between the TIDieR and CERT and the ACLR conceptual framework was that our framework was specifically designed to report on the ST EDs of ACLR rehabilitation programmes.

5.9.7.1 ACLR conceptual framework finalisation

During the validation meeting, the preliminary conceptual framework that was developed (cf. Appendices...) was presented to participants to contextualise and provide feedback for the framework content to finalise the framework for integration within the ACLR exercise rehabilitation programs. The ACLR conceptual framework is, therefore, based on a conceptual framework that was, as part of the research process, reviewed by experts and finalised for possible implementation.

Figure 5.6 indicates an inside-to-outside approach starting with the more frequent to less frequent reporting of strength training (ST) exercise descriptors (EDs) utilised during ACLR exercise rehabilitation programing. Contextual factors in a cloud format surrounding the three inner circles provide evidence for other external influences on the reporting of ST EDs. The dotted lines between COS 1-3 indicate a free flow of these elements within an ACLR ST program. The dash lines around each ST ED indicate the participating relationship between these descriptors.

Currently, this is the only validated ST framework that supports the reporting and documentation of ST EDs utilised during ACLR exercise rehabilitation.

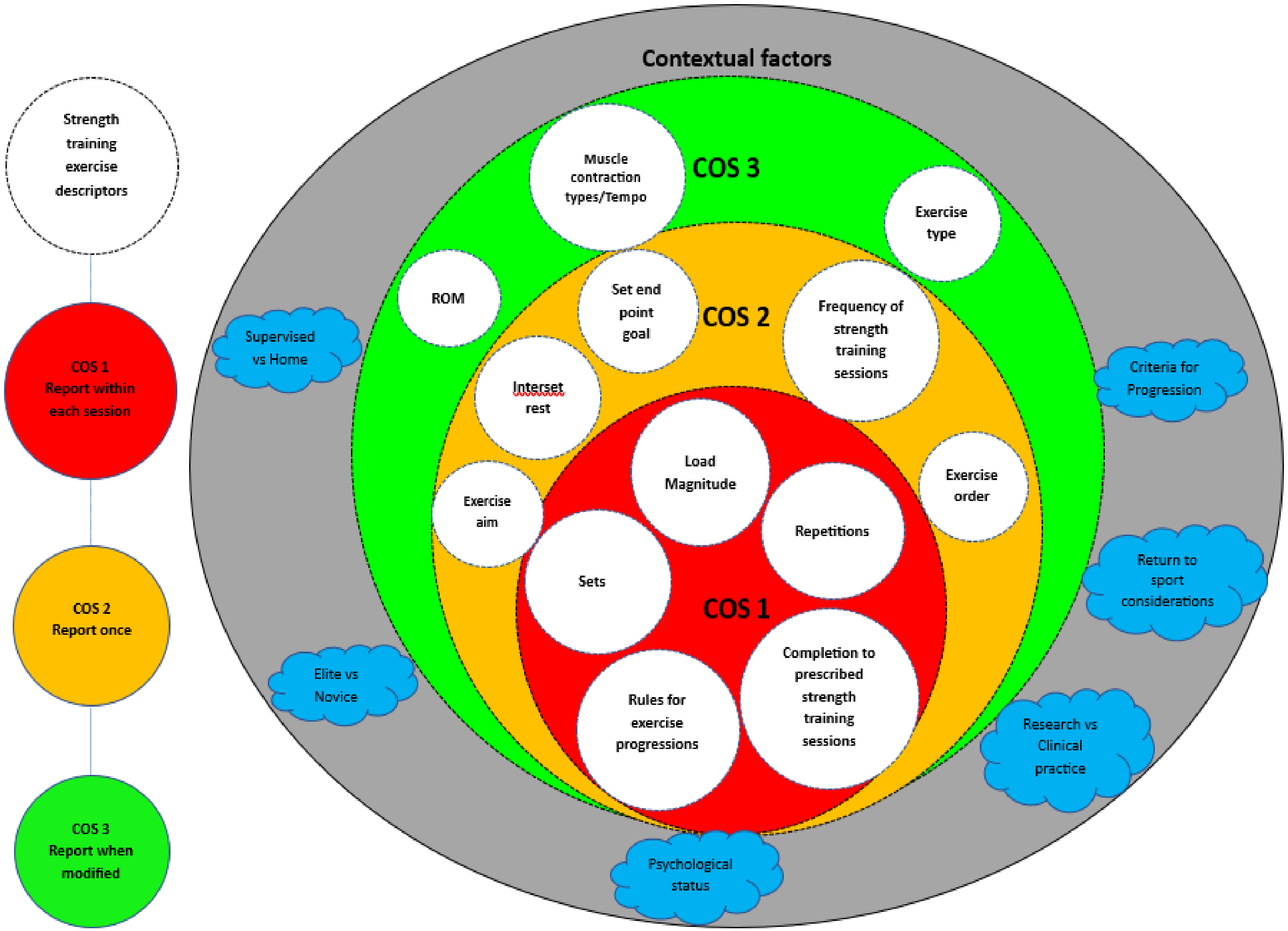

Figure 5.6: Final ACLR Conceptual Framework to improve the reporting of strength training exercise descriptors in ACLR exercise rehabilitation programs

5.9.7.2 Application of the ACLR conceptual framework

The researcher developed a customised ACLR Excel tool (Table 5.5) (**LINK**) with multiple drop-down lists and dummy data that encompassed all COS 1-3 strength training (ST) exercise descriptors (EDs) to be used either in clinical trials or in private practice. The colour coding reflects the frequency of reporting, as stated in Figure 5.6. This ACLR worksheet would enable researchers to report the essential ST EDs while performing the ACLR ST intervention either as first-line treatment for ACL injuries or in collaboration with ACLR surgery. As we see, other reporting checklists like the TIDieR and CERT cannot capture the essential information regarding ACLR ST interventions, making the ACLR worksheet a requirement in ACLR exercise programing.

Considering the applicability of ACLR clinical practice guidelines (CPGs), the ACLR worksheet may enable the end-user to replicate high-quality ACLR exercise intervention through quality reporting, capturing details regarding exercise dosages previously not reported (Andrade *et al*., 2019; Culvenor *et al*., 2022 Goff *et al.,* 2018).

5.9.7.3 Clinical status of the knee joint assessment[1] and ACLR strengthening program[2]

Joint effusion was identified as a re-injury risk factor three months post-operative, and knee pain was indicated as residual knee symptoms that prevent ACLR patients from some physical activities (Toale *et al.,* 2021; Kikuchi *et al*., 2023). Therefore, measuring these two clinical indicators, and utilising the ACLR worksheet, would be inevitable as part of the ACLR conceptual framework execution (Table 5.5).

We opt for designing a framework for ACLR strengthening exercises while executing an ACLR ST exercise program[2], excluding neuromuscular control exercise descriptors.

5.9.7.4 Repetition maximum (RM) continuum practice in ACLR strength training (ST) programs

One of the main advances of the ACLR worksheet is the ability to integrate the RM continuum (Beachle & Earle, 2008) with the ACLR rehabilitation phases by selecting the specific ACLR strengthening exercise aim[3]. (**Please note that these upper script**

numbers are relevant in the spreadsheet as a reference. See Table 5.5). Consequently, the exercise mechanical stimuli can frequently (per session) be tailored towards the preferred load magnitude[8], repetitions[9], sets[10], and rules for exercise progressions[11] based on the clinical status of the knee joint[1] and the proposed ST exercise aim[3].

To target ST towards neuromuscular strength deficits after ACLR surgery (Maestroni *et al*., 2021; Tayfur *et al*., 2021), one should select the preferred ST exercise aim[3] from the dropdown list that represents the RM continuum and populate the rest of the exercise descriptors (EDs) accordingly[5-15]. Additionally, research confirms the lack of reporting exercise frequency and exercise completion to prescribed sessions (Vlok *et al.,* 2022; Adam *et al.,* 2020). The ACLR spreadsheet can be utilised to capture both frequency of exercise prescribed[16] and the completion of prescribed sessions[17] to solve this matter. As rightly stated by Cormier (2022: 2371), ***"The best program for your athlete recovering from an ACL tear is the one that gets completed"***.

