Better reporting standards are needed to enhance the quality of hop testing in the setting of ACL return to sport decisions: a narrative review

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ABSTRACT

Background/aim There is a lack of consistency in return to sport (RTS) assessments, in particular hop tests to predict who will sustain a reinjury following anterior cruciate ligament (ACL) reconstruction. Inconsistent test battery content and methodological heterogeneity might contribute to variable associations between hop test performance and subsequent injury. Our aim was to investigate whether commonly used hop tests are administered in a consistent manner and in accordance with reported guidelines.

Methods We conducted a narrative review of studies that examined whether hop testing could differentiate RTS pass rates, reinjury and rerupture in athletes after ACL reconstruction. Our specific focus was on the methodological procedures of hop testing as this component is widely used to evaluate patients’ function and readiness to RTS.

Main findings Substantial variation exists in RTS hop test administration, scoring and interpretation. Authors often failed to report important details of methods such as warm up activities, randomisation, number of trials, rest periods and landing requirements.

Conclusion We recommend researchers provide clearer descriptions of how hop tests are performed to increase standardisation and promote accurate data collection. Absence of reporting to describe test methods and using different test procedures makes it difficult to compare study findings.

INTRODUCTION

Return to sport (RTS) decision making following anterior cruciate ligament (ACL) reconstruction is a complex process involving many factors. A criterion-based approach is now accepted, where a range of tests are used in various combinations. Passing a test battery including a series of single leg hop and isokinetic tests was associated with lower rerupture rates following RTS, and an increased likelihood of returning to previous sporting levels. However, hop and isokinetic tests do not consistently predict successful outcomes following ACL rehabilitation. Losciate et al reported no associations between the use of RTS discharge tests and greater risk of reinjury, stating the low quality of evidence affects our ability to make definitive conclusions. Toole et al reported that many young athletes had been cleared to RTS by their surgeon and rehabilitation specialist but failed to pass the RTS cut-offs cited in the literature. A recent 2019 systematic review demonstrated that only 23% of patients passed RTS test batteries. These authors also suggested an apparent paradox that ‘passing’ an RTS battery was associated with a greater risk of injury to the contralateral limb.

That conclusion led us, and others, to question whether the existing data relating to RTS and subsequent reinjury displays too much clinical variability among the patient groups (race, age, sex, level of performance, type of ACL surgery, other associated injuries) and inconsistent application of test batteries (different clinicians and studies use a widely ranging set of tests). On deeper reflection, and after scoping the literature, we wondered whether the tests themselves (eg, the hop tests) are described clearly and used in a reproducible manner. For RTS tests to be valid and generalised across clinical settings, standardised methods are required for administration, scoring and interpretation.

The primary aim of this narrative review was to provide an overview of the RTS testing batteries of the studies included in the 2019 synthesis of the literature (table 1), and the cited studies in the methods sections of these manuscripts (table 2). Our focus was applied to hop testing methods and administration procedures following ACL reconstruction. This current review provided the most comprehensive and up-to-date body of literature in the area of RTS testing and numerous discussions followed its publication. Our second aim was to demonstrate how even minor alterations to the test protocol might affect interpretation and subsequent RTS decisions.

RESULTS

Table 1 shows that a wide range of approaches in test administration, scoring and interpretation were used, and important methodological details were infrequently reported. To illustrate this point, we created a colour code system to indicate the methodological quality of each of the included studies (green=aligned with current evidence; yellow=reported but not aligned with current evidence; red=not stated) (tables 1 and 2). A discussion of why these factors affect test outcomes is provided below.

