**Supplementary Table 1: MEDLINE Search Strategy**

Database(s): **Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R)**1946 to Present

|  |  |
| --- | --- |
| **#** | **Searches** |
| 1 | exp Brain Concussion/ |
| 2 | concuss\*.mp. |
| 3 | exp Post-Concussion Syndrome/ |
| 4 | postconcuss\*.mp. |
| 5 | post-concuss\*.mp. |
| 6 | mtbi.mp. |
| 7 | (sport\* adj3 concuss\*).mp. |
| 8 | mild traumatic brain injur\*.mp. |
| 9 | or/1-8 |
| 10 | exp Athletic Injuries/ |
| 11 | athletic\*.mp. |
| 12 | athlete\*.mp. |
| 13 | exp Sports/ |
| 14 | sport\*.mp. |
| 15 | player\*.mp. |
| 16 | competitor\*.mp. |
| 17 | jockey\*.mp. |
| 18 | football.mp. |
| 19 | soccer.mp. |
| 20 | baseball.mp. |
| 21 | boxing.mp. |
| 22 | equestrian.mp. |
| 23 | hockey.mp. |
| 24 | lacrosse.mp. |
| 25 | skating.mp. |
| 26 | skiing.mp. |
| 27 | diving.mp. |
| 28 | wrestling.mp. |
| 29 | exp Martial Arts/ |
| 30 | martial arts.mp. |
| 31 | racquet sports.mp. |
| 32 | or/10-31 |
| 33 | exp Trauma Severity Indices/ |
| 34 | exp Neuropsychological Tests/ |
| 35 | exp "Severity of Illness Index"/ |
| 36 | exp Checklist/ |
| 37 | exp "Surveys and Questionnaires"/ |
| 38 | test\*.mp. |
| 39 | instrument\*.mp. |
| 40 | assess\*.mp. |
| 41 | tool\*.mp. |
| 42 | questionnaire\*.mp. |
| 43 | scale\*.mp. |
| 44 | inventor\*.mp. |
| 45 | battery.mp. |
| 46 | batteries.mp. |
| 47 | measure\*.mp. |
| 48 | exp Physical Examination/ |
| 49 | examin\*.mp. |
| 50 | scoring.mp. |
| 51 | score\*.mp. |
| 52 | diagnostic evaluation.mp. |
| 53 | clinical evaluation.mp. |
| 54 | screening.mp. |
| 55 | checklist\*.mp. |
| 56 | physical exam\*.mp. |
| 57 | medical exam\*.mp. |
| 58 | exp Tomography, X-Ray Computed/ |
| 59 | ct.mp. |
| 60 | exp Magnetic Resonance Imaging/ |
| 61 | mri.mp. |
| 62 | exp Neuroimaging/ |
| 63 | neuroimaging.mp. |
| 64 | neurological exam\*.mp. |
| 65 | or/33-64 |
| 66 | exp Postural Balance/ |
| 67 | postural balance.mp. |
| 68 | balance.mp. |
| 69 | exp Oculomotor Muscles/ |
| 70 | exp Vestibular Diseases/ |
| 71 | exp Fixation, Ocular/ |
| 72 | vestibular.mp. |
| 73 | oculomotor.mp. |
| 74 | symptom\*.mp. |
| 75 | exp Cognition Disorders/ or exp Neurocognitive Disorders/ |
| 76 | neurocognit\*.mp. |
| 77 | exp Gait/ |
| 78 | gait.mp. |
| 79 | postural stability.mp. |
| 80 | exp Executive Function/ |
| 81 | exp Psychomotor Performance/ |
| 82 | motor performance.mp. |
| 83 | exp Affective Symptoms/ |
| 84 | disabilities.mp. |
| 85 | postural sway.mp. |
| 86 | exp Eye Movements/ |
| 87 | vestibular oculomotor.mp. |
| 88 | exp Dizziness/ |
| 89 | dizziness.mp. |
| 90 | neurosensory.mp. |
| 91 | exp Sleep/ |
| 92 | sleep\*.mp. |
| 93 | exp Fatigue/ |
| 94 | fatigue.mp. |
| 95 | exp Headache/ or exp Post-Traumatic Headache/ |
| 96 | headache\*.mp. |
| 97 | executive function\*.mp. |
| 98 | emotional function\*.mp. |
| 99 | psychological function\*.mp. |
| 100 | neuropsycholog\*.mp. |
| 101 | sequelae.mp. |
| 102 | cogniti\*.mp. |
| 103 | cerebral\*.mp. |
| 104 | cerebrovascular.mp. |
| 105 | exp Neurobehavioral Manifestations/ |
| 106 | neurobehav\*.mp. |
| 107 | exp Memory/ |
| 108 | memory.mp. |
| 109 | ocular motor.mp. |
| 110 | visuomotor.mp. |
| 111 | or/66-110 |
| 112 | 9 and 32 and 65 and 111 |
| 113 | remove duplicates from 112 |

**Supplementary Table 2: Inclusion/Exclusion Criteria**

|  |  |
