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Measuring Agility in Tennis, Badminton, and Squash: A Systematic Review

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ABSTRACT

A systematic review in PubMed, Web of Science, SPORTDiscus, PsycINFO, and Google Scholar was conducted to provide a state-of-the-science overview of agility tests in the racquet sports tennis, badminton, and squash while evaluating their measurement properties. Twenty articles were included covering 28 agility tests. Results showed 10 sport-specific agility tests of which 5 were assessed on reliability and 6 on validity. Both the Badcamp and the badminton-specific speed ("agility") test were identified as suitable agility tests available for badminton. For tennis and squash, there were no sport-specific agility tests identified in the literature showing both reliable and valid results. Future research should focus on developing sport-specific agility tests for tennis and squash, including assessment of the reliability and validity of the tests.

INTRODUCTION

The main challenges in the racquet sports tennis, badminton, and squash are relatively similar. To be successful, all 3 sports require the athlete to place a missile (e.g., tennis ball, shuttle, or squash ball) with a racquet in an unreturnable position for the opponent. All racquet sports have an intermittent nature, where the rally duration varies from 3 to 10 seconds for tennis and badminton and around 18 seconds for squash with work-to-rest ratios between 1:2 and 1:5 depending on the sport and the surface (10,19,23,29). During the rallies, players need to perform rapid accelerations, decelerations, and changes of directions (CODs), also referred to as agility performance (19). These CODs must not only be performed in a linear and lateral direction but also multidirectional (18). Although there is a wide range due to the great variation in rally lengths, a tennis rally includes on average 2–4 CODs per rally (8,14). For badminton and squash, no research has been performed on the number of CODs, but because the rallies are relatively longer with 3–5 shots in tennis versus 6 for badminton and 13 for squash, the number of CODs is most likely higher in these racquet sports compared with tennis (11,23,29,32). With the evolution of the racquet sports, players have become fitter and stronger (9). In combination with the equipment allowing the players to hit harder, the games have become more demanding and players need to move faster on court in reaction to the missile and/or opponent. Therefore, agility has become more critical for success (23).

Although agility in sports often refers to the ability to change direction rapidly (26), task analyses of racquet sports directly on court reveal that the agility cannot be considered as a pure physical skill (13). Actions in racquet sports combine physical, cognitive, and technical skills while responding on the opponent's actions (48). A definition reflecting this multifactorial nature of agility would be a more ecologically valid approach. In line with this, a more recent definition of agility adds the cognitive component "reaction to a stimulus" (41). In many sports, athletes must accelerate, decelerate, and change their direction of movements in response to a stimulus such as a missile and/or the movement of the opponent. To successfully return this missile, they must not only perform rapid sport-specific movements. Instead, they first need to react correctly to the stimulus presented. Therefore, the definition "a rapid whole-body movement with

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change of velocity or direction in response to a stimulus" (41,49) will be a better representation of the agility performance faced in rally situations in racquet sports.

Studies have shown that agility is positively related to on-court performance (13,36,42). Therefore, agility tests are used to assess agility to monitor performance and/or progress of players. Test results are, among others, used to build up an athlete's profile and identify training targets defining the content of training. Many agility tests have been developed within the field of sports (e.g., Illinois, 505 agility, and T test; 27). As agility tests should be sport specific (i.e., ecological valid; 35,50), it is unclear which tests are most suitable in practice for tennis, badminton, and squash. As such, this review will provide a state-of-the-science overview of agility tests for racquet sports (i.e., tennis, badminton, and squash) while including an evaluation of the measurement properties included in the articles and assessing the sport specificity. The overview will help trainers and coaches to identify a suitable agility test and will provide background for a design of a newly developed agility test if necessary.

METHODS

The Preferred Reporting Items for Systematic reviews and Meta-Analysis statement (PRISMA) was used for reporting where applicable (30).

LITERATURE SEARCH

For this review, a literature search was performed using the electronic databases PubMed, Web of Science, SPORTDiscus, PsycINFO, and Google Scholar to identify articles assessing one or more agility tests. All articles until January 2020 were screened for inclusion. The keywords used represented agility tests in the racquet sports tennis, badminton, and squash: "Agility test*" OR "COD test*" AND "Racquet Sport*" OR "racket sport*" OR "badminton*" OR "tennis" OR "squash*". Articles were first screened on title and abstract and selected for further screening if test-retest reliability and/or a form of validity were evaluated for one or more agility tests in one of the chosen racquet sports. Because it was intended to provide a comprehensive overview of the available test, COD tests were also included according to the earlier definition of agility. Articles were then screened for duplicates and full-text availability. Inclusion criteria for full-text screening were (a) agility test(s) including at least COD movements, (b) test-retest reliability or validity was measured or mentioned, and (c) participants were involved in tennis, badminton, or squash. The participants' age or level was not considered by the articles' inclusion, whereas the primary purpose was to give an overview of all the available agility tests. Studies were excluded if (a) articles were not available in English, German, or Dutch, and/or (b) participants were nonracquet sport athletes. Additional screening was performed by manual reference screening of the included articles according to the same inclusion and exclusion criteria. A second investigator also conducted the whole research process, and discrepancies were discussed until consensus was reached.

QUALITY ASSESSMENT

The critical review form for quantitative studies (21) was used to assess the methodological quality of the included articles. This quality assessment consists of 16 items regarding study purpose (item 1), background literature (item 2), study design (item 3), included sample (item 4–5), informed consent (item 6), outcome measures (item 7–8), intervention (item 9), results (item 10–13), and conclusions and implications (item 14–16). The complete list with full questions is presented below Table 3. Scores consisted of 1 (meets criteria), 0 (does not meet the criteria fully), ? (indeterminate rating), or NA (not applicable) if the item was not appropriate to the study. The authors individually scored the articles according to the items, and differences were discussed until consensus was reached. Items 7 and 8 were rated as "?" for all articles before quality assessment because both reliability and validity outcomes were not assessed by the authors of this review. The reliability and validity assessment of the tests were conducted by the authors of the included articles. The aim of the current review was only to give an overview of the reliability and validity scores on the agility tests. Moreover, the nature of the articles included in this review led to the assignment of NA to items 9 and 12 for all included articles because no intervention was present in the articles and clinical importance is also not applicable. A total score was calculated to compare the articles based on their methodological quality. This score was calculated as a percentage, where the sum score was divided by the total amount of relevant questions (excluding NA). Articles with a total score ≤50% were labeled as low, between 51 and 75% as moderate, and ≥75% as excellent methodological quality. The procedure for quality assessment of the articles was based on previous reviews (5,43).