5.9.7.5 Different exercise modes

The ACLR worksheet enables users to select the exercise name[5], and exercise type[6], in a certain exercise order[7] to maximise the exercise ST stimuli. Exercises like knee extension and leg press were the prerequisites for our research (Vlok. *et al.,* 2022). Exercise type[6] can differ between OKC or CKC and can be ordered[7] in either multi-joint to single joint exercise or single to multi-joint depending on the aim of the exercise program. Exercise type and exercise order can be reported once off or when it deviates from the norm, respectively (Table 5.5).

Practitioners and researchers would be able to distinguish between different muscle contraction types/tempo[14], like eccentric, isometric, and concentric muscle tempos, when executing an ACLR ST exercise program. Evidence emphasises including eccentric training modes in exercise execution, targeting quadriceps and hamstring muscle weakness after ACLR (Lepley *et al.,* 2013; Buckthorpe *et al.,* 2021).

Previous literature indicated the lack of effectively reporting resistance training intensity following ACLR surgery (Nichols *et al.,* 2021). The ACLR worksheet would be able to capture ST intensity[8] through the predetermined COS 1-3 ST EDs embedded in the ACLR conceptual framework.

Table 5.5: ACLR Worksheet

Clinical status of the knee joint[1]

Clinical assesment	Metric	Time Measured	Activity /Test position	Session 1	Session 2	Session 3	Session 4	Session 5
VAS Pain	NPRS	Before rehab session	Body weight Squatting*3	2	6	0	1	1
Effusion	Stroke test ratings	Before rehab session	Seated on Plinth	0	3+	1+	0	0 [0 / 1+ / 2+ / 3+]

ACLR Strengthening program[2]

Rehabilitation exercises configurations				ACLR Phase 2 (3-6 months) [ACLR Phase 1(<3 months) / ACLR Phase 2 (3-6 months) / ACLR Phase 3 (>6 months)]	Frequency of sessions prescribed/week[16]				5
					Completion to prescribed session/week[17]				3
Aim of the exercise[3]	Exercise name[5]	Exercise Type[6]	Exercise order[7]	Exercise descriptors	1	0	0	1	1
[Endurance focus / Hypertrophy Focus / Maximum Strength Fo / Power and RFD focus] Maximum Strength Focus	Knee Extension	Open kinetic chain / Close kinetic chain	Single Joint / Multi-Joint	Load Magnitude[8] (%RM/kg)	>80% / 170	0 / 0	>80% / 185	>80% / 185	>80% / 185
				Repetition[9]	6	0	6	6	6
				Sets[10] (Injured:Uninjured)	3:3	0	4:4	4:4	4:4
				Rule for Exercise Progessions[11]	Same [+ 2 Rule / ↑Volume / ↑Speed / Same / N/A]	N/A	↑Volume	+ 2 Rule	Same
				Interset rest[12] (Sec:Min)	3-5 Min [30-60 Sec / 1-2 Min / 2-4 Min / 3-5 Min]				
				Set end Point goal[13] (RPE:RiR)	8:2				
				Muscle contraction type/Tempo[14] (Ecc: Isom: Con)	3:1:1				
				Range of Motion[15]	Full	Full	Full	Full	Restricted

Red Cells : Reporting within each session

Orange Cells : Reporting once

Green Cells : Reporting when deviates from norm

5.9.7.6 Capturing exercise dosages

Most importantly, the ACLR worksheet reporting the critical components of exercise dosage (Table 5.4 red section; Table 5.5 superscript reps[9], sets[10], load magnitude[8], rule for exercise progresions[11], completion of sessions[17]), confirmed by all three frameworks (ACLR conceptual framework, TIDieR and CERT) can enable researchers and clinicians to build on existing evidence and reproducing ACLR clinical trial results (Hoffmnan *et al.,* 2014, Slade *et al.,* 2016). Appreciating the individuality of ACLR patient treatment and refining the reporting of dosages regarding ACLR strengthening exercises may be one of the missing pieces of the puzzle of translating evidence into private practice (Page, 2017).

5.9.7.7 Target pathophysiological alterations after ACLR surgery

AMI contribute to extensive quadriceps muscle weakness after ACLR, leading to a decrease in muscle strength and power when athletes want to return to their pre-injury levels of play (Lepley *et al.,* 2020). Accordingly, the application of our ACLR worksheet would enable practitioners to target quadriceps/hamstring strength deficits from an inside-out manner (Figure 5.7 blue arrows). By starting with the question of what is needed to target AMI on structural and neurological levels, the answer would be to provide a stimulus to these structures that would enable an adaptational response within (Figure 5.7: green arrows and yellow circle). Targeting the activation of Type I and II muscle fibres on morphological and cellular levels through high-intensity (>80%RM) CKC and OKC exercises can impact the quadriceps to weakness continuously after ACLR (Fry *et al.,* 2004; Sonnery-Cottet *et al.,* 2018; Maestroni *et al.,* 2020).

Targeting AMI, the aim of the exercise[3] (Figure 5.7 repetition maximum (RM) elements surrounding) deemed a certain exercise dosage configuration (Figure 5.7 grey circle and Table 5.6 ACLR worksheet superscript[6-15]), which can impact neurophysiological adaptations (yellow circle) with the effect on strength and power outputs after ACLR (blue circle).