| --- | --- |
| **Inclusion Criteria** | **Exclusion Criteria** |
| English publications | Non-English publications |
| Publication type: original research articles | Publication type: editorials, comments, conference abstracts, theses, etc |
| Sports related concussion or mTBI as source of injury | No concussion or mTBI No sports related injury mechanism |
| Focus on post-injury assessment and evaluation of diagnostic tools | Diagnosis not made by team memberAssessment at sideline onlyInitial post-injury assessment >14 daysInjury assessment not establishedFocus on concussion modifierFocus on FU |
| Population 13 years or older | Population 12 years or younger |
| 5 or more cases | 4 or fewer cases |
| Human population | Animal population |

**Supplementary Table 3: Risk of bias assessment according to the adapted Newcastle Ottawa Scale for crossectional studies**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Category** | **Criteria** | Broglio et al. 2009 | Fazio et al. 2007 | Furman et al. 2013 | Gardner et al. 2012 | Iverson et al. 2004 | Iverson et al. 2007 | Lovell et al. 2006 | Maddocks et al. 1995 | Maddocks et al. 1996 | Murray et al. 2014 | Pearce et al. 2015 | Pearce et al. 2015 | Register-Mihalik et al. 2013 | Tsushima et al. 2013 |
| **Selection** | 1) Representativeness of the exposed cases | \* | 0 | 0 | 0 | 0 | \* | \* | \* | \* | 0 | \* | 0 | 0 | 0 |
| 2) Selection of the non-exposed cases | \* | 0 | 0 | \* | \* | \* | \* | \* | 0 | 0 | 0 | 0 | \* | 0 |
| 3) Ascertainment of exposure | \* | \* | 0 | \* | \* | \* | \* | \* | \* | 0 | 0 | \* | 0 | \* |
| 4) Selection of outcome parameters  | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* |
| **Comparability** | 1) Comparability of exposed and non-exposed participants  | 0 | \* | 0 | \* | 0 | \* | 0 | 0 | \* | 0 | 0 | 0 | 0 | 0 |
| 2) Comparability of cohorts on the basis of the design or analysis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Outcome** | 1) Assessment of outcome? | \* | \* | \* | \* | \* | \* | 0 | \* | 0 | \* | \* | \* | \* | \* |
| 2) Appropriate observation | \* | 0 | 0 | \* | 0 | \* | \* | \* | 0 | \* | \* | 0 | 0 | 0 |
| 3) Non-response rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total number of items fulfilled (0-9)** | 6 | 4 | 2 | 6 | 4 | 7 | 5 | 6 | 4 | 3 | 4 | 3 | 3 | 3 |

**Supplementary Table 4: Risk of bias assessment according to the adapted Newcastle Ottawa Scale for cohort studies**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Category** | **Criteria** | Broglio et al.2007 | Broglio et al.2008 | Cavanaugh et al. 2005 | Cavanaugh et al. 2006 | Collie et al.2006 | Collins et al.2003 | Covassin et al. 2010 | Echemendia et al. 2001 | Echlin et al.2012 | Eckner et al.2011 | Fuller et al.2014 | Graves et al.2016 | Honaker et al. 2014 | Houston et al. 2016 | Lau et al.2009 | Lau et al.2011 | Lau et al.2012 | Louey et al.2014 | Lovell et al.2004 | Makdissi et al. 2001 | McClincy et al. 2006 | McCrea et al. 2002 | McCrea et al. 2003 | Parsons et al.2009 | Pedersen et al. 2014 | Pellman et al. 2004 | Putukian et al. 2015 | Schatz et al. 2006 | Schatz et al. 2014 | Schmidt et al. 2012 | Seidman et al. 2015 | Van Kampen et al. 2006 |
| **Selection** | 1) Representativeness of exposed cases | 0 | 0 | 0 | 0 | \* | \* | \* | \* | \* | 0 | \* | \* | 0 | \* | \* | \* | \* | \* | 0 | \* | \* | \* | \* | 0 | \* | \* | \* | 0 | 0 | \* | \* | 0 |