Test order

Substantial variation existed across the included studies in relation to testing order. No studies randomised the order of testing, seven did not state the sequence performed, and the remaining studies included additional hop/jump tests.
| Study                  | Tests included                              | Testing order             | Warm up activities | Familiarisation session | # Practice trials | # Trials on each limb | Limb order | Best or mean score | Rest period | Hand placement | Landing requirements | Point of measurement | Checks for systematic bias | Procedures |
|------------------------|---------------------------------------------|----------------------------|-------------------|-------------------------|------------------|---------------------|------------|-------------------|-------------|-----------------|----------------------|---------------------|-----------------------------|------------|
| Beischer at al         | Isometric quad strength, isokinetics, single hop, side hop | Controlled as stated | 10 mins exercise bike | Not stated | 3–5 | 3 | Not stated | Best | 3 mins between trials for side hops, other tests not stated | Not stated | Not stated | Not stated | Yes | Gustavsson at al  |
| Di Stasi et al         | Quadriceps strength index, single hop, triple hop, cross-over hop, timed hop | Order not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Fitzgerald |
| Ebert et al            | Single hop, timed hop, triple-hop, cross-over hop | Controlled as stated | 6 mins walk test, optional unstandardised stretching | Not stated | 2–3 | 2–4 | test dependent | Uninvolved then involved | Mean | Based on patient readiness | Not stated | Controlled landing | Not stated | Not stated | Yes | Reid |
| Fältström et al        | Star excursion balance, single hop, 5 jump test, side hop, drop jump, tuck jump | Controlled as stated | 5–10 mins run, 10 squats, toe raises, 1 min resting | Not stated | A few | 3 | Not stated | Uninvolved then involved | Best | 3 mins between tests, between trials not stated | Not stated | Not stated | Not stated | Yes | Gustavsson et al  |
| Golieier et al         | Drop jump, single hop, triple hop, side hop, isokinetics | Controlled as stated | 10 mins exercise bike | Not stated | 3 | Not stated | Not stated | Not stated | Not stated | 10 mins between trials; 3–5 mins between tests | Not stated | Not stated | Not stated | Not stated | None |
| Giannino et al         | Isokinetics, single hop and subjective movement test battery | Order not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Logerstedt et al  |
| Grindem et al          | Isokinetics, single hop, triple-hop, cross-over hop, timed hop | Controlled as stated | Not stated | Not stated | 1 | 2 | Not stated | Uninvolved then involved | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Jarvela et al  |
| Krych et al            | Isokinetics, vertical jump, single hop, triple-hop | Order not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Petschin et al  |
| Kyritsis et al         | Isokinetics, single hop, cross-over hop, timed hop, agility T-Test | Controlled for hops, order not stated for other tests | Not stated | Not stated | Not stated | 3 | Not stated | Not stated | Not stated | Not stated | Land without losing balance | Not stated | Not stated | Not stated | Noyes et al  |
| Logerstedt et al       | Isokinetics, single hop, cross-over hop, agility T-Test | Controlled as stated | Not stated | Not stated | 1–2 | 2 | Not stated | Uninvolved then involved | Mean | Not stated | Not stated | Landing was stable | Heel | Not stated | Noyes et al  |
| Luo et al              | Isokinetics, vertical jump, single hop, triple-hop | Order not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Potschin et al  |
| Nawareh et al          | Isometric quad strength, single hop, triple-hop, cross-over hop, timed hop* | Order not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Jarvela et al  |
| Sousa et al            | Isokinetics, vertical jump, single hop, triple-hop | Order not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Not stated | Jarvela et al  |
| Thomeé et al           | Vertical jump, single hop, side hop | Controlled as stated | 10 mins exercise bike | Not stated | 3–5 | 3 | Not stated | Uninvolved then involved | Best | 3 mins between side hops only | Not stated | Not stated | Not stated | Yes | Gustavsson et al  |
| Toole et al            | Isokinetics, single hop, triple-hop, cross-over hop, timed hop, IKDC | Controlled as stated | Not stated | Not stated | 1 | 2 | Randomised | Mean | Not stated | Not stated | Not stated | Not stated | Not stated | Noyes et al  |