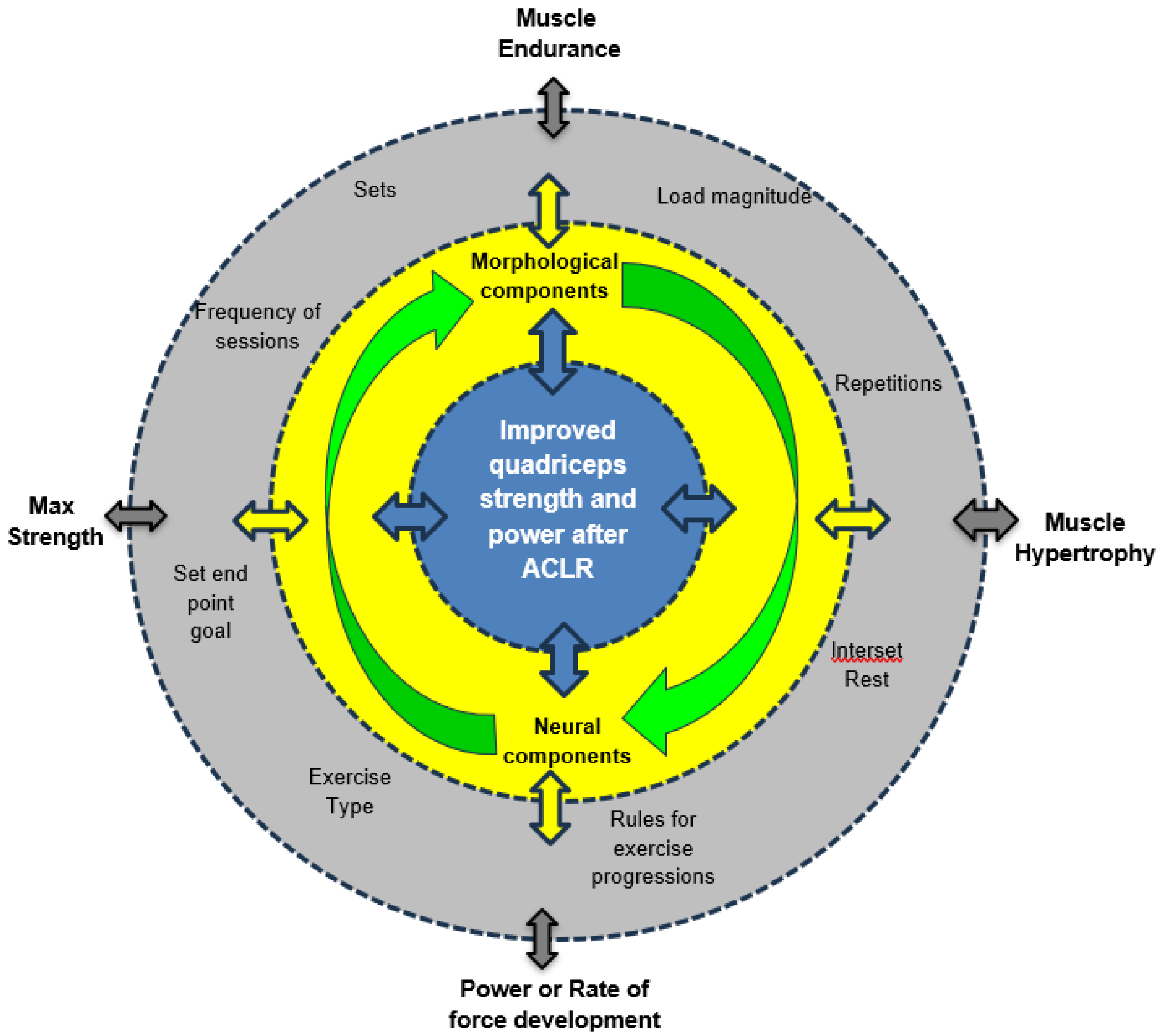

Figure 5.7: Strength training exercise configurations drive neurophysiological responses after ACLR surgery

5.9.7.8 No "one size fits all" ACLR exercise prescription

There is no optimal "one size fits all" strength training (ST) dose-response configurations in ACLR exercise programing (Vlok, 2023: Delphi unpublished). Therefore, a deep understanding of the science behind neuromuscular adaptational responses, ST best practice guidelines, and persisting neuromuscular functional deficits after ACLR and RTS intention deemed compulsory for any researcher and clinician to optimise their own clinical ACLR strengthening programs. Best practice recommendations regarding ST (Ratamess *et al.,* 2009; Welling *et al*., 2019; Currier *et al.,* 2023; Maestroni *et al.,* 2020) would enable users of the ACLR worksheet (Table 5.5) to fill in the exercise dosages considering Figure 5.6. Thus, reporting the exercise descriptors (EDs) responsible for muscle gains and strength improvement either in clinical practice or in research interventions can provide essential information about neuromuscular adaptational responses throughout the ACLR rehabilitation period.

5.9.8 Limitations

A few challenges and possible limitations were identified during the study. The search in our scoping review was limited to the last 30 years. However, we assessed development over time, strengthening our ability to conclude on contemporary ACLR rehabilitation programs. In the Scoping Review, we only included rehabilitation studies after ACLR with autografts, and our conclusions may not apply to rehabilitation programs after ACLR with allograft and non-surgical ACL rehabilitation programs.

According to the literature, the e-Delphi and consensus research methodology has many potential weaknesses. We speculate that bias was possible within our study. Our ACLR ERG was not heterogenous in profession, with 74% (20/27) physiotherapists, 22% biokineticists and one athletic trainer. This could result in inclusion bias for one profession. However, in our validation meeting, the researcher aimed to include 50% clinically based panellists and 50% research-based panellists. Ensuring an equal distribution of ACLR, experts enabled the collection of input from a broader community concerning strength training (ST) exercise descriptor utilisation for a balanced viewpoint to a wider ACLR rehabilitation community.

As previously stated, while we trusted the survey respondents (our ACLR ERG) to have excellent knowledge of ACLR with excellent academic qualifications, it may be possible that ST prescriptions were outside their domain and level of expertise or scope of practice.

5.9.9 Strength

The main strength of this study was the robust methods that was used to execute phase 1-4. Secondly the development of an ACLR conceptual framework would enable researchers and clinicians to work closer together in rehabilitating ACLR injured patients. Lastly, further research can build on solid reported ACLR clinical trial interventions.

5.9.10 Conclusion

The researcher used data obtained during all four study phases to develop an ACLR conceptual framework to improve the reporting of strength training (ST) exercise descriptors (EDs). The final framework developed after the conclusion of the validation meeting (cf. Figure 5.6) illustrates a fluid and dynamic approach to reporting ACLR ST EDs while conducting ACLR exercise rehabilitation. Categorising the COS 1-3 ST EDs according to the frequency of reporting enables users to monitor ACLR patients easily and accurately and individualise rehabilitation programs. To improve the implementation of the framework in research and clinical practice, the researcher developed a custom-made ACLR worksheet as an extension of the validated ACLR conceptual framework.

CHAPTER 6

CONCLUSION

6.1 Introduction

The aim of the study was to develop a credible and contextualised ACLR framework to improve the reporting quality of strength training (ST) exercise descriptors (EDs) in ACLR rehabilitation programs. In order to achieve this aim, four phasic projects were established to inform the ACLR framework development. In this conclusion, the researcher will discuss the extent to which each of the individual study phases achieved the stated objectives, contributed to the research process, and how it influenced the researcher's decisions, and finally, the contribution of the thesis, study-specific limitations, and recommendations will be presented.

6.2 ACLR conceptual framework development and finalisation

The first study phase aimed to achieve the objective proposed in Study 1, which was to review the reporting of strength training (ST) exercise descriptors (EDs) for patients with ACLR to identify which descriptors were used in exercise rehabilitation. Secondly, we compared the ACLR rehabilitation literature to international standards of reporting ST EDs to understand the quality of reporting. Therefore, a scoping review design was selected to identify and analyse knowledge gaps regarding the broader scope of reporting ACLR ST EDs in Levels 1-4 studies. The scoping review concluded with 19 EDs extracted from international ST resources. However, only a few of these best practice ST EDs were included in the majority of the ACLR exercise rehabilitation interventions, which indicated a poor quality of reporting. There were no consensus regarding which ST EDs should be reported while conducting ACLR exercise programs. This led to the succeeding phase of the project.

The second study phase objective was three-folded: 1) to capture clinical consensus on ST terminology**,** 2) work towards agreement on a core outcome set (COS) of ST EDs to classify and describe ST exercises in ACLR rehabilitation programs, 3) outline the exercise dosages of ST EDs during different phases of ACLR. Thus, a modified e-Delphi study design was selected to capture consensus on the objectives of the study. Twenty-seven national and international ACLR experts were purposefully selected to participate in a three-round modified e-Delphi survey. Results concluded the consensus terminology of clinical experts and described ACLR ST EDs. Secondly, a consent COS of EDs needed for reporting ST were identified. Unfortunately, a low level of expert consensus could be achieved on the exercise dosages captured regarding ST implementation during different phases of ACLR rehabilitation.

Reflecting on the outcomes of the Delphi survey, a preliminary ACLR conceptual framework was developed.

The third study phase's primary objective was to develop a preliminary ACLR conceptual framework based on the information from the modified e-Delphi study and the Scoping Review, improving the robustness of the core outcomes set and the definitions proposed during the modified e-Delphi, the PhD evaluation committee of the study project advised an external validation meeting. Consequently, a hypothetical ACLR conceptual framework was designed as a skeleton framework to be validated. The main objectives of this validation study were to critically review, validate and finalise the constructs of the ACLR conceptual framework for reporting ST EDs to be included in research and clinical practice settings.

A qualitative descriptive research design was utilised to collect expert opinions on the ST EDs captured in the ACLR conceptual framework draft. Experts unanimously agreed to segregate EDs based on the frequency of reporting intervals. Otherwise, reporting all descriptors too frequently would be administratively intensive.

Phase 4 of this study considered the validation meetings' proposal of the level of reporting frequency of EDs in the final ACLR conceptual framework. The researcher categorised the remaining 13 core outcomes set ST EDs into a COS 1-3 (Figure 5.6) based on the frequency of reporting ST EDs. The researcher further developed a user-friendly ACLR worksheet to enable users to implement the COS 1-3 ACLR conceptual framework (Table 5.5).