SPORT SPECIFICITY

Before evaluation of the measurement properties of the agility test (i.e., reliability and validity), the articles were screened on sport specificity and divided in sport-specific tests (SSTs), medium SSTs (MSSTs), and non-SSTs (NSSTs). Every article was scored on several characteristics of the test regarding sport specificity of the test (51): (a) inclusion of cognitive component, (b) use of racquet, (c) distances in the test, (d) number of CODs, (e) angles of the CODs (multidirectional nature), (f) task representativeness, and (g) on the court. Every characteristic of the test was scored with 0–2 points (Table 1). Because criteria a and b were considered as most important, the total score was calculated as follows: Total score = 2a + 2b + c + d + e + f + g. This led to a maximal score of 18. A test with a total score of >9 was indicated as a SST, 7–9 as an MSST, and a score of ≤6 as an NSST. All groups were evaluated for test-retest reliability, concurrent validity, and discriminative validity.

TEST-RETEST RELIABILITY

After the assignment of SSTs, MSSTs, or NSSTs, the articles were evaluated on reliability. To evaluate the reliability, test-retest reliability measures were extracted for the agility tests as described in the articles. The most frequently used

Table 1
Characteristics for evaluation of the sport specificity of the agility tests

Characteristic	Points	Requirement	Comment
(a) Inclusion of cognitive component	0 1 2	No cognitive component Inclusion of reactive element Sport-specific reactive element	Included in the definition of agility
(b) Use of racquet	0 1 2	No racquet Holding racquet Hitting movements	All CODs in the rallies also include a racquet
(c) Distances in the test	0 1 2	No sport-specific distances Some sport-specific distances All distances sport specific	Tennis: ±3 m[a] Badminton: <3 m[b] Squash: <3 m[b]
(d) Number of CODs	0 1 2	Large difference with sport-specific situation Small difference with sport-specific situation Mimic rally situation	Tennis: 2–4 CODs[c] Badminton: >4 CODs[d] Squash: >8 CODs[e]
(e) Angles of the CODs[f]	0 1 2	Only one angle <3 different angles >3 different angles	Multidirectional nature of racquet sports
(f) Task representativeness	0 1 2	Number of repetitions Only split times Total completion time	Split times useful in combination with total time
(g) On the court	0 1 2	Off-court measurements — On-court measurements	Either on court or not

[a](8).

[b]No research, but smaller sizes of the court compared with tennis.

[c](8,14).

[d]No research, but longer rally duration than tennis.

[e]No research, mean rally duration twice as long as badminton.

[f]The angles are indicated using the direction of movement as reference point, where recovery toward the starting position was seen as 180° COD. The 90° COD from start position ("ready position") was included while this is more tennis specific than the linear start position.

value to assess test-retest reliability is the intraclass correlation coefficient (ICC). An ICC of <0.50 was indicated as poor, between 0.50 and 0.75 as moderate, between 0.75 and 0.90 as good, and >0.90 as excellent (17). Usually, ICC is reported in 95% confidence interval (CI). Moreover, other values for test-retest reliability reported in the articles were coefficient of variation (CV) and correlation coefficients (r). The cut-off values for CVs are difficult to define as they range from 7.5 to 20% in the literature. The most common cut-off values used are 11 and 15% (40). For the correlation coefficient, in general an r of <0.50 was indicated as poor, between 0.50 and 0.70 as moderate, between 0.70 and 0.90 good, and >0.90 as excellent relation (31).

CONCURRENT VALIDITY

In assessing the concurrent validity, the newly developed test outcomes were compared with a validated agility test, where they should show similar results and/or checked for association with performance. Concurrent validity was assessed using correlation coefficients and/or *p* values. As mentioned in the reliability, for correlations in general an r of <0.50 was indicated as poor, between 0.50 and 0.70 as moderate, between 0.70 and 0.90 good, and >0.90 as excellent relation (31). For comparison of a newly developed agility test with a validated test, a correlation of 0.70–0.80 is preferred. A recognized agility test has been widely tested in the literature and you can therefore assume that the test contains information about the agility