Continued
Table 1 Continued

| Study                        | Tests included                                                                 | Testing order | Warm up activities | Familiarisation session | # Practice trials on each limb | Limb order | Best or mean score | Rest period | Hand placement | Landing requirements | Point of measurement | Checks for systematic bias | Studies cited for procedures |
|------------------------------|--------------------------------------------------------------------------------|---------------|-------------------|------------------------|--------------------------------|------------|-------------------|-------------|------------------|------------------------|--------------------------|-------------------------|-----------------------------|
| Welling et al.               | Drop jump, single hop, triple-hop, side hop, isokinetics                        | Controlled as stated | Not stated        | Not stated             | Not stated                     | Not stated | Not stated        | Not stated   | Not stated      | Not stated             | Not stated               | Not stated              | Kockum et al.              |
| Wellsandt et al.             | Isokinetic quad strength, single hop, triple-hop, cross-over hop, timed hop     | Order not stated | Not stated        | Not stated             | 2                              | 2          | Uninvolved then involved | Mean        | Not stated      | Not stated             | Not stated               | Not stated              | Munro and Harrington.     |
| Herbst et al.                | Functional assessments for decision making regarding return to sports following ACL reconstruction. Part II: clinical application of a new test battery. Knee Surg Sport Traumatol 2015;23:1283–1291 was included in the systematic review but the hop tests described in our review were not used in their study. Consequently, the details were not provided here. Procedural review applied to hop tests only. |
| Noyes et al.                 | Isokinetics                                                                     | Not stated    | Not stated        | Not stated             | Not stated                     | Not stated | Not stated        | Not stated   | Not stated      | Not stated             | Not stated               | Not stated              | Wellsandt et al.          |

Influence of preceding tests measuring different performance constructs

- **Table 1**
- **Limb testing order**
- **Quadriiceps muscle fatigue can affect ACL reconstruction**
- **Single leg hop tests**
- **Performing hop tests soon after or even before maximal strength testing**
- **Randomisation of test order will reduce the potential of order effects**
- **Table 1 Expanded**
- **Influence of preceding tests measuring different performance constructs**
| Study                  | Tests included                                                                 | Testing order          | Warm up activities                     | Familiarisation session | # Practice trials | # trials on each limb | Limb order | Best or mean score | Rest period | Hand placement | Landing requirements | Point of measurement | Checks for systematic bias |
|------------------------|--------------------------------------------------------------------------------|------------------------|----------------------------------------|-------------------------|------------------|----------------------|-------------|-------------------|-------------|-----------------|------------------------|------------------------|-----------------------------|
| Barber et al[^21]      | Isokinetics, single hop, timed hop, vertical jump, shuttle run                  | Order not stated       | Not stated                             | Not stated              | Not stated        | 2                    | Not stated  | Mean              | Not stated  | Not stated     | Not stated              | Not stated              | Not stated                 |
| Bolgla and Kekula[^22] | Single hop, triple-hop, cross-over hop, timed hop                              | Randomised order       | 3 mins cycling, static stretching & practice trials | Not stated              | 3                | 3                    | Dominant limb only | Mean              | Not stated  | Not stated     | Not stated              | Not stated              | Not stated                 |
| Fitzgerald et al[^23]  | Single hop, cross-over hop, timed hop, isometric quad strength                 | Controlled as stated   | Not stated                             | Not stated              | 2                | 2                    | Not stated  | Mean              | Not stated  | Not stated     | Not stated              | Not stated              | Not stated                 |
| Grindem et al[^4]      | Single hop, cross-over hop, triple-hop, timed hop                              | Controlled as stated   | Not stated                             | Not stated              | 1                | 2                    | Not stated  | Best              | Not stated  | Arm use was permitted | Not stated              | Not stated              | Not stated                 |
| Gustavsson et al[^5]   | Vertical jump, single hop, drop jump, square hop, side hop                     | Controlled as stated   | 5 mins cycling plus squats, toe raises and jumps | Yes                    | three to 5        | 3                    | Un-involved       | Best              | 3 mins between tests, between trials not stated | Hands behind back | 2 to 3 s | Not stated       | Not stated              | Not stated              |
| Hopper et al[^6]       | Timed hop, cross-over hop, stair hop, vertical hop                            | Randomised order       | 5 mins cycling and static stretching   | Not stated              | 1                | 3                    | Randomised        | Best              | Not stated  | Not stated     | Not stated              | Toe                    | Not stated                 |
| Jarvelä et al[^7]      | Isokinetics, single hop                                                        | Order not stated       | 5 mins cycling                         | Not stated              | Not stated        | 3                    | Not stated  | Mean              | Not stated  | Not stated     | Not stated              | Not stated              | Not stated                 |
| Kodum et al[^8]        | Vertical jump, single hop, side hop, single leg squat jump, knee power test    | Order not stated       | 10 mins cycling, toe raises, tuck jumps | Not stated              | three to 5        | 3                    | Right first and then alternating | Mean              | Not stated  | Not stated     | Not stated              | Controlled landing       | Not stated                 |
| Legerstedt et al[^9]   | Single hop, cross-over hop, triple-hop, timed hop                             | Order not stated       | Not stated                             | Not stated              | 2                | Un-involved          | Not stated  | Mean              | Not stated  | Not stated     | Landing was stable, on one limit, under control, no additional hops forward | Heel                    | Not stated                 |
| Munro and Herrington[^10] | Agility t-test, single hop, triple-hop, timed hop                           | Order not stated       | Not stated                             | Not stated              | 3                | Not stated           | Not stated  | Mean              | 30 s between trials and 2 mins between tests, landing held for 2 s | Arm use was permitted | Landing held for 2 s | Heel | Not stated       |
| Nawasreh et al[^11]    | Isometric quad strength, single hop, cross-over hop, triple-hop, timed hop    | Controlled as stated   | Not stated                             | Not stated              | 2                | 2                    | Un-involved  | Not stated | Not stated  | Not stated              | Maintained balance without touching the ground | Not stated                 |
| Noyes et al[^12]       | Isokinetics, single hop, timed hop, triple-hop, cross-over hop                | Order not stated       | Not stated                             | Not stated              | 2                | Not stated           | Not stated  | Mean              | Not stated  | Not stated     | Not stated              | Not stated              | Not stated                 |
| Petschnig et al[^13]   | Vertical jump, single hop, leg hop, triple-hop, isokinetics                   | Order not stated       | Not stated                             | Not stated              | 3                | Not stated           | Best (SICMI) and mean (hops) | 2 mins between tests, between trials not stated | Hands behind back | Not stated | Not stated       | Not stated              | Not stated              |
| Reid et al[^14]        | Single hop, timed hop, triple-hop, cross-over hop                            | Controlled as stated   | None other than practice trials        | Yes                    | 1                | 2                    | Un-involved  | Mean              | 30 s between trials and 2 mins between tests, landing held for 2 s | Arm use was permitted | Landing held for 2 s | Toe | Not stated       |