Considering the robust methods and well-defined objectives followed in building the ACLR conceptual framework, it was possible to close the knowledge gaps which existed within the reporting of current ACLR ST rehabilitation programs. Secondly, proper reporting of the COS 1-3 EDs may enable everyday practitioners working either once off with ACLR patients or more frequently to duplicate research results from research papers.

6.3 Recommendations

Based on the results obtained during the research phases, the following recommendations for framework implementation, piloting and areas requiring further research are put forward.

- To better understand the implications of these results, future studies could address the practical application of the ACLR conceptual framework within ACLR clinical trials, publishing the data in journal publications or supplementary files.
- Editors can use the ACLR conceptual framework to evaluate manuscripts that report exercise interventions.
- Piloting the ACLR conceptual framework in clinical as well as research settings may be beneficial to streamline the framework further.
- The framework can be used to set the reporting standard for future research in strength training (ST) exercise programs considering other region-specific joint pathologies.

6.4 Contribution

This research study has successfully created a unique platform for researchers and clinicians to report important elements of exercise dosages such as repetitions, sets, rule of progression, and load magnitude while conducting an ACLR strength training (ST) rehabilitation program. The essence of such a scientific ACLR reporting framework lies in the empowerment of private practitioners to replicate ACLR clinical trial research results in clinical practice. Translating quality ACLR research into private practice will deliver quality service to patients who experience ACLR surgery.

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APPENDICES

APPENDIX A: Approval letter from Health Sciences Research Ethics Committee

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

12-May-2023

Dear Mr Arnoldus Vlok

Ethics Number: UFS-HSD2019/1889/2502-0001

Ethics Clearance: **A conceptual framework to improve the reporting quality of strength training exercise descriptors in anterior cruciate ligament reconstruction rehabilitation programmes**

Principal Investigator: **Mr Arnoldus Vlok**

Department: **Exercise and Sport Sciences Department (Bloemfontein Campus)***

Submission Page

SUBSEQUENT SUBMISSION APPROVED

With reference to your recent submission for ethical clearance from the Health Sciences Research Ethics Committee. I am pleased to inform you on behalf of the HSREC that you have been granted ethical clearance for your request as stipulated below:

The reasons for the slight modification are as follow:
The title must clearly and accurately reflect the focus of the study. Based on the first article published as part of the thesis "Exercise descriptors that determine muscle strength gains are missing from reported anterior cruciate ligament reconstruction rehabilitation programs: a scoping review of 117 exercises in 41 studies. Journal of Orthopaedic Sports Physical Therapy, 52(2): 100-112. it became apparent that the old title does not reflect the focus of the study.
I was advised by my study leaders to rather modify the title slightly.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2020); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; International Council for Harmonisation (ICH) Harmonised Guideline, Integrated Addendum to ICH E6(R1), Guideline for Good Clinical Practice (GCP) E6(R2), 2016, SAHPRA Guidelines as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

The Principal Investigator (PI) bears final responsibility for the RIMS application. In the event of any misconduct or improper activities perpetuated by a third party, the PI will be held vicariously liable. The HSREC will bear no responsibility or liability for any actions of a PI and/or third party or breach of confidentiality caused by the PI and/or third party.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this request for ethical clearance and we wish you continued success with your research.

Yours Sincerely

Prof. A. Sherriff
Chairperson : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
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(UFS)

APPENDIX B: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

"SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Done
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Done
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Done
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualise the review questions and/or objectives.	Done
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and, if available, provide registration information, including the registration number.	Done
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Done
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Done
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Done
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Done
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Done
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Done
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	Not applicable
Synthesis of results	13	Describe the methods of handling and summarising the data that were charted.	Done
RESULTS			

“SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Done
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Done
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Done
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Done
Synthesis of results	18	Summarise and/or present the charting results as they relate to the review questions and objectives.	Done
DISCUSSION			
Summary of evidence	19	Summarise the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Done
Limitations	20	Discuss the limitations of the scoping review process.	Done
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Done
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	Not applicable

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of “risk of bias” (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.”

APPENDIX C: Boolean phrase to search the databases

(ACLR or acl or "anterior cruciate ligament*") and (surgery or surgical or reconstruct*) and (178esistan* or train* or progress* or therap*) n5 (strength* or resistance* or weight*) and (interven* or program* or protocol*)

APPENDIX D: Articles excluded with reasons Boolean

	Name	Autor and Year	Reason for Exclusion
1	“[Rehabilitation following reconstruction of the anterior cruciate ligament. The effect of a 6-week training program].	Bochdansky et al., 1990	Conference papers, study protocol, abstracts, updates, and studies in non-English language.
2	A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction’, Journal of Orthopaedic and Sports Physical Therapy, 33(9), pp. 492–501. Doi: 10.2519/jospt.2003.33.9.492.	Fitzgerald et al., 2003	Studies that include participants with ACL allografts, ACL repair, ACL injuries
3	Acceptability of a digital health intervention alongside physiotherapy to support patients following anterior cruciate ligament reconstruction	Dunphy et al., 2017	No description of strength training exercises with fixed mass as resistance
4	ACL Rehabilitation Progression: Where Are We Now?’ Current Reviews	Cavanaugh et al., 2017	Conference papers, abstracts, updates, and studies in non-English language.
5	An Australian survey of in-patient protocols for quadriceps exercises following anterior cruciate ligament reconstruction	Shaw et al., 2002	Only recording acute rehabilitation phase (0-2 months after surgery)
6	Anterior Cruciate Ligament Reconstruction Rehabilitation: A 6 months Follow-Up of Isokinetic Testing in Recreational Athletes	Wilk et al., 1991	Duplicate interventions
7	Assessment of metabolic response and functional changes	Petschnig et al., 1997	No description of strength training exercises with fixed mass as resistance
8	Blood flow restriction training in the post-operative management of a female soccer player with an ACLR and left Lateral Meniscus repair: A case report	Lafot, 2018	Studies that describe strength training only in combination with supplementary modalities
9	Application of electric stimulation and eccentric exercise vs Standard exercise protocol for Anterior cruciate ligament reconstruction.	Alexander et al.,2018	Studies that describe strength training only in combination with supplementary modalities
10	The effect of targeted exercise on knee muscle function in patients with persistent hamstring deficiency following ACL reconstruction – study protocol for a randomized controlled trial	Bregenhof et al., 2017	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
11	Current Rehabilitation Concepts for Anterior Cruciate Ligament Surgery in Athletes	Malempati et al. 2015	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
12	The Long-term Effect of 2 Postoperative Rehabilitation Programs After Anterior Cruciate Ligament Reconstruction	Risberg et al., 2009	Duplicate interventions
13	Early Versus Late Start of Isokinetic Hamstring-Strengthening Exercise After Anterior Cruciate Ligament Reconstruction with Patellar Tendon Graft	Sekr et al., 2010	Studies that describe strength training only in combination with supplementary modalities
14	Combination of Eccentric Exercise and Neuromuscular Electrical Stimulation to Improve Quadriceps Function Post-ACL Reconstruction	Lepley et al., 2015	Duplicate interventions
15	Comparison of Functional Outcome Measures After ACL Reconstruction in Competitive Soccer Players	Mohammadi et al., 2013	No description of strength training exercises with fixed mass as resistance