| 2) Selection of non-exposed cases | NA | 0 | 0 | NA | \* | \* | NA | \* | NA | NA | NA | \* | \* | \* | \* | NA | \* | \* | 0 | \* | 0 | \* | \* | NA | NA | \* | \* | 0 | 0 | \* | \* | 0 |
| 3) Ascertainment of exposure | \* | 0 | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | 0 | 0 | \* | \* | \* | \* | \* | \* | \* | \* | \* | 0 | \* | \* | \* | \* | \* | \* | \* | \* |
| 4) Demonstration that outcome of interest was not present at start of study | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* |
| **Comparability** | 1) Comparability of exposed and non-exposed participants on the basis of the design or analysis | NA | 0 | 0 | NA | \* | \* | NA | 0 | NA | NA | NA | 0 | \* | 0 | \* | NA | \* | 0 | 0 | 0 | 0 | 0 | \* | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | 0 |
| 2) Comparability of cohorts on the basis of the design or analysis | NA | 0 | 0 | NA | 0 | 0 | NA | 0 | NA | NA | NA | 0 | 0 | 0 | 0 | NA | \* | 0 | 0 | 0 | 0 | 0 | \* | NA | NA | NA | 0 | 0 | 0 | 0 | 0 | \* |
| **Exposure** | 1) Assessment of outcome? | \* | \* | \* | \* | \* | \* | \* | 0 | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* |
| 2) Appropriate observation period | \* | \* | \* | \* | 0 | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | \* | 0 | \* | \* | \* | \* | 0 | 0 | \* | \* |
| 3) Non-response rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | \* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total number of items fulfilled (0-9)** | 4 | 3 | 4 | 4 | 6 | 7 | 5 | 5 | 5 | 4 | 5 | 6 | 6 | 5 | 7 | 5 | 8 | 6 | 4 | 6 | 5 | 6 | 8 | 2 | 5 | 6 | 6 | 4 | 3 | 5 | 6 | 5 |

**Supplementary Table 5: Data extraction**

| **Lead author, study year****(observation period)** | **Design** | **Data collection chronology** | **Number of athletes;****age (mean±SD);****number of males** [**%**] | **Times cited (Google; Web of Science)** | **Sport;****level of play** | **Comparison group(s)** | **Base-line** | **Definition of concussion used** | **Diagnosis of concussion: who; where; when?** | **Latency until further exam (FU)** | **Assessment components** | **Results** | **NOS** **(0-9)** | **Level of** **Evi-dence** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Broglio et al., 20071(1998-2005) | PCS | Prospective | 75;NA;62 [83] | 187;123 | AF, FB, BB, cheer-leading, others;NA | None | Yes | The American Academy of Neurology guidelines | Physician;NA;immediately | 24 hrs | Symptoms [9 items]Neuropsychological Test [paper-pen including HVLT, TMT, SDMT, DST, COWAT (1998-2001), ,CNP [HCRI] (2001-2004), ImPACT (2004-2005), Postural stability [SOT] | When looking at all tests separately, ImPACT and HCRI were most sensitive for concussion (79.2% and 78.6% respectively). When all tests were combined, sensitivity exceeded 90%. | 4 | 3 |
| Broglio et al.,20082(1998-2005) | RCS | Retrospective | 63;20.3±1.4 (only male);50 [79] | 43;18 | NA;NA | Healthy young adults (n=66) without injury to lower extremity (20.1±1.7) | Yes | The American Academy of Neurology guidelines | Physician;NA:immediately | 24 hrs | Postural stability [SOT] | The reliable change technique was used to calculate cut-scores for each SOT variable. When cut-scores were applied an evaluation for change on one or more SOT variable(s) resulted in the highest combined sensitivity (57%) and specificity (80%) at a 75% confidence interval (CI). | 3 | 3 |