*Continued*
**Table 2** Continued

| Study                     | Tests included                          | Testing order | Warm up activities                          | Familiarisation session | # Practice trials | # trials on each limb | Limb order | Best or mean score | Rest period | Hand placement | Landing requirements | Point of measurement | Checks for systematic bias |
|---------------------------|----------------------------------------|---------------|---------------------------------------------|-------------------------|-------------------|-----------------------|------------|-------------------|-------------|----------------|----------------------|--------------------------|--------------------------|
| Ross et al<sup>25</sup>   | Single hop, triple-hop, cross-over hop | Randomised order | 5 mins cycling and static stretching | Not stated              | 3                 | One limb only - randomly selected | Best       | 30 s between trials | Arm use was permitted | Not stated | Not stated | Heal                | Not stated               | Green, aligned with current evidence; yellow, reported but not aligned with current evidence; red, not stated. |

Procedural review applied to hop tests only.

Green, aligned with current evidence; yellow, reported but not aligned with current evidence; red, not stated.

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**Rest period**

No consistent prescription of rest periods between rest intervals was applied across the studies included in the prior synthesis of the literature. Protocols varied from 30 s to 3 min, with many studies not stating how long participants rested. Previous recommendations have indicated work to rest ratios of at least 1:5 during plyometric exercise. Thus, counterbalancing limb order and 30 s rest between trials should provide adequate recovery and control for order and fatigue effects. Further, clinicians may wish to randomise the limb order for each hop performed during the test battery so that the uninvolved limb is not always first.

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**Reporting the best versus the mean score**

Many studies reported either the best trial (three studies) or mean score (four studies), while the remaining 10 studies did not state which data were used for reporting. There are no clear recommendations for the preferred method (best vs mean score) to report hop test performance, and this is often based on individual preference. For example, the best score may be more sensitive than the mean score to detect changes in performance, whereas the mean score may capture some of the inconsistencies between trials and the innate variability of asymmetry. Thus, it is possible that the mean score is preferable when measuring hop performance following ACL reconstruction.