16	Comparison of Home Versus Physical Therapy–Supervised Rehabilitation Programs After Anterior Cruciate Ligament Reconstruction a Randomized Clinical Trial,	Grant et al., 2005	Duplicate interventions
17	Comparison of the acute perceptual and blood pressure response to heavy load and light load blood flow restriction resistance exercise in anterior cruciate ligament reconstruction patients and non-injured	Huges et al., 2019	Studies that describe strength training only in combination with supplementary modalities
18	'Coper Classification Early After Anterior Cruciate Ligament Rupture Changes with Progressive Neuromuscular and Strength Training and Is Associated With 2-Year Success the Delaware-Oslo ACL Cohort Stud	Thoma et al.,2019	Min age < 16 years
19	Current Evidence in Anterior Cruciate Ligament Rehabilitation: Neuromuscular Electrical Stimulation Combined with a Strengthening Program: A Critically Appraised Topic'	Lynch et al., 2017	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
20	Do Patients Failing Return-to-Activity Criteria at 6 Months After Anterior Cruciate Ligament Reconstruction Continue Demonstrating Deficits at 2 Years?	Nawasreh et al., 2016	Studies that include participants with ACL allografts, ACL repair, ACL injuries
21	'Does concomitant meniscectomy or meniscal repair affect the recovery of quadriceps function post-ACL reconstruction?	Lepley et al., 2015	Min age < 16 years
22	Effect of Blood Flow Restriction Training on Quadriceps Muscle Strength, Morphology, Physiology, and Knee Biomechanics Before and After Anterior Cruciate Ligament Reconstruction	Erickson et al., 2019	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
23	Effects of an Accelerated Rehabilitation Program after Anterior Cruciate Ligament Reconstruction with Combined Semitendinosus-Gracilis Autograft and a Ligament Augmentation Device	MacDonald et al., 1995	Other associated ligamentous knee injuries combined with ACL index injury
24	Evaluation of strength muscle recovery with isokinetic, squat jump and stiffness tests in athletes with ACL reconstruction: a case-control study	Jacopetti et al., 2016	No description of strength training exercises with fixed mass as resistance
25	Kilgas, M. A. et al. (2019) 'Exercise with Blood Flow Restriction to Improve Quadriceps Function Long After ACL Reconstruction	Kilgas et al., 2019	Studies that describe strength training only in combination with supplementary modalities
26	'Fatigue' s Lack of Effect on Thigh-Muscle Activity in Anterior Cruciate Ligament – Reconstructed Patients During a Dynamic-Landing Task.	Lepley et al., 2013	No description of strength training exercises with fixed mass as resistance
27	Outcomes Improve Over the Course of Rehabilitation: A Secondary Analysis	Arundale et al., 2018	Studies that include participants with ACL allografts, ACL repair, ACL injuries
28	Functional Bracing After Anterior Cruciate Ligament Reconstruction a Prospective, Randomised, Multicenter Study	McDevitt et al., 2004	No description of strength training exercises with fixed mass as resistance
29	Gait Mechanics and Tibiofemoral Loading in Men of the ACL-SPORTS Randomized Control Trial	Khanda et al., 2018	Studies that include participants with ACL allografts, ACL repair, ACL injuries
30	Immediate effects of neuromuscular joint facilitation intervention after anterior cruciate ligament reconstruction	Wang et al., 2016	No description of strength training exercises with fixed mass as resistance
31	Implementation of Open and Closed Kinetic Chain Quadriceps Strengthening Exercises After Anterior Cruciate Ligament Reconstruction	Ross et al., 2001	Conference papers, study protocol, abstracts, updates, and studies in non-English language.
32	Isokinetic assessment of muscle strength following anterior cruciate ligament reconstruction	Cardone et al., 2004	No description of strength training exercises with fixed mass as resistance

33	Isokinetic knee strength and life quality after anterior cruciate ligament reconstruction : Nintendo Wii vs conventional rehabilitation A review of criteria prior to return to sports following ACL reconstruction	Haksever et al., 2012	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
34	Isokinetic knee strength and proprioception before and after anterior cruciate ligament reconstruction: A comparison between home-based and supervised rehabilitation.	N/A	Full-text studies unavailable
35	Knee function after ACL rupture and Reconstruction Effects of Neuromuscular Training	Hartigan et al., 2009	Min age < 16 years
36	Neuromuscular Electrical Stimulation Superimposed on Movement Early after ACL Surgery	Labanca et al., 2018	No description of strength training exercises with fixed mass as resistance
37	Neuromuscular training optimises knee function after arthroscopic ACL reconstruction.	Ageberg et al., 2007	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
38	Gregory Myer, Mark Paterno, T. H. (2008) 'Neuromuscular training techniques to target deficits before return to sport after anterior cruciate ligament reconstruction	Meyer et al., 2008	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
39	Open and Closed Kinetic Chain Exercises in the Early Period after Anterior Cruciate Ligament Reconstruction Improvements in Level Walking, Stair Ascent, and Stair Descent	Hooper et al., 2001	Only recording acute rehabilitation phase (0-2 months after surgery)
40	Range of motion specificity resulting from close and open kinetic chain 181 resistance training after ACLR	Hooper et al., 2002	Only recording acute rehabilitation phase (0-2 months after surgery)
41	Rehabilitation and Return to Play After Anatomic Anterior Cruciate Ligament Reconstruction	Yabroudi et al., 2019	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
42	Cruciate Ligament Injury Current Recommendations for Sports Participation	Kvist, 2004	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
43	Rehabilitation of the anterior cruciate ligament.	N/A	Full-text studies unavailable
44	Report of the Clinical and Functional Primary Outcomes in Men of the ACL-SPORTS Trial : Similar Outcomes in Men Receiving Secondary Prevention With and Without Perturbation Training 1 and 2 Years After ACL Reconstruction	Arundale et al., 2017	Studies that include participants with ACL allografts, ACL repair, ACL injuries
45	Report of the Primary Outcomes for Gait Mechanics in Men of the ACL-SPORTS Trial : Secondary Prevention With and Without Perturbation Training Does Not Restore Gait Symmetry in Men 1 or 2 Years After ACL Reconstruction	Capin et al., 2017	Studies that include participants with ACL allografts, ACL repair, ACL injuries
46	Resistance Strength Training in Anterior Cruciate Ligament Rehabilitation	Hosea et al., 1996	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
47	Restoring knee extensor strength after anterior cruciate ligament reconstruction: A clinical commentary	Buckthorpe et al., 2019	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
48	'Superior 2-Year Functional Outcomes Among Young Female Athletes After ACL Reconstruction in 10 Return-to-Sport Training Sessions With Delaware-Oslo and MOON Cohorts'	Capin et al., 2019	Studies that include participants with ACL allografts, ACL repair, ACL injuries
49	Temporal neuromuscular alterations of the quadriceps after unilateral anterior cruciate ligament reconstruction.	Cabler, 2016	Min age < 16 years
50	The Effect of Exercise and Rehabilitation on Anterior-Posterior Knee Displacements After Anterior Cruciate Ligament Autograft Reconstruction	Barber-westin et al., 1999	Min age < 16 years

51	The Effect of Kinesiotaping Implementation After Anterior Cruciate Ligament Reconstruction	Ural et al., 2016	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
52	The effect of rehabilitation and return to activity on anterior-posterior knee displacements after anterior cruciate ligament reconstruction	Barber-westin et al., 1993	Studies that include participants with ACL allografts, ACL repair, ACL injuries
53	The effects of neuromuscular training on the ability to return to activity for the ACL reconstructed athlete.	White et al., 2014	Studies that include participants with ACL allografts, ACL repair, ACL injuries
54	The Fickle ACL deficient athlete: investigation of the non-coper response to injury, surgery, and neuromuscular training.	Di Stasi et al., 2011	Studies that include participants with ACL allografts, ACL repair, ACL injuries
55	The Long-term Effect of 2 Postoperative Rehabilitation Programs After Anterior Cruciate Ligament Reconstruction	Risberg et al., 2009	Duplicate interventions
56	The Warrior Athlete Part 2-Return to Duty in the US Military : Advancing ACL Rehabilitation in the Tactical Athlete The Warrior Athlete Part 2 — Return to Duty in the US Military : Advancing ACL Rehabilitation in the Tactical	Peebles et al., 2019	Conference papers, study protocol, abstracts, updates, and studies in a non-English language.
57	Time Line for Noncopers to Pass Return-to-Sports Criteria After Anterior Cruciate Ligament Reconstruction.	Hartigan et al., 2013	Studies that include participants with ACL allografts, ACL repair, ACL injuries
58	Timing of surgery and isokinetic muscle performance in patients with an anterior cruciate ligament injury	Melikoglu et al., 2oo8	Studies that include participants with ACL allografts, ACL repair, ACL injuries
59	Two-year ACL reinjury rate of 2.5%: outcomes report of the men in a secondary ACL injury prevention program (ACL-SPORTS)	Arundale et al., 2018	Min age < 16 years
60	Unilateral Quadriceps Strengthening With Disinhibitory Cryotherapy and Quadriceps Symmetry After Anterior Cruciate Ligament Reconstruction	Kuenze et al., 2017	Studies that describe strength training only in combination with supplementary modalities
61	Unilateral Stance Strategies of Athletes With ACL Deficiency	Di Stasi et al., 2013	Studies that include participants with ACL allografts, ACL repair, ACL injuries
62	Differential Effects of 2 Rehabilitation Programs Following Anterior Cruciate Ligament Reconstruction	Setuain et al., 2016	No description of strength training exercises with fixed mass as resistance"