| Broglio et al., 20093(2004-2006) | \*CrS | Retrospective | 32;19.7±1.2;24 [75] | 51;33 | AF, FB, cheer-leading, equestrian; college | None | Yes | The American Academy of Neurology guidelines | Athletic trainer, confirmed by team physician;sideline;immediately | 48 hrs | Symptoms [PCSS ImPACT]CNP [ImPACT]Postural stability [SOT] | Compared to baseline, 19.2% of concussed athletes showed significant decline in postural balance and 68.8% showed significant decline in neurocognitive function. Not all athletes who showed significant decrease in function reported related symptoms. However, moderate to high correlations (0.36-0.57) where found between specific symptoms and related functions. | 6 | 4 |
| Cavanaugh et al., 20054(1997-2003) | RCS | Retrospective | 27;19.5;21 [78] | 142;94 | AF, FB, lacrosse, wrestling, FH; college | Healthy non-athlete: 15 male, 15 female | Yes | "Injury to the brain caused by … acceleration or deceleration of the head … resulted in … alteration in brain functions” | Certified athletic trainers and team physicians;NA;48 hrs | 48 hrs | Postural stability [Centre of pressure data collected during SOT] | Compared to healthy athletes, approximate entropy values declined after injury in all sensory conditions, for medial lateral time series (p=0.02). Athletes, who demonstrated normal postural stability after concussion displayed subtle changes in postural control | 4 | 4 |
| Cavanaugh et al., 20065(1997-2003) | RCS | Retrospective | 29;19.1;19 [66] | 128;79 | AF, FB, lacrosse, others;college | None | Yes | NA | NA;NA;48 hrs | 96 hrs | Symptoms (17 items)Postural stability [SOT] | Compared to baseline, approximate entropy values for medial lateral time series were significantly repressed direct after injury and after 48-96 hrs (mean difference 0.268, p<0.01). | 4 | 4 |
| Collie et al., 20066(2001-2003) | PCS | Prospective | 61,(25 symptomatic / 36 asymptomatic);22.3±3.6 / 23.3±3.9;61 [100] | 126;78 | ARF;professional | Non concussed athletes same sports (n=84) | Yes | The Vienna Consensus guidelines | Club medical staff;NA;immediately | 11 d | Symptoms (14 items)CNP [CogSport], paper pen (DSST, TMT) | Compared to asymptomatic and control group, the performance of the concussed symptomatic group declined after injury on computerised tests for simple, choice, and complex RT. On paper and pen tests the symptomatic group displayed no change after reassessment, whereas large improvements were seen in the other two groups. | 6 | 3 |
| Collins et al,. 20037(2000-2002) | Case Control | Prospective | 78;16.8±2.4;69 [89] | 307;180 | AF, FB, hockey, BB, lacrosse, baseball; high school, college | Non injured athletes just to estimate practice effects; comparison of symptomatic vs asymptomatic | Yes | GCS 13 till 15, normal day-of-injury CT scan | Sports medicine practitioners;on field;immediately | within 5 d, mean 1.7 d | Symptoms [PCSS ImPACT]CNP [ImPACT], | Compared to the asymptomatic group, the symptomatic group was over 10 times more likely (p<0.001) to exhibit retrograde amnesia and over 4 times more likely (p<0.013) to have exhibit posttraumatic amnesia. However, there was no difference between the groups in terms of on-field loss of consciousness. | 7 | 4 |