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**Including task constraints to avoid movement compensation**

Absence of task constraints was a common task constraint in the studies included in the prior synthesis of the literature. Protocols varied from 30 s to 3 min, with many studies not stating how long participants rested. Previous recommendations have indicated work to rest ratios of at least 1:5 during plyometric exercise. Thus, counterbalancing limb order and 30 s rest between trials should provide adequate recovery and control for order and fatigue effects. Further, clinicians may wish to randomise the limb order for each hop performed during the test battery so that the uninvolved limb is not always first.

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**Review**

Agberg and Cronstrom examined single leg hop performance in participants with lower extremity injury under two conditions: (1) with arms free and (2) arms behind back. Hop tests are influenced by the use of arms, and participants may use them to aid their performance. In the studies cited (table 2), inconsistency was present with two studies requesting athletes place their hands behind the back, while four permitted arm use. Proponents of arm use suggest it is more functional and could lead to more natural or functional arm use. Proponents of arm use argue that hop testing itself is not a functional task. The inclusion of arm movement during power movements may improve performance, as the inclusion of arm movement can reduce the risk of injury. This was acknowledged by Noyes et al who stated the four hop tests used in the study were not sensitive enough to detect changes in performance, providing evidence of the importance of task constraints in hop testing. Therefore, when testing upper extremity function, it is advisable to consider the use of arms.

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distance was shorter on their involved versus uninvolved leg when the arms were placed behind their back, and nearly twice as many participants displayed ‘abnormal’ LSI (<90%). Agreement between the two conditions was also poor. These findings highlight the importance of limiting arm use, and that a stricter protocol should be adopted to avoid overestimating knee function.

**Familiarisation and practice trials**

Table 1 shows that no studies included a separate familiarisation session where athletes were provided with opportunities to practice the tests prior to data collection. There was also inconsistency in the number of practice trials, ranging from 3–5, 2–3, 1 and ‘a few’. This affects data interpretation, as systematic learning will occur between trials and test sessions in both healthy recreational athletes and patients following ACL reconstruction. Significant differences in hop performance have been reported between test sessions 1 and 2, but not days 2 and 3 in previous research. These findings indicate a learning effect, supporting the need for a separate familiarisation session prior to testing.

The number of practice trials provided should allow for adequate familiarisation. Munro and Herrington showed that learning affects were present in all four hop tests, where scores improved across trials. Single and triple-hop for distance test scores stabilised after three trials; whereas, cross-over hop scores stabilised after four trials. The timed hop stabilised after four trials in women and three in men. Therefore, practice trials should be provided to ensure a more reliable test outcome. Specifically, three practice trials are recommended for the single and triple-hop tests, with an additional trial included for the cross-over hop and timed hop.

**Warm up procedures**

A warm up is common practice in athletic endeavours. Table 1 shows 12 of the included studies did not state what/if any warm up procedures were applied, while five studies included either cycling, walking or running, with durations ranging from 5 to 10 min. Additional warm up activities included static stretching (one study) and dynamic exercises such as squats and toe raises (one study).

An active warm up can improve performance and test outcomes might vary with such a large variation in physiological readiness. It has been shown that practice trials alone are insufficient to elicit maximal strength and jumping performance, which are positively related to muscle temperature. It is also recommended to avoid static stretching immediately prior to testing as jump performance has been shown to reduce compared with dynamic warm up protocols.

Selecting the optimal warm up for athletes will depend on a variety of factors. We recommend a protocol consisting of general cardiovascular activity (eg, stationary cycling or jogging performed at approximately 60% of maximum perceived effort) for 5 min and task-specific activities (squats, lunges, practice jumps/ hops, etc) to increase muscle temperature and movement pattern sequencing.

**Other considerations**

Results might be affected by a range of other factors beyond the scope of this review including the use of a knee brace, shoe-surface interaction and the athlete’s state of readiness. These aspects should be considered in the study design and reported within the methods section. In addition, test administrators should be well trained and have a thorough understanding of all protocols and procedures. Examples applied to hop tests have been outlined below.