APPENDIX E: Delphi participants' information sheet

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS

PARTICIPANT INFORMATION SHEET

Title

Development of a core outcome set for strength training exercise descriptors in anterior cruciate ligament reconstruction (ACLR) rehabilitation programs using the best available evidence and an international consensus process.

What is the purpose of the study?

This survey aims to achieve consensus on exercise descriptors that should be included in an ACLR rehabilitation program. Our recent scoping review (Vlok et al., 2021) shows a discrepancy in reporting strength training exercise descriptors in ACLR rehabilitation programs. Therefore, an expert consensus technique (Delphi method) has been identified as the best method to achieve consensus regarding exercise descriptors used in ACLR documentation. This Delphi survey is part of the principal investigators' (Mr Arnold Vlok) doctorate study at the University of the Free State, with co-authors Prof Derik Coetzee, Dr Clare Arden, and Dr Nicol van Dyk being supervised.

What is a Delphi Survey?

A Delphi survey is a systematic approach with the aim of achieving consensus amongst experts. The survey consists of proposed statements that are refined according to participant feedback through independent completion of sequential questionnaires. Consensus means that a certain percentage (75%) of participants agree on the value of each individual statement, resulting in a convergence of opinion and consensus.

Why have I been approached?

You have been identified as an expert in the field of ACLR rehabilitation following surgery. Below you will see a detailed breakdown of the inclusion criteria:

- **Exercise or health professionals:** Any professional who uses exercise to manage ACLR patients according to our expert definition (e.g., physiotherapists, clinical exercise physiologists, biokineticist, athletic trainers, etc.). Eligible participants should have a relevant postgraduate qualification and treat ≥3 patients with ACLR per month using exercise as a rehabilitation modality or >5 years of experience in the field of ACLR rehabilitation. Clinicians who have previously worked with ACLR patients will be included based on their expertise.

- **Academics:** Eligible academics should have ≥2 peer-reviewed publications over the last ten years focused on exercise rehabilitation in the management of ACLR patients. Based on their expertise, clinical academics who have previously worked with patients with ACLR will be included.
- Academics supervising ACLR rehabilitation programs will be included.

Do I have to take part?

No, participation in this study is voluntary. You are under no obligation to complete all three questionnaires. You have up to the data analysis of the third questionnaire (approximately three months) to withdraw from the study but may withdraw at any point prior to this without giving a reason. Due to the nature of the Delphi process, your responses will be used to the point of withdrawal. Withdrawal or declining participation will not affect your employment or relationship with the researchers. Non-completion of a survey round within the allocated time would indicate withdrawal, and you will not be included in the subsequent survey rounds. If you receive a survey link and wish to withdraw, you are welcome to contact the researcher, Arnold Vlok, at arnold@tripp.co.za

What will I need to do when I participate?

If you wish to participate in this research study, please click on the survey link provided in the email. Informed consent is viewed as a participant completing the online survey.

We will provide you with a link to the first electronic questionnaire (SurveyMonkey web-based platform) containing questions detailing your clinical, demographic, and professional background. Your expert opinion on the presented statements regarding strength training exercise descriptors for ACLR rehabilitation programs (2-12 months after surgery) will be gathered through your agreement level with the proposed statements. The first questionnaire will take between 20-30 minutes to complete and will be open for four weeks. You can save the questionnaire at any time and return to it later. Email reminders will be sent in weeks 1 and 3 from the SurveyMonkey software platform.

Data from the first questionnaire will generate a series of statements. You will be asked to rate your agreement with these statements in the second and third rounds of questionnaires, which are expected to take 25 minutes to complete.

What are the risks?

No risks are anticipated for study participants other than the small amount of time required to complete the questionnaires.

Will my taking part in the study be confidential?

Personal information will be collected, anonymised, and stored electronically on a password-protected computer in line with the Protection of personal data (POPI) Act of South Africa. Only anonymised data will be shared with external collaborators for the purposes of this study. You will remain anonymous to the other participants and in any written reports.

What are the benefits of taking part?

You will have contributed to developing a cluster of strength training exercise descriptors for ACLR rehabilitation programs 2-12 months after surgery, which will inform future clinical trials. Furthermore, by completing the Delphi research, intervention reports of ACLR rehabilitation programs can be replicated in clinical practice. Study results will be published in a relevant peer-reviewed journal and shared at conferences.

What next?

If you decide you would like to participate, please click on the survey link and indicate your consent prior to commencing the survey. Consent will be viewed as a participant completing the online survey.

Link to survey: https://www.surveymonkey.com/r/FDCPGCH

Further information and contact details

This study has been approved by the University of the Free State, Health Sciences Research Ethics Committee, with the reference number: UFS-HSD2019/1889/2502.

If you have any questions about the study, do not hesitate to get in touch with the principal investigator, Arnold Vlok, by email at arnold@tripp.co.za

Thank you for your time and consideration

Principal investigator	Main Supervisor
Mr Arnold Vlok	Prof Derik Coetzee
Pre-Doctorate	Head of Department and Senior Lecturer in Musculoskeletal Rehabilitation and Exercise Sciences
Department of Exercise and Sport Science	Department of Exercise and Sport Science
University of the Free State	University of the Free State
Bloemfontein	Bloemfontein
Email: arnold@tripp.co.za	Email: coetzeef@ufs.ac.za

APPENDIX F: Validation of participant information

PARTICIPANT INFORMATION SHEET FOR VALIDATION MEETING

Title

A conceptual framework to improve the reporting quality of strength training exercise descriptors in anterior cruciate ligament reconstruction rehabilitation programs.

Dear Participant

My name is Arnold Volk, and I am currently enrolled for my PhD degree at the Department of Health and Rehabilitation Sciences in the Faculty of Health Sciences at the University of the Free State (South Africa). To fulfil my qualification, I am undertaking to research and developing a proposed ACLR conceptual rehabilitation framework to be used in research and clinical practice.

In this study, the researcher wants to determine: 1) the correct definitions of strength training exercise descriptors used in ACLR rehabilitation programs and 2) develop a core outcome set of ACLR strength training descriptors to be used in ACLR rehabilitation programs.

Participating in this validation meeting will benefit the future of ACLR research reporting in utilising and specifying the strength training exercise descriptors targeting muscle weakness after ACLR surgery.

Background

A knowledge gap is emerging that suggests a need for consensus on the specifics related to reporting strength training exercise descriptors for ACLR rehabilitation programs (Vlok *et al.,* 2021; Nicolas *et al.,* 2020). Standardising ACLR strength training terminology, classifying strength training exercise descriptors, and developing a core outcome set of strength training exercise descriptors will help fill a gap in ACLR rehabilitation research and practice. Building a bridge between the rich science locked up in ACLR rehabilitation intervention programs and the practical application of such interventions in clinical practice will enable practitioners to translate research effectively into practice.

Where are we in the PhD project?