| Covassin et al., 20108(NA) | Case Series | Prospective | 72;15.8 ± 1.3;58 [81] | 45;23 | baseball, BB, cheerleading, AF, gymnastics, IH, FB, softball, VB, wrestling, others; high school | None | Yes | 3rd Consensus Statement on Concussion in Sport, Zurich | Certified athletic trainers, team physicians; sideline; immediately | 2, 7, 14, 21, 30 d | Symptoms [ImPACT]CNP [ImPACT] | Compared to baseline, concussed athletes scored worse on reaction time (p=0.000), verbal memory (p=0.012), motor processing speed (p=0.000) and total symptoms (p=0.000). Values returned to baseline level within 7-21 days. | 5 | 4 |
| Echemendia et al., 20019(1995-1999) | PCS | Prospective | 29;NA;NA | 340;202 | AF, IH, FB, BB; college | Non concussed athletes (n=20), same sport | Yes | NA | Athletic trainer, neuropsychologist, physician;sideline;immediately | 2 & 48 hrs, 1 wk, 1 mth | Symptoms [PCSS]Neuropsychological [HVLT, SDMT, SCWT, TMT, VCPT,DST, PSCT, COWAT, SCWT] | Compared to controls, concussed athletes scored worse on neuropsychological tests 2 hrs (p=0.000-0.020) and 48 hrs (p=0.000-0.038) after injury. However, a significantly greater number of symptoms was found 2 hrs after injury only (p=0.044). | 5 | 4 |
| Echlin et al., 201210(2011-2012) | PCS | Prospective | 11;NA;5 [46] | 18;7 | IH;college | None | Yes | 2009 Zurich Consensus | Physician, self-reported; sideline; immediately | 72 hrs, 2 wks, 2 mth, post-season | Symptoms [SCAT2]CNP [ImPACT, SCAT2]Imaging [3 T-MRI (DTI, MRS, SWI)]Balance [SCAT2] | Compared to baseline, ImPACT scores were significantly declined 72 hrs after injury in concussed athletes (p<0.05). The number of symptoms increased significantly immediately after injury and returned to baseline by the time of post-season evaluation. | 5 | 4 |
| Eckner et al,. 201111(2 seasons) | Case Series | Prospective | 9;20.6±1.0;8 [89] | 20;12 | AF, FB, wrestling; university | None | Yes | NA | Physician;NA;NA | 72 hrs | Symptoms [SCAT]CNP [CogSport, RT] | Compared to baseline, clinical RT was prolonged in 8 out of 9 concussed athletes while computerized RT was prolonged in 5 out of 9 concussed athletes. Indicating clinical RT might be more sensitive for detecting concussion. | 4 | 4 |
| Fazio et al., 200712(2001-2004) | CrS | Prospective | 122 (78 symptomatic and 44 asymptomatic);16.7;99 [81] | 132;78 | AF, FB, BB, wrestling, swimming, track, others;high school, college | Non concussed athletes different sports (n=70) | Yes | The American Academy of Neurology | Certified athletic trainers or team physicians; sideline; immediately | within 7 d, mean 45.1 hrs | Symptoms [ImPACT]CNP [ImPACT] | Compared to controls and asymptomatic athletes, symptomatic athletes scored worse on all four composite scores of the ImPACT (in all cases p<0.00). | 4 | 4 |
| Fuller et al., 201513(2012-2013) | Diagnostic Accuracy | Prospective | 65;NA;65 [100] | 13;4 | Rugby;elite | None | No | The American Society for Sports Medicine Position Statement concussion in sport | Physician;sideline (suspected), confirmed in clinical setting; immediately | within 48 hrs postgame | PSCASymptoms [SCAT2]CNP [CogSport, ImPACT, SCAT2] | The PSCA tool demonstrated a sensitivity of 84.6 %(95% CI 73.5% to 92.4%) and a specificity of 74% (95% CI 64.3% to 82.3%) for identification of concussion. | 5 | 2 |