Table 2
Study characteristics of the included studies with their agility tests

Study	Population					Agility test	
	N	Sex	Age (y)[a]	Sport	Performance level		
Sekulic et al. (2017)	33	13M 20F	18.3 ± 1.1	Tennis	Near-expert	20-Yard test	180° COD test 5-10-5 yards
Eriksson et al. (2015)	34	21M 13F	14 ± 1.6	Tennis	Nonexpert	20-Yard test	180° COD test 5-10-5 yards
Huggins et al. (2017)	10	—	15.1 ± 2.6	Tennis	Semiexpert	Pro-agility test	180º COD test 5-10-5 yards
Fernandez-Fernandez et al. (2016)	60	M	12.5 ± 0.3	Tennis	Nonexpert	Modified 505 agility test	180° COD 5-m sprint
Sekulic et al. (2017)	33	13M 20F	18.3 ± 1.1	Tennis	Near-expert	Illinois test	135° COD test Sprint (10 m) and slalom (3.3 m)
Sekulic et al. (2017)	33	13M 20F	18.3 ± 1.1	Tennis	Near-expert	T test	90 + 180° COD test Sprint FW + BW (9.1 m) and shuttle (4.6 m)
Huggins et al. (2017)	10	—	15.1 ± 2.6	Tennis	Semiexpert	Modified T test	90 + 180° COD test Sprint FW + BW (2.5 m) and shuttle (2.5/5 m) Touching cones
Huggins et al. (2017)	10	—	15.1 ± 2.6	Tennis	Semiexpert	Spider drill	135 + 180° COD test 5 points on tennis court (3/4,1/5.5 m)
Barber-Westin et al. (2010)	15	5M 10F	13.0 ± 1.5	Tennis	Nonexpert	SBSAT	90 + 180° COD 3 sprints in service box of tennis court (2/4.1 m)
Barber-Westin et al. (2010)	15	5M 10F	13.0 ± 1.5	Tennis	Nonexpert	Suicide test	180° COD Shuttle between lines on tennis court + racquet
Leone et al. (2006)	38	24M 14F	12.6 ± 2.5 13.1 ± 2.5	Tennis	Near-expert	TDT TDTB	3 CODs of 90° (4.1 m), 180° (8.2 m), and 45° (5.8 m) on tennis court (+hitting balls in TDTB)
Leone et al. (2006)	38	24M 14F	12.6 ± 2.5 13.1 ± 2.5	Tennis	Near-expert	SSR SSL	90° COD 4-m sprint
Barber-Westin et al. (2010)	15	5M 10F	13.0 ± 1.5	Tennis	Nonexpert	BSA-FH BSA-BH	90 + 180° CODs Shuttle on tennis court to corner (5 m) + hitting ball

Table 2
(continued)

Ulbricht et al. (2016)	1,052	634M 418F	13.14 ± 1.4 13.06 ± 1.3	Tennis	Semiexpert Near-expert	TSS forehand TSS backhand	90 + 180° CODs Shuttle to FH/BH on stimulus + hitting ball pendulum
Ward (2011)	14	M	20 ± 1 19.5 ± 1.5	Tennis	Semiexpert Nonexpert	PRAT	180° COD Single shuttle (2.5 m) Reaction to stimulus
Zemková and Hamar (2014)	17 15	M/F	20.7 ± 3.2 21.8 ± 2.0	Tennis Badminton	Nonexpert	RAT	45 + 135° CODs 4 mats (0.8-m square) Touch with right/left foot on stimulus
Güçlüöver et al. (2012)	16 15	M M	16.8 ± 1.5 16.3 ± 0.8	Badminton	Near-expert Nonexpert	505 agility test	180° COD 5-m sprint
Loureiro and Freitas (2016)	43	29M 14F	20.97 ± 4.2	Badminton	Expert Near-expert	Badcamp vs SRAT	45/90/180° CODs 4 corners (3.5 m) + 2 sideways (2.1 m) Reaction to stimulus Touching cones
Loureiro et al. (2017)	16 16 16 16	8M 8F 8M 8F 8M 8F 8M 8F	16.07 ± 0.8 15.7 ± 0.6 15.7 ± 0.5 15.6 ± 0.6	Badminton Team sports Tennis Track and field	Nonexpert	Badcamp vs SRAT	45/90/180° CODs 4 corners (3.5 m) + 2 sideways (2.1 m) Reaction to stimulus Touching cones
Walklate et al. (2009)	12	6M 6F	19 ± 1.8	Badminton	Expert	RASA	135° COD 20 s agility sprints diagonal (1.9 m) and forward (1.4 m) 4 corners of badminton court
Phomsoupha et al. (2018)	9 9 9 9 6	—	24.6 ± 5.2 25.7 ± 5.1 26.4 ± 7.0 19.6 ± 2.3 23.7 ± 7.3	Badminton	Expert Near-expert Semiexpert Nonexpert Nonathletes	MRSAB	45 + 180° CODs 4 corners of badminton court (4.9 m) Touching light with racquet
Paterson (2016)	15	15M 3F	28.8 ± 10.7 19.0 ± 3.6	Badminton	Nonexpert	MDCT	45/90/135/180° CODs 4 corners (4.7 + 3.3 m) +2 sideways (2.6m) + Forward/ backward (4/2.4 m) Mock shots
Ooi et al. (2009)	24	M	24.6 ± 3.7 20.5 ± 0.7	Badminton	Expert Near-expert	Sideways agility test	90 + 180° CODs Shuttle (2.6 m) + hit

(continued)

Table 2 (continued)

Ooi et al. (2009)	24	M	24.6 ± 3.7 20.5 ± 0.7	Badminton	Expert Near-expert	Four-corner agility test	45 + 180° CODs 4 corners (3.3 m) Hit in corner
Madsen et al. (2015)	20 21 20	M	24.6 ± 4.5 24.9 ± 4.8 21.7 ± 5.1	Badminton	Near-expert Semiexpert Nonathletes	BST	45/135/180° CODs 4 corners of badminton field (4.9 m) Hitting sensors
Hughes et al. (2016)	27 74	11M 16F 48M 26F	16.5 ± 0.2 15.5 ± 0.2 16.5 ± 0.2 15.6 ± 0.2	Badminton	Expert Nonexpert	BSST	45/135/180 CODs 4 points (4.9 + 2.6 m) On badminton field Touching/mock shots/hitting
Kusuma et al. (2015)	20	—	17–21	Badminton	Near-expert Nonexpert	BAT	45/90/135/180° CODs 4 corners (4.7 + 3.3 m) +2 sideways (2.6 m) + 2 forward/backward (4/2 m)
Wilkinson et al. (2009)	20	M	23 ± 4	Squash Football/rugby	Semiexpert Nonexpert	SCODS vs Illinois test	45/135/180° CODs Shuttle on squash court around 8 cones, touching 6 cones

[a]Values in mean ± SD, except for Kusuma et al. (years).