**Point of measurement**

Only one study reported this procedure, where measurement was to the heel. Of the cited studies, four measured the distance to the heel and two to the toe. Measuring the distance hopped to the toe does not account for the wide variation in foot length, which is irrespective of the horizontal hop distance achieved during the task. Differences in the point of measurement (heel vs toe) can also affect the LSI score. Practitioners are encouraged to measure the distance hopped from the start line to the participant’s heel. It is also prudent to report the absolute hop distances, and scores relative to leg length or body height to account for different anthropometric profiles, enabling comparisons of performance across different studies and athletes of the same sport/playing level.

**Reporting details of the test raters**

In cases where more than one person is conducting RTS testing, inter-rater reliability should be examined prior to data collection and the relevant statistics should be reported. To illustrate this point, consider the timed hop and the many inherent sources of error. The timer starts when the athlete’s heel leaves the ground at the beginning of the test and stops when the athlete completes the 6-m distance. Thus, clinicians encounter four potential sources of error (1) heel raise; (2) hit start; (3) visually observe the athlete complete the 6 m distance and (4) hit stop). Ensuring appropriate consistency between raters prior to testing is therefore essential to ensure accurate data collection.

**Check for systematic bias between trials**

Raters should check the scores of each individual trial during hop testing to control for systematic bias. An athlete’s score can progressively improve during the test (due to learning, increased confidence or warm up effects) or get worse (maybe from fatigue or wavering motivation). In the studies reviewed, only three stated that they checked for systematic bias. The most frequent protocols were ‘if subjects increased their hop performance in all three trials, additional hops were performed until no increase was seen,’ ‘if the test administrator felt that an even better result could be achieved, one or two additional hops were allowed’. An alternative is to use values greater than the minimal detectable change (MDC) to indicate the minimal amount of change required to determine if the observed performance increases or decreases between trials are ‘real’, accounting for the measurement error in the test. MDC values for the four hop tests have been reported in ACL patients (single hop: 8.09%; triple-hop: 10.02%; cross-over hop: 12.25%; timed hop: 12.96%; overall combination of hop tests: 7.05%). To be confident a ‘real’ systematic increase in performance has been observed, a general guideline of −10% may be applied, although this may increase for the cross-over and timed hop tests.

**Description of hop test procedures in research studies**

Several important methodological procedures were often not stated in the studies reviewed (Table 1). Even when citing the methods of previous research (Table 2), it was not possible to determine which procedures had been used. An example of this is the study of Kyriritis et al. Text from their manuscript states: ‘Single and triple hop distance tests were used’. The authors cited three manuscripts indicating further procedural
CONCLUSION

Even small alterations to hop test procedures can affect performance outcomes and we propose the following:

- Increased rigour of test methods and reporting standards to enhance the quality and reproducibility of future research that examines RTS outcomes following ACL reconstruction.
- A standardised approach is needed with specific protocol instructions to obtain accurate data, heighten test sensitivity, and avoid overestimating or underestimating knee function.
- The procedural review guidelines provided in tables 1 and 2 could form part of a reporting checklist for future research.

What is already known?

- There is a lack of consistency in the ability of anterior cruciate ligament (ACL) return to sport (RTS) tests to predict who has a successful clinical outcome following ACL rehabilitation and who has a serious reinjury.
- We and other clinicians suspect there is insufficient rigour in how the hop tests are administered during an RTS battery.

What are the new findings?

- Authors reporting procedures used in RTS testing frequently did not detail how they administered the hop tests.
- We found substantial variation in RTS test administration, scoring and interpretation in different studies that reported hop testing post-ACL reconstruction.
- Small alterations to hop test procedures can affect performance outcomes, making it difficult to compare the findings of the respective studies; a more standardised approach is required.
- There is a need for better quality in the reporting of hop test methods to allow practitioners and researchers to compare the findings of different studies. This is an important prerequisite to testing the utility (or not) of RTS batteries (that include the hop test).

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Contributors The lead author and one other author conceptualised the article contents. The lead author wrote the original draft of the manuscript. All authors contributed substantially to editing the manuscript in preparation to submit a final draft as well as subsequent revisions. All authors read and approved the final copy of the manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

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