| Furman et al., 201314(NA) | CrS | Prospective | 10,[symptom duration <2wk in total 43 concussed];16±1.5;9 [90] | 22;8 | NA;high school | Non injured participants (n=27)Symptom duration >2 wk (n=33) | Yes | Based in recent head trauma and presentation to the concussion clinic with postconcussive symptoms | Physician;Clinical setting;Within 14 d postinjury | Acute 8 d ± 3 d | Postural stability [BAM, BESS] | Compared to controls, concussed adolescents scored worse on the BESS (p<0.04), but no difference between the groups was observed on the BAM. A total BESS score of ≥21 errors identified athletes in the acute concussion group at 60% sensitivity and 82% specificity with 95% confidence interval. | 2 | 3 |
| Gardner et al., 201215(2007-2009) | CrS | Prospective | 46;24.2±4.2;46 [100] | 12;6 | rugby;amateur | Non concussed athletes (n=41) same sports | No | Presence of one of the following: confusion or disorientation, LOC 30min or leass, amnesia < 24 hrs, transient neurological abnormalities | Team medical staff;NA;NA | 72 hrs (mean 46.4 hrs) | Symptoms [ImPACT]CNP [CogSport, ImPACT] | When comparing a demographic model with a model, which includes CNP testing, diagnostic accuracy does not improve (p=0.102).When looking at all tests separately, the ImPACT post-concussion symptoms total was most accurate in classifying concussed athletes (accuracy 88.5%, Wald statistic p=0.006). | 6 | 3 |
| Graves et al., 201616(NA) | PCS | Prospective | 15;18.9±0.9;15 [100] | 0 | AF;college, division 1 | Non concussed athletes different sports, currently not competing (n=15) | Yes | NA | Athletic trainer and team physician:sideline;immediately | 24 hrs, after injury and 14 d after declared asymptomatic | Symptoms [NA]Postural stability [SOT, BESS] | Compared to baseline and control group, the concussed athletes had a significant decline in SOT score after injury (p=0.037 and p=0.025 respectively). | 6 | 4 |
| Honaker et al., 201417(2005-2010) | RCS | Retrospective  | 27 (11 without dizziness, 16 with dizziness);19.7±1.6;27 [100] | 2;1 | AF;college | None | Yes | 4th Consensus statement on concussion in sports, Zurich | NA;NA;NA; | 1-2 and 5-7 d | Symptoms [ImPACT]CNP [ImPACT] | Compared to concussed athletes without dizziness and imbalance, concussed athletes, who reported these symptoms had significantly lower ImPACT scores for visual and verbal memory (p=0.047 for both). However, after controlling for symptom inventory, time was the only significant effect. | 6 | 4 |
| Houston et al., 201618(NA) | Case Series | Prospective | 122;15.8±1.1;102 [84] | 0 | AF, FB, others;high school | None | Yes | NA | Athletic trainers; sideline; immediately | 3 d, 10 d | Symptoms [SCAT2]HRQoLQuestionnaire [PedsQL, PedsQL-MFS, HIT-6}Neuropsychological [SAC]Postural Stability [BESS] | When comparing symptoms to HRQoL questionnaires and neuropsychological on how much variance in time lost they can explain, HRQoL questionnaires are able to explain17.9-15.2% while symptoms explain 7.1% and neuropsychological explains 12.0% of this variance. | 5 | 4 |