BAT = badminton agility test; BSA-BH = baseline speed and agility backhand test; BSA-FH = baseline speed and agility forehand test; BSST = badminton-specific speed ("agility") test; BST = badminton-specific test; MDCT = multidirectional cyclic COD test; MRSAB = multiple repeated sprint ability; PRAT = planned and reactive agility test; RASA = repeated agility sprint ability; RAT = reactive agility test; SBSAT = service box speed and agility test; SCODS = squash-specific test of change of direction speed; SRAT = shuttle run agility test; SSL = short sprinting to the left; SSR = short sprinting to the right; TDT = tennis drill test; TDTB = tennis drill test while hitting balls; TSS = tennis-specific sprint test.

performance. Therefore, you would like the new agility test to not only correlate with the recognized agility test but also contain extra information after the inclusion of the sport-specific element.

DISCRIMINATIVE VALIDITY

Third in evaluating the measurement properties is discriminative validity. Articles that assessed discriminative validity evaluated the ability of the test to discriminate between sports and/or between performance levels. To assess the discriminative validity, an approach with 5 different levels of performance was used to be able to compare between articles: (a) nonathletes: no competition or training experience, (b) nonexpert: amateur level, (c) semiexpert: semiprofessional level, (d) near-expert: second highest national or international level of their age group, and (e) expert: highest national or international ranking of their age group. The performance levels were assigned to the articles based on the participants' characteristics described in the Methods sections.

RESULTS

LITERATURE SEARCH

A total of 112 studies were identified after screening the electronic databases and references, of which 12 studies were duplicates. Title and abstract screening resulted in the exclusion of 64 articles. The remaining 36 articles were screened for full text resulting in the exclusion of 16 articles. The main reason for exclusion was that participants were not involved in racquet sports (n = 10). Other reasons were full text not available in English, German, or Dutch (n = 3) and no agility testing (n = 3). Finally, 20 studies were included in this review testing reliability and/or validity in the racquet sports badminton (n = 11), tennis (n = 10), and squash (n = 1) (Table 2 and Figure 1). A total of 28 agility tests were evaluated in the included articles, of which 15 were for tennis, 11 were for badminton, one was for both tennis and badminton players, and one was for squash. Except for one, all the studies included both male and female participants in their study population. Most of the study population

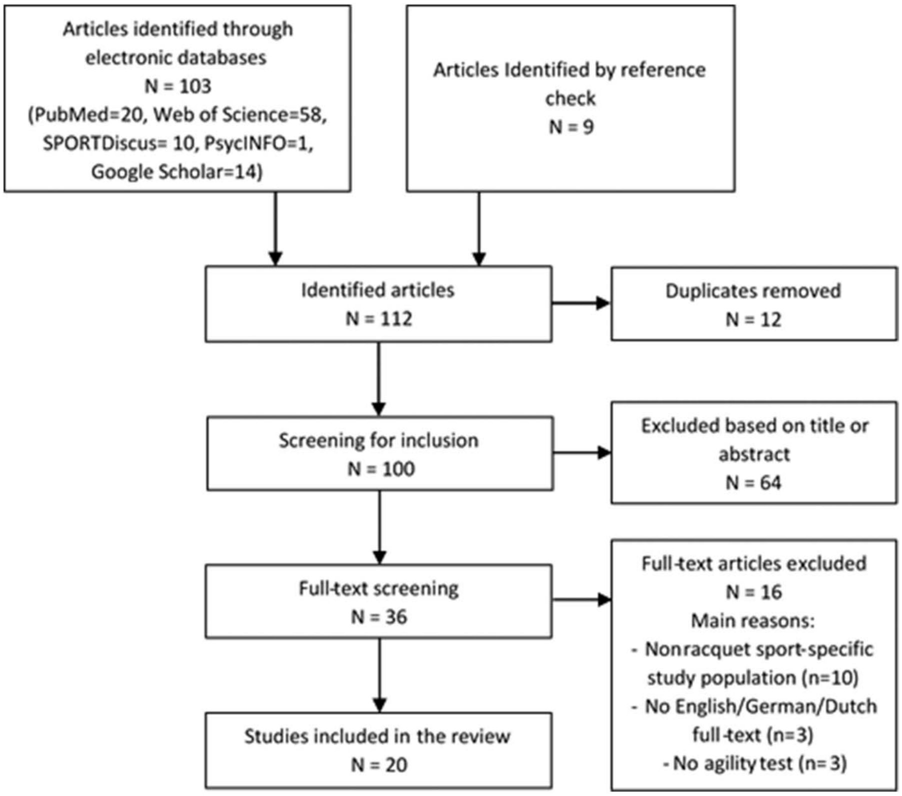

Figure 1. Flowchart of the literature search.

consisted of young adults with some studies consisting of prepubertal participants (2,4,7,22,44) and a mean age of 28.8 years for the oldest study group (34).

QUALITY ASSESSMENT

The quality assessment with the critical review form for quantitative studies (21) resulted in one study with a total score ≤50%, 14 studies with a total score between 51 and 75%, and 5 studies with a total score ≥75%, labeled as low, moderate, and high methodological quality, respectively. The maximal sum score was 14 instead of 16 in calculating the total score (%), whereas items 9 and 12 were rated as NA for all articles. These questions were not included in Table 3 because they were not important for the total score. For further details on the quality assessment refer to Table 3.

SPORT SPECIFICITY

Table 4 shows the scoring of the sport specificity for each agility test. Scoring of the sport specificity according to the 7 characteristics resulted in 10 SSTs of which 2 tests measured the agility performance in tennis players (TSS-FH/TSS-BH and TDTB), 7 in badminton players (BST, BSST, MDCT, Badcamp, sideways agility test, four-corner agility test, and BAT), and one in squash players (SCODS). A total of 13 agility tests were assigned as MSSTs, with most including a study population of tennis players (n = 12). The other 5 agility tests were assigned as NSSTs.