This validation meeting is part of the principal investigators' (Mr Arnold Vlok) doctorate study at the University of the Free State, with co-authors Prof Derik Coetzee, Dr Nicol van Dyk, and Dr Hege Grindem being supervised. We are currently in the project's last phase (4/4), the international validation of the ACLR conceptual framework. It aims to critically evaluate the ACLR conceptual framework to improve its uptake in research and clinical practice.

Do I need to take part?

No, participation in this once-off validation meeting is voluntary. You are not obligated to participate in this meeting, although you have been specifically selected because of your extensive rehabilitation expertise in rehabilitation programs.

What does this validation meeting entail?

During the validation meeting, a set of structured questions will be asked regarding your opinion and recommendations for the framework. You are encouraged to engage in an open and free discussion with the other participants. The validation meeting will be audio-recorded, and the researcher may make additional field notes. If the meeting is interrupted and cannot continue, a date and time that suits all participants will be arranged to complete the session. It is anticipated that the validation meeting will take approximately 60 minutes. Participating in this study will provide the researcher with expert feedback and opinions regarding the context-specific elements deemed essential for the proposed framework. The researcher's vision is that by compiling this framework for strength training exercise descriptors, private practice will be able to capitalise on better reporting standards targeting strength deficits after ACLR.

What will I need to do when I participate?

Suppose you wish to participate in this last part of the project. In that case, you need to read through the modal script, which will be sent out after acceptance of the invitation email, through which we propose the ACLR conceptual framework. After that, you need to participate in the validation meeting of the ACLR conceptual framework through the Microsoft Teams online platform.

What next?

If you want to participate, please reply to this email: arnold@tripp.co.za

Further information and contact details

Principal investigator	Main Supervisor
Mr. Arnold Vlok	Prof Derik Coetzee
Pre-Doctorate	Head of Department and Senior Lecturer in Musculoskeletal Rehabilitation and Exercise Sciences
Department of Exercise and Sport Science	Department of Exercise and Sport Science
University of the Free State	University of the Free State
Bloemfontein	Bloemfontein
Email: arnold@tripp.co.za	Email: coetzeef@ufs.ac.za

This study has been approved by the University of the Free State, Health Sciences Research Ethics Committee, with the reference number: UFS-HSD2019/1889/2502.
If you have any questions about the study, do not hesitate to get in touch with the principal investigator, Arnold Vlok, by email at arnold@tripp.co.za
Thank you for your time and consideration

Regards,

Arnold Vlok

APPENDIX G: Preliminary draft of ACLR conceptual framework for validation

UNIVERSITY OF THE FREE STATE UNIVERSITEIT VAN DIE VRYSTAAT YUNIVESITHI YA FREISTATA UFS

Title:

A conceptual framework to improve the reporting quality of strength training exercise descriptors in anterior cruciate ligament reconstruction rehabilitation programs

Who will utilise the framework:

Researchers and clinicians who work with ACLR patients in private practices, sports clinics, gyms, hospital-based facilities, and research institutions or combinations. Our viewpoint for including both groups was that although they are different in function, they have the same end goal.

What is the main aim of this framework:

1. Improve the reporting quality of the prescribed ACLR strengthening exercise by utilising a well-defined consensus core outcomes set of strength training exercise descriptors during the rehabilitation program.
2. Serve as an EBP platform to capture exercise dosages during ACLR rehabilitation.

Background for study

Utilisation and specification of exercise descriptors are vital for a uniform approach to ACLR rehabilitation. A pure knowledge gap is emerging that suggests a need for consensus on what and how to report strength training exercise descriptors for ACLR rehabilitation programs. Therefore, the researcher aimed to develop an ACLR conceptual framework specifically guiding strength training rehabilitation as part of ACLR management following ACLR surgery. Standardising strength training terminology and developing a core set of exercises will help fill a gap in ACLR rehabilitation research and practice. This work offers a critical step towards standardising strength training exercise descriptors for effectively translating ACLR rehabilitation programs to clinical practice. Therefore, we launched this four-phase PhD project.

Phase 1: The first study concluded a need for comprehensive reporting of strength training exercise descriptors utilised in ACLR rehabilitation programs. Additionally, the adoption of international guidelines for strength training in ACLR strength training rehabilitation programmes was explored.

Scoping review DOI: 10.2519/jospt.2022.10651

Phase 2: A modified-Delphi study, including 27 international and national ACLR rehabilitation experts, to reach a consensus on 1) the definitions of exercise descriptors used in ACLR rehabilitation programs; 2) core outcomes set of strength training exercise descriptors to be reported for better utilisation and specification of the ACLR exercise intervention (Modified Delphi Study unpublished).

Phase 3: Phase three of the study focused on developing the preliminary ACLR conceptual framework for strengthening exercise descriptors to improve reporting quality of ACLR interventions, including researchers and clinicians. The framework was informed by the data obtained during phases one and two.

Phase 4: Following the development of the ACLR conceptual framework, the aim was to validate and finalise this framework through a validation meeting, including international and national experts.

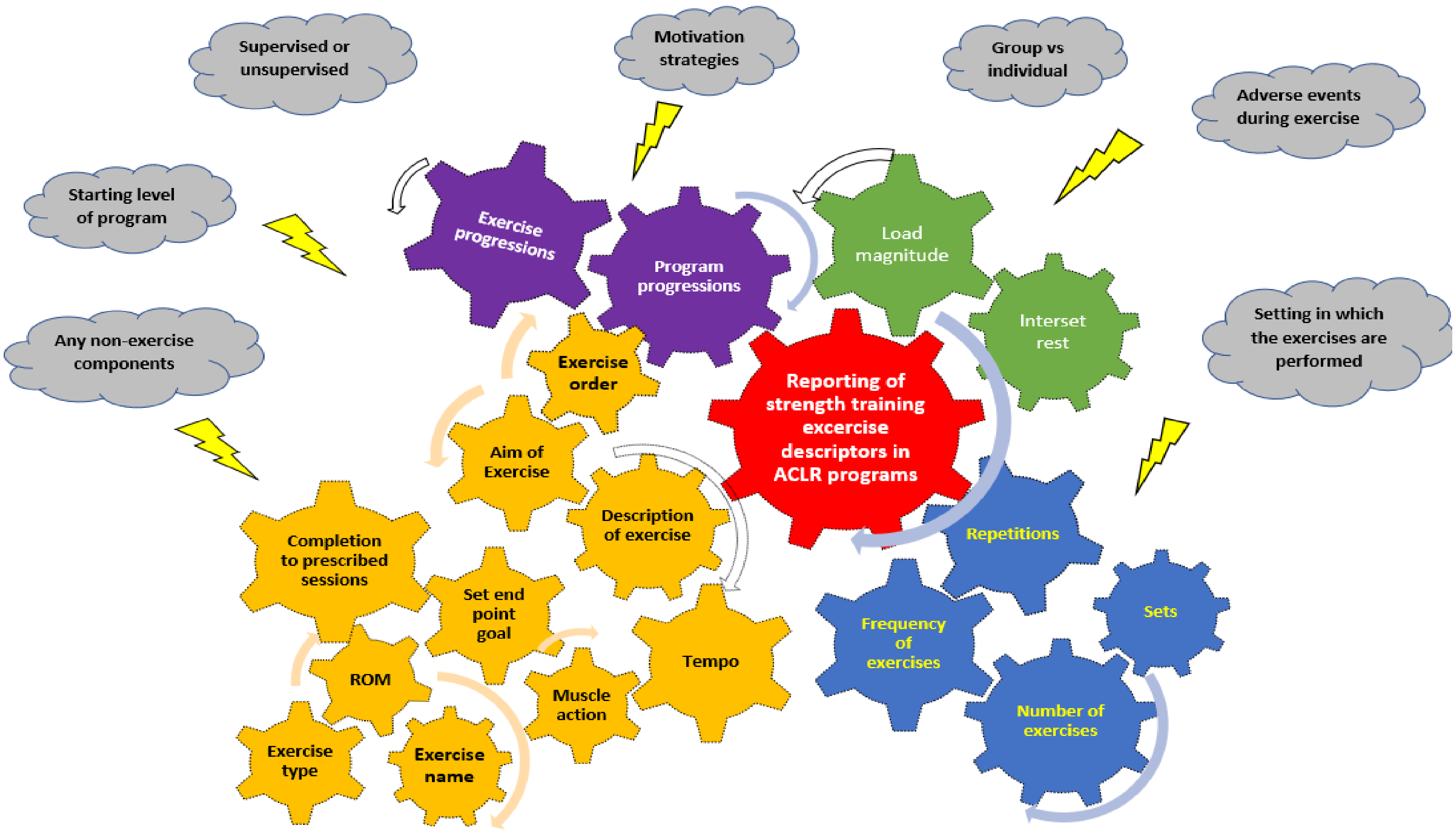
Section A:

Table 1: Consensus definitions and a core outcome set of strength training descriptors to be included in ACLR strengthening programs			
Number	**Exercise descriptor**	**Consensus definitions of strength training exercise descriptors**	**Core outcomes set of ACLR strength exercise descriptors**
1	**The name of the exercise/s:**	The name of the strength training exercises prescribed during the ACLR strength training sessions (e.g., Leg Press, Knee Extensions).	✓
2	**Number of ACLR strengthening exercises prescribed**	The number of ACLR strength training exercises reported during a single session in the ACLR strength training program.	✓
3	**Frequency of ACLR strength training sessions**	The number of ACLR strength training sessions per week prescribed.	✓
4	**Sets completed**	The number of cycles of strength training repetitions performed during a strength training exercise.	✓
5	**Repetitions prescribed**	The number of strength training movements completed during a particular exercise set.	✓
6	**Exercise progressions**	The progression of individual strengthening exercises during an ACLR strength training set (e.g., increase in repetitions, load or speed).	✓
7	**Exercise type**	The mode of exercise selected for a training program (e.g., neuromuscular training exercises, strength training, close kinetic chain/open kinetic chain exercises).	✓
8	**Load magnitude assigned to an ACLR strength training exercise**	The amount of resistance assigns to the individual repetitions during an exercise set.	✓
9	**Range of motion**	The degree of movement around a specific joint during an ACLR strengthening exercise (e.g., leg curls @ 0-90° of knee flexion).	✓
10	**Interset rest is prescribed between ACLR strength training sets**	The recovery time allowed between sets (e.g., 60 seconds or 5 minutes).	✓
11	**Tempo**	The velocity/speed at which an ACLR strengthening exercise is performed.	✓
12	**Muscle contraction**	The type of muscle contraction during a specific repetition executed (e.g., concentric, isometric and eccentric).	✓
13	**Exercise order**	The sequence of exercises in a single exercise session (e.g., multi-joint exercises before single-joint exercises).	✓
14	**Strength training session duration of an ACLR strengthening program**	The total duration of the strength training component of each session (e.g., 30 minutes).	×
15	**Exercise aim**	The specific purpose/focus of the ACLR strengthening exercise (e.g., muscular hypertrophy or maximum strength).	✓
16	**The description of the individual exercise/s:**	A clear description of the execution of the strengthening exercises prescribed during the ACLR rehabilitation sessions either through e.g., photographs, illustrations, video, Smartphone app, website, protocol paper, etc.	✓

17	**The duration of the ACLR rehabilitation phases**	The extent to which an individual patient completes the strength training objectives within an ACLR rehabilitation program (e.g., entails the time between two muscle strength evaluations).	✓
18	**Program progressions:**	Detailed description of how the entire ACLR rehabilitation program (as a whole) is progressed (e.g., increase the durations of the ACLR exercises session/s or increase the number of ACLR rehabilitation training sessions per week).	✓
19	**Set end point goal/target:**	Exercise repetitions performed to the point of 1) total muscular exhaustion, 2) autoregulated like RPE or RiR)	✓
20	**Progressive overload rule of ACLR strengthening exercises:**	It is the rule that indicates the gradual increase in demand placed upon a system in response to the adaptation to previously imposed demands (e.g., increase in training volume{reps* sets*resistance}; training intensity(% 1RM,%BW, RPE, tempo}; frequency or time trained)	×
21	**ACLR strength training program:**	A tailored exercise program with the purpose towards targeting the ACLR strength deficits through a specific focus on the strength training continuum (e.g., strength endurance, strength, max strength etc.).	×
22	**Exercise completion to the prescribed sessions:**	The extent (amount of ACLR strength training sessions fully completed during the course of the rehabilitation period) to which the patient performed the prescribed program.	✓

The foundation of this ACLR conceptual framework lies in the proposed well-defined core outcomes set of exercise descriptors to be used during the ACLR rehabilitation period (See Table 1).

Section B: Figure 1: Below is the draft conceptual framework to improve the reporting quality of strength training exercise descriptors in anterior cruciate ligament reconstruction rehabilitation programs.



Clinical status of the knee joint							
Clinical assessment	**Metric**	**Time Measured**	**Activity /Test position**	**Session 1:**	**Session 2:**	**Session 3:**	**Session 4:**
VAS Pain	NPRS	Before rehab session					
VAS Pain	NPRS	After rehab session					
Effusion	Stroke test ratings	Before rehab session					
Changes in Range of motion	Degree	Before rehab session					

ACLR strength training program								
Exercise number	**Aim of the ACLR strengthening exercise**	**Exercise name**	**Exercise Type**	**Exercise descriptors**	**Session 1:**	**Session 2:**	**Session 3:**	**Session 4:**
	ACLR rehabilitation phase	**Description of exercise**	**Exercise order**					
				Repetition per set				
				Tempo/Muscle action(sec)				
				Sets (Injured: Uninjured)				
				Interset rest (Sec:Min)				
				Load Intensity (%RM:kg)				
				Set end Point(RPE:RiR)				
				Exercise Progressions				
				Range of motion				
				VAS pain during the exercise(NPRS)				
				Exercise completion				

Section C: Below is an example of how the researcher visualizes the practical/clinical application of the conceptual frame

APPENDIX H: Interview sheet questions

Pre-interview:

Testing of equipment and familiarisation with the online environment.

Interview administration:

Time:______________________________________

Date:______________________________________

Participant details:

Participant number	Area of expertise	Years’ experience in field

Answering any questions pertaining to provided information leaflet, clarifying terms, ensure informed consent has been provided.

Validation meeting procedure:

Presentation by the researcher detailing the study process up till now and also highlighting that it is only the strength training part as well as clarification of any words (COS/ exercise descriptor).

Facilitator describes the meeting procedure discussion will be facilitated by an independent facilitator regarding the proposed conceptual framework. The meeting will be audio-recorded in order for the researcher to transcribe the meeting and analyse the data. Any personal identifiers will be removed from the transcripts. Participants should please state their participant number before providing their views during the meeting. All relevant comments, concerns and recommendations raised will be explored during the meeting, and you are encouraged to answer questions freely, as all data will be treated confidentially.

The validation meeting commences following the selection of the recording function on Microsoft Teams.

Time for interview completion- estimated at one hour.

QUESTIONS

1. Please provide your opinion on the core outcomes set of strength training exercise descriptors and their definitions included in the framework (Table 1 in provided document).
2. In your opinion, how do you perceive the framework as supporting more detailed and/or accurate/complete reporting of ACLR strength training?
3. Would you consider this framework beneficial to improve the specification of ACLR strengthening exercises utilized during rehabilitation in research institutions and clinical practice?
4. In your opinion, can this framework be used for targeted strength training for muscle weakness after ACLR surgery, although not the primary purpose of it?
5. Would you consider this framework a value proposition to existing CERT and TiDIER frameworks for reporting exercise interventions?
6. What is your view regarding the practicality of the proposed framework?
7. Do you have any suggestions and/or comments regarding the visual presentation of the framework? Please provide your reasoning for your suggestions.

Thank you for your willingness to participate in this research study. The researcher greatly appreciates your time and your valuable input.

[Stop recording]