| Iverson et al., 200419(2000-2001) | CrS | Prospective | 110 (91 no fogginess, 19 with fogginess);15.8±1.2;93 [85] | 96;68 | AF, BB, FB, Hockey, lacrosse, softball, , track, volleyball, wrestling;high school | None | Yes | 1or more of the following criteria: observational alteration in mental status or consciousness, presence of LOC or amnesia, post-concussion symptoms following collision involving head or body. | Certified athletic trainers or physicians; sideline; immediately | 5-10 d post injury (mean 6.8 d) | Symptoms [ImPACT]CNP [ImPACT] | Compared to concussed athletes without fogginess, concussed athletes had a significant higher total symptom score (p<0.0001), slower reaction time (p<0.0002), reduced memory performance (p<0.01), and slower processing speed (p<0.004). | 4 | 4 |
| Iverson et al., 200720(2002-2004) | Case Control | Retrospective | 114,(55 simple concussion, 59 complex concussion);16.2±1.1;114 [100] | 69;43 | AF;high school | None | Yes | Prague summary agreement | Athletic trainers or physicians; sideline; immediately | 72 hrs | Symptoms [ImPACT]CNP [ImPACT] | Compared to athletes with simple concussion, athletes with complex concussion scored significantly worse on visual memory, reaction time, processing speed and total symptom score (p=0.001 for all). However, no difference was found in verbal memory performance (p=0.088). | 7 | 4 |
| Lau et al., 200921(2002-2006) | PCS | Prospective | 108 (47 simple concussion, 61 complex concussion);16.0±1.2;108 [100] | 127;93 | AF;high school | None | Yes | Prague summary agreement | Athletic trainers or physicians; sideline; immediately | complex 0-12d (mean 2.4 d), simple 0-5d (mean 2.0 d) | Symptoms [ImPACT]CNP [ImPACT] | Compared to athletes with simple concussion, athletes with complex concussion scored significantly worse on visual memory (p=0.016), processing speed (0.007) and total symptom score (p=0.002). However, no difference was found in reaction time (p=0.088) and verbal memory performance (p=0.796). When comparing concussed athletes who experienced loss of consciousness (n=20) with the rest of the concussed athletes, no differences were found with regard to either neuropsychological performance (p=0.217) or symptoms (p=0.610). | 7 | 4 |
| Lau et al., 201122(2002-2006) | PCS | Prospective | 108,(58 short recovery, 50 protracted recovery);16.0±1.2;108 [100] | 110;67 | AF;high school | None | Yes | NA | Athletic trainers and/or team physicians; sideline; immediately | Short recovery 0-5 d (mean 1.5d), protracted 0-12d (mean 2.6d) | Symptoms [ImPACT]CNP [ImPACT] | Compared to using total symptom score alone to predict concussion, combining symptoms with CNP increases sensitivity with 24.41% and specificity with 1.05%, resulting in a total sensitivity of 65.22% and specificity of 80.36% with CI of 80%. | 5 | 4 |
| Lau et al., 201223(2002-2006) | PCS | Prospective | 108,(58 short recovery, 50 protracted recovery);16.0±1.2;108 [100] | 55;33 | AF;high school | None | Yes | on field presentation of 1 or more of the following criteria: noticeable change in mental status, LOC, Disorientation, amnesia, headache, dizziness, visual changes, and balance difficulities | Athletic trainers or physicians; sideline; immediately | Short recovery 0-5 d (mean 1.5d), protracted 0-12d (mean 2.6d) | Symptoms [ImPACT]CNP [ImPACT] | Compared to the short recovery group, the protracted recovery group reported significantly more often migraine (p=0.01) and cognitive symptoms (p=0.04). They also performed worse in visual memory (p=0.01) and processing speed (p=0.02). | 8 | 4 |