TEST-RETEST RELIABILITY

A total of 20 agility tests were assessed on test-retest reliability, of which 14 were in tennis, 6 were in badminton, and none in squash (Table 5). For tennis, only 3 of the 12 agility tests were rated as SSTs: the TSS-FH (8,44), TSS-BH (8,44), and TDTB (22). For the TSS-FH and TSS-BH, no procedure and only one value for 2 tests was provided including no confidence interval. The retest of the tennis drill with hitting balls (TDTB) showed a correlation of 0.75 with the first trial, where the MSST version without hitting balls (TDT) showed a correlation of 0.83 with the first trial. The inclusion of hitting balls in the drill was a better representation of the normal rally situation, but also affected the reliability of the test. Most of the MSSTs in tennis, which were recognized agility tests in the literature, showed, in general, good to excellent reproducibility (T test: CV: 4–6%, 39; modified T test: ICC 95% CI: 0.87–0.99, 15; spider drill: ICC 95% CI: 0.82–0.99, 15; 20-yard test: CV: 3–5%, ICC 95% CI: 0.91–0.98, 4, 39). Similar results were found for the NSSTs in tennis (modified 505 agility test: ICC 95% CI: 0.90–0.94, 7). For badminton, 4 of the 6 agility tests were SSTs. The test-retest reliability was good to excellent for the BST, BSST, and Badcamp, where the MDCT showed moderate reliability. The MRSAB (MSST, 37) showed

Table 3
Quality assessment according to critical review form—quantitative studies (21)

Author (y)	1	2	3	4	5	6	7	8	10	11	13	14	15	16	Score (%)
Barber-Westin et al. (2010)	1	1	1	1	0	1	?	?	1	1	1	1	1	1	79
Eriksson et al. (2015)	1	1	1	1	0	1	?	?	1	1	1	1	1	1	79
Fernandez-Fernandez et al. (2016)	1	1	1	1	0	1	?	?	1	1	1	1	0	1	71
Güçlüöver et al. (2012)	1	1	1	1	0	1	?	?	1	1	1	1	0	0	64
Huggins et al. (2017)	1	1	1	1	0	1	?	?	0	1	1	1	1	1	71
Hughes et al. (2016)	1	1	1	1	0	0	?	?	1	1	1	1	1	0	64
Kusuma et al. (2015)	1	1	1	0	0	1	?	?	1	1	1	1	1	1	71
Leone et al. (2006)	0	0	1	1	0	1	?	?	1	1	1	1	1	1	64
Loureiro and Freitas (2016)	1	1	1	1	0	1	?	?	1	1	1	1	1	0	71
Loureiro et al. (2017)	1	1	1	1	0	1	?	?	1	1	1	1	1	1	79
Madsen et al. (2015)	1	1	1	1	0	1	?	?	1	1	1	1	1	0	71
Ooi et al. (2009)	1	0	1	1	0	1	?	?	1	1	1	1	1	0	64
Paterson (2016)	1	1	1	0	0	1	?	?	0	1	0	1	1	1	57
Phomsoupha et al. (2018)	1	1	1	1	0	1	?	?	1	1	1	1	1	1	79
Sekulic et al. (2017)	1	1	1	1	0	0	?	?	1	1	1	1	1	1	71
Ulbricht (2016)	1	1	1	1	0	1	?	?	1	1	0	1	1	0	71
Walklate et al. (2009)	1	0	1	0	0	1	?	?	1	1	1	1	1	0	57
Ward (2011)	1	1	1	1	0	1	?	?	1	1	1	1	1	1	79
Wilkinson et al. (2009)	1	1	1	1	0	0	?	?	1	1	1	0	1	0	57
Zemková and Hamar (2014)	1	0	1	1	1	0	?	?	1	1	0	0	1	0	50

? = indeterminate rating; 1 = was the study purpose stated clearly?; 2 = was relevant background literature reviewed?; 3 = was the design appropriate for the research question?; 4 = was the sample described in detail?; 5 = was sample size justified?; 6 = was informed consent obtained? (if not described, assume no); 7 = were the outcome measures reliable? (if not described, assume no); 8 = were the outcome measures valid? (if not described, assume no); 9 = was intervention described in detail?; 10 = were results reported in terms of statistical significance?; 11 = were the analysis methods appropriate?; 12 = was clinical importance reported?; 13 = were any dropouts reported?; 14 = were conclusions appropriate given the study methods?; 15 = are there any implications for clinical practice given the results of the study?; and 16 = were limitations of the study acknowledged and described by the authors?.

moderate reliability and the RASA (NSST, 45) good reliability.

CONCURRENT VALIDITY

Concurrent validity was assessed by 2 SSTs, one for badminton comparing Badcamp with the recognized SRAT (24) and one for squash to assess the association of the SCODS with rank (Table 5; (47)). The Badcamp shared a common variance of 69%, which means that the Badcamp is not fully explained by the SRAT and the Badcamp measures an extra component. For the SCODS, a significant correlation was found with rank. The difference in rank disappeared when the participants performed the Illinois test. No MSSTs and NSSTs assessed the concurrent validity.

DISCRIMINATIVE VALIDITY

A total of 11 agility tests were assessed on discriminative validity (12,16,24,25,33,37,44,46,47,51), evaluating the ability to discriminate between sports and/or performance levels of which 7 were SSTs (Table 5; (16,24,25,33,44,47)). Two of those agility tests were tennis agility tests: the TSS-FH and TSS-BH (44); only the males in the TSS-BH group found better performance for the more expert levels. The PRAT (MSST, (46)) was not able to discriminate between performance levels. Four SSTs assessed the discriminative ability in badminton (BSST, (16); Badcamp, (24,25); four-corner agility test, (33); and sideways agility test, (33)). Both the BSST and the Badcamp showed superior performance for more expert levels, where the Badcamp also showed superior performance for badminton players compared with other sports in

Table 4
Sport specificity of the agility tests of the included studies

Agility test	a	b	c	d	e	f	g	Total[a]
BST (28)	2	2	1	0	2	2	2	15
BSST (16)	0	2	1	2	2	2	2	14
TSS-FH/TSS-BH (44)	1	2	2	1	1	2	2	14
MDCT (34)	0	2	2	2	2	1	2	13
TDTB (22)	0	2	1	2	2	2	2	13
Badcamp (24,25)	2	0	2	2	2	2	0	12
Sideways agility test (33)	0	2	2	1	1	2	2	12
Four-corner agility test (33)	0	2	2	0	1	2	2	11
BAT (20)	1	0	2	0	2	2	2	10
SCODS (47)	0	0	2	2	2	2	2	10
Illinois test (39)	0	1	1	2	0	2	2	9
MRSAB (37)	0	1	0	2	1	2	2	9
SBSAT (2)	0	1	2	2	1	0	2	9
Suicide test (2)	0	1	1	2	0	2	2	9
TDT (22)	0	0	1	2	2	2	2	9
T test (39)	0	1	0	2	1	2	2	9
20-Yard test (39)	0	1	1	1	0	2	2	8
BSA-FH/BSA-BH (2)	0	2	0	1	1	0	2	8
Modified T test (15)	0	0	1	2	1	2	2	8
Spider drill (15)	0	0	1	2	1	2	2	8
20-Yard test (4)	0	0	1	2	0	2	2	7
PRAT (46)	1	0	2	1	0	2	0	7
Pro-agility test (15)	0	0	1	2	0	2	2	7
SSR/SSL (22)	0	0	1	1	0	2	2	6
RAT (51)	1	0	0	0	1	2	0	5
505 agility test (12)	0	0	1	1	0	2	0	3
Modified 505 agility test (7)	0	0	0	1	0	2	0	3
RASA (45)	0	0	0	1	0	0	2	3

a = inclusion of cognitive component; b = use of racquet, c = distances of the test, d = number of CODs, e = angles of the CODs, f = task representativeness, g = on the court.

[a]Total score = 2a + 2b + c + d + e + f + g; score >9 = SST; score 7–9 = MSST; score ≤6 = NSST.

the SRAT (25). The sideways agility test and four-corner agility test showed no significant difference between performance levels. The MRSAB (MSST, (37)) and 505 agility test (NSST, (12)) showed better performance for the more expert levels. For squash, there was only one SST: the SCODs (47), where squash players showed superior performance compared with other sports and the differences were not present in the performance on the Illinois test.

DISCUSSION

Agility, defined as "a rapid whole-body movement with change of velocity or direction in response to a stimulus," is crucial for racquet sports such as tennis, badminton, and squash because the players need to be able to perform rapid changes of directions in response to a missile and/or the movement of the opponent. Players showing superior agility performance are faster on the court and have therefore more time to prepare their shot which makes it hard to score a point against such opponents. To compare the performance between players and identify training targets, agility performance is monitored by standardized tests. The agility tests should show reliable results to be able to assign a difference on the test to a change in performance of the player. Moreover, it is important that the tests are valid and measure the component you aim to assess. Therefore, sport specificity is an important factor because the agility test should mimic the agility requirements during the game, as these are the characteristics they are trained on. To identify if there are such agility tests available for tennis, badminton, and squash, the aim of this review was to provide a state-of-the-science overview of the agility tests present in the literature for these racquet sports evaluating the measurement properties included in the articles and assessing the sport specificity.

Agility performance tests should mimic the sport's nature to represent the match situation and correctly capture the players' performance (35,50). It is, therefore, essential to test the sport specificity of the agility tests. In this review, the sport specificity of the agility tests was scored by 7 characteristics. A total of 10 agility tests were indicated as SSTs (16,20,22,24,25,28,33,34,44,47), of which 3 tests measured the agility

Table 5
Test-retest reliability, concurrent, and discriminative validity for the SSTs, MSSTs, and NSSTs

Study	Agility test	Sport specificity		Test-retest reliability	Concurrent validity	Discriminative validity
		Score[a]		Score		
Madsen et al. (2015)	BST	15	SST	CV = 1.7% CV = 2.6% CV = 2.5%		
Hughes et al. (2016)	BSST	14		ICC: 0.97–0.99		Experts faster than nonexperts ($p < 0.05$)
Ulbricht et al. (2016)	TSS-FH TSS-BH	14		ICC = 0.94[b] ICC = 0.94_b		NS between regional and national U12 National male player better in TSS-BH ($p \leq 0.05$)
Paterson (2016)	MDCT	13		ICC: 0.57–0.98		
Leone et al. (2006)	TDTB	13		$r = 0.75$		
Loureiro and Freitas (2016)	Badcamp vs SRAT	12		ICC = 0.82–0.97 (95% CI)	Correlation between Badcamp and SRAT ($r = 0.69$)	Experts better ($p < 0.01$)
Loureiro et al. (2017)	Badcamp vs SRAT	12				Badminton superior performance ($p < 0.001$) No difference between sports in SRAT
Ooi et al. (2009)	Sideways agility test	12				Near-expert faster in sideways (NS)
Ooi et al. (2009)	Four-corner agility test	11				Expert faster in four corner (NS)
Kusuma et al. (2015)	BAT	10				
Wilkinson et al. (2009)	SCODS vs Illinois test	10			SCODS with rank ($p < 0.01$)	Squash best in SCODS ($p < 0.001$) No difference between sports Illinois

Table 5
(continued)

Sekulic et al. (2017)	Illinois test	9	MSST	CV: 4–8%		
Phomsoupha et al. (2018)	MRSAB	9		ICC: 0.53–0.95		Expert best in MRSAB for best and mean time ($p < 0.001$)
Barber-Westin et al. (2010)	SBSAT	9		ICC = 0.85		
Barber-Westin et al. (2010)	Suicide test	9				
Leone et al. (2006)	TDT	9		$r = 0.83$		
Sekulic et al. (2017)	T test	9		CV: 4–6%		
Sekulic et al. (2017)	20-Yard test	8		CV: 3–5%		
Barber-Westin et al. (2010)	BSA-FH BSA-BH	8				
Huggins et al. (2017)	Modified T test	8		ICC: 0.87–0.99 (95% CI)		
Huggins et al. (2017)	Spider drill	8		ICC: 0.82–0.99 (95% CI)		
Eriksson et al. (2015)	20-Yard test	7		ICC: 0.91–0.98 (95% CI)		
Ward (2011)	PRAT	7				Non-expert best in planned (NS)
Huggins et al. (2017)	Pro-agility test	7		ICC: 0.11–0.90 (95% CI)		
Leone et al. (2006)	SSR SSL	6	NSST	$r = 0.79$ $r = 0.70$		
Zemková and Hamar (2014)	RAT	5				Badminton faster than tennis ($p < 0.05$)
Güçlüöver et al. (2012)	505 agility test	3				Near-expert faster ($p < 0.01$)
Fernandez-Fernandez et al. (2016)	Modified 505 agility test	3		ICC: 0.90–0.94 (95% CI)		
Walklate et al. (2009)	RASA	3		CV: 0.6–2% (95% CI) #reference points		

[a]Score >9 = SST; score 7–9 = MSST; score ≤6 = NSST.

[b]The ICC value was retrieved from Fernandez-Fernandez et al. (2014).

CV = coefficient of variation; ICC = intraclass correlation coefficient; r = correlation coefficient; NS = non-significant.

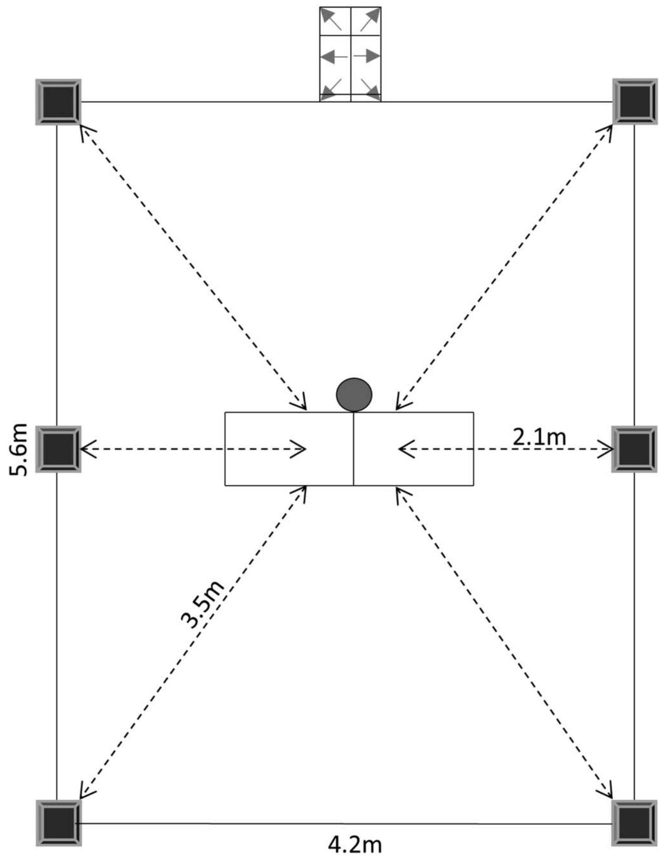

Figure 2. Test setup Badcamp. In the middle, the starting position with one foot in each square and the switch support to initiate the direction on the panel (top of the figure). The figure is created based on the articles of Loureiro and Freitas and Loureiro et al. (24,25).

performance in tennis players (TSS-FH, (44); TSS-BH, (44); and TDTB, (22)), 7 in badminton players (BST, (28); BSST, (16); MDCT, (34); Badcamp, (24,25); sideways agility test, 33; four-corner agility test, (33); and BAT, (20)), and one in squash players (SCODS, (47)) of which all showed moderate to excellent methodological quality. This means that although there is a lot of literature available for tennis on agility, sport-specific agility research is lacking. For squash on the other hand, agility literature in general is lacking. Moreover, where almost all the SSTs included a racquet in combination with hitting sensor/cones, only 4 agility tests used a stimulus of which 2 were sport specific (BST, (28); and Badcamp, (24,25)). Because players must not only perform rapid sport-specific movements during matches, rather they first need to react correctly to the sport-specific stimulus presented. It is expected that agility tests that include a sport-specific stimulus would be a better representation of the agility demands during the game.

The test-retest reliability showed comparable results over all 3 sport-specificity levels. As the SSTs, agility tests included in the moderate and non–sport-specific test group (MSST and NSST) showed moderate to good reliability scores. Moreover, for the tennis drill test, while hitting balls (TDTB, (22); SST) the reliability was even less than the tennis drill test (TDT, (22); MSST) without the inclusion of hitting balls. The inclusion of hitting balls adds degrees of freedom, whereas the test results also depend on the timing and placement of ball supply and will be less standardized (1). Although this situation is more sport specific for the agility demands in tennis, it will influence the test-retest reliability negatively.

Two forms of validity were assessed in the articles included in this study: concurrent and discriminative validity. Concurrent validity was only assessed on 2 agility tests, both scored as SSTs. The Badcamp (badminton; (24,25)) and the SCODS (squash; (47)) showed positive results regarding the concurrent validity. For the discriminative validity, half of the SSTs showed positive discriminative validity (BSST, (16); Badcamp, (24,25); and SCODS, (47)) with the TSS-BH (44) showing only superior performance for the male players. For the sideways and four-corner agility tests, the differences were insignificant. The MSSTs assessing discriminative validity showed contrary results, with the MRSAB (37) showing positive discriminative validity in contrast to the PRAT (46). For the NSST, the 505 agility test (12) and RAT (51) were assessed showing positive discriminative validity.

Because most agility tests only measured the reliability, there are not enough data to conclude anything about the differences in measurement properties (reliability and validity) of SST, MSST, and NSST. Although it could not be concluded from the results of this study, the literature highlights the importance of sport-specific testing with the superiority of elite players in sport-specific skills. Elite players were able to read cues in the opponent's movement needed for anticipation to the opponent's game, which distinguished them from lower-level players (6,41). Also, the use of a racquet during agility testing showed faster times than runs without a racquet, probably because the players are used to this constraint during the game (39). Although this was true for the 20-yard test, the tennis players were not superior with racquet when they performed the Illinois test (39), which may be because tennis players are used to sprinting short distances that do not include slalom running. Therefore, it would be a more ecologically valid approach to develop an agility test specifically for each sport,

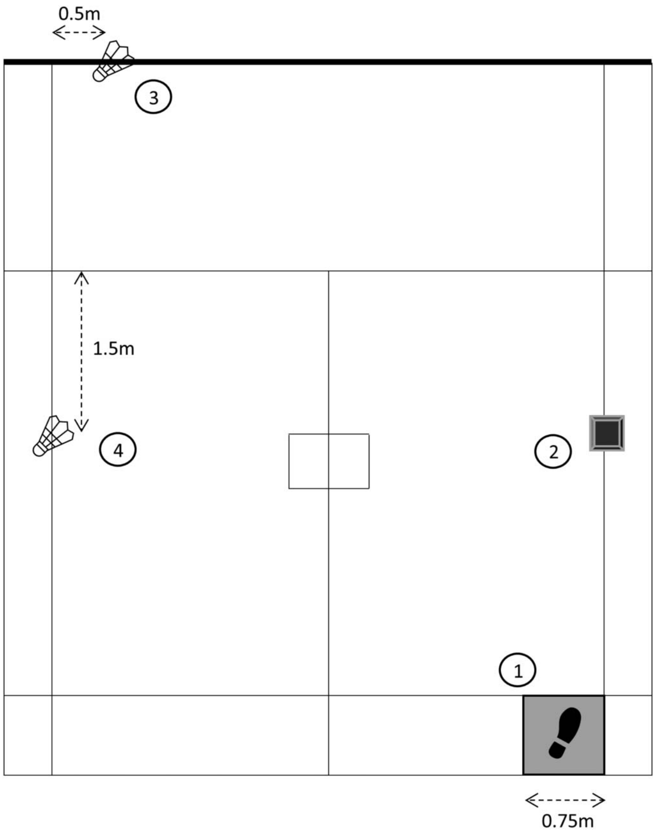

Figure 3. Test setup badminton-specific speed ("agility") test. From the starting position in the middle of the badminton court the players need to move to position 1 make an overhead hitting movement with one foot in the square, touch a post at position 2, hit a shuttle resting on the net at 3, and hit a shuttle placed on the inner tramline at 4. The figure is created based on the article of Hughes et al. (16).

representing the agility demands of the sport.

Focusing on the different racquet sports can give us more information on the availability of suitable agility tests in the literature per sport. For tennis, 3 agility tests (TSS-FH, (44); TSS-BH, (44); and TDTB, (22)), of which 2 related (TSS-FH and TSS-BH; (44)), were found to be sport specific, although the TDTB (22) did not include a response to a stimulus. Where the TDTB was only tested on reliability, the TSS-FH and TSS-BH were assessed on discriminative validity and an ICC value for the reliability was mentioned. However, no procedure and only one value for 2 tests was provided including no confidence interval. The reliability of this test is therefore hard to interpret. Although a lack of reliability or validity measures does not prove a minor quality of the test, it cannot be concluded that there is a sport-specific, reliable, and valid agility test available in the literature. On the other hand, the patterns used in the tennis agility tests can provide information for future agility tests. These tests required movement toward the forehand and backhand corner in combination with hitting the ball. The literature also emphasizes the movement to the wide forehand/backhand in combination with recovery to the middle as fundamental CODs in tennis (3). Other CODs that were added as fundamental in tennis were running forward toward the net, as would be needed to intercept a drop shot, and moving backward to the baseline, in case of a smash or lob. TDTB was the only agility test in this review including such forward movement toward the center of the service lines (T). For tennis, more research should be conducted using a tennis-specific approach to identify if these fundamental CODs are suitable for agility testing in tennis players. For badminton, both the Badcamp (24,25) and the BSST (16) were indicated as SSTs, showing both reliable and valid results. Thus, there are 2 suitable agility tests available for badminton (16,24,25). Similarity in movement patterns of these 2 badminton tests can be found in the incorporation of all the corners and sideways movements on the badminton field in combination with touching/hitting objects (see Figures 2 and 3). This information can be used for the design of agility tests in other racquet sports. For squash, the evaluation of agility testing is based on one test (SCODS; (47)), which was indicated as an SST, and shows good validity results as being able to discriminate between sports as well as performance level. Although the SCODS shows good validity results, the multidirectional nature of the game in response to a stimulus is not represented by the fixed order of running in the SCODS (38). Other sport-specific agility tests should be designed to compare the outcomes with the SCODS and learn more on agility testing in squash.

A limitation of this review is that the overview of the measurement properties of the agility tests was mostly based on one article, and it was not possible to combine the results of different articles, which is common in systematic reviews. Second, the development of the characteristics by the authors for measuring the sport specificity of the agility tests could have influenced the results. This is however unlikely because the characteristics were developed based on the literature and sport specificity was designed to be a continuum using 3 categories instead of a hard cut-off. Finally, the reassignment of the performance groups might have influenced the results. Although there were some differences with the original performance groups assigned by the authors of the articles, the groups created in the articles were still intact and of different performance levels.

The main purpose of this review was to give an overview of the existing tests that can be useful in practice for trainers, coaches, and embedded scientists. Monitoring performance will never be as ecologically valid as measuring during matches. However, measuring agility during matches is hard because of the major influence of the opponent during racquet sports and the varying intensity of the game. This review could give some useful information about the content of agility testing, needed for monitoring agility performance. The Badcamp and BSST are both suitable to be used in practice for agility monitoring in badminton. For both tennis and squash, no sport-specific agility tests were identified showing reliable and valid results. For these sports, future research should focus on developing sport-specific agility tests and improving the validity of the test. The challenge in designing a sport-specific test is obtaining a balance between standardized environments for good test-retest reliability and including an environment that is sport specific, such as including hitting a missile. Hitting movements without a missile might be a good solution. Movement patterns, which were identified as sport specific, can be used when designing a new agility test.

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