| Louey et al., 201424(NA) | PCS | Prospective | 29;22.3± 2.90;29 [100] | 18;11 | ARF; Rugby, professional, college | Non concussed athletes (n=235) | Yes | 3rd and 4th Consensus statements onConcussion in Sport | Team doctor,sideline;immediately | mean 32.1 ±4.1 hrs | Symptoms [Collie, A 2006]CNP [CogSport] | Compared to the normative method, the baseline method showed higher sensitivity (96.6 compared to 69.0, 95% CI); specificity did not differ between the different methods (86.9 compared to 91.5, 95% CI). | 6 | 4 |
| Lovell et al. 200425(NA) | Case Series | Prospective | 43;15.6;35 [81] | 302;200 | AF, FB, BB, IH, lacrosse, baseball, softball;high school | None | Yes | AAN guidelines | Trained athletic trainers physicians; sideline; immediately | 36 hrs (mean1.4 d), 6 d | CNP [ImPACT]Symptoms [ImPACT] | Compared to baseline, concussed athletes showed a decline in memory (p<0.003) and an increase in self-reported symptoms (p<0.00001) after injury. | 4 | 4 |
| Lovell et al., 200626(NA) | CrS+Case Series | Prospective | 260;16.5±2.0;217 [84] | 260;178 | Athletes;high school, college | None | Yes | NA | Certified athletic trainer or team physician; sideline; immediately | within 5 d (mean 48 hrs), 52 athletes 3 times (mean 1.4 d ± 0.7, 2= 5.6 d ± 1.3, 3= 11.7 d ± 4.2). | Symptoms [PCSS] | Compared to men, women tended to report more symptoms. Taken both genders together, the most frequently endorsed symptoms, at a severity of mild or greater, were: headache and difficulty concentrating. PCSS showed a good internal consistency for concussed athletes (r=0.93) | 5 | 4 |
| Maddocks et al. 199527(1985-1991) | PCS | Prospective | 28;NA;28 [100] | 235;130 | ARF;college, professional | Non concussed athletes same sports (n=28) with injury other than concussion | No | a) Observed head trauma b) loss of or altered consciousness c) development of postimpact symptoms such as headache, dizziness, and blurred vision | Medical practitioner; dressing room; immediately | Within 2 hrs | Symptoms [7 items]Neuropsychological (orientation, memory) | Compared to the control group, the concussed athletes reported more frequently symptoms of headache (93% vs 18%) and blurred vision (75% vs 0%), they also performed significantly worse on short time memory items (p values between 0.001-0.004). However, no group difference was found with respect to orientation (p values between 0.06-1.00). | 6 | 4 |
| Maddocks et al., 199628(NA) | CrS | Prospective | 10;NA;10 [100] | - | ARF;professional | Non concussed athletes same sports (n=10) | Yes | NA | Club medical practitioner;NA;NA | 5 d | Neuropsychological [PASAT, DSST, FCRT (divided in DT and MT)] | Compared to controls, concussed athletes performed worse on DSST (p=0.04) and DT (p=0.01) after injury. However, no significant differences were found for MT (p=0.11) or PASAT (p=0.71). | 4 | 4 |
| Makdissi et al., 200129(2001) | PCS | Prospective | 6;20.5± 3.1; 9 [100] | 157; 88 | ARF;elite professional, semi-professional, amateur | Non concussed athletes same sports (n=7) | Yes | The Congress of Neurological Surgeons | Club medical practitioner;NA;NA | 2 d | Symptoms [7 items]CNP [CogSport (SRT)], Neuropsychological [DSST, TMT] | Compared to baseline, concussed athletes showed an increase in variability in SRT (p=0.01). However, no differences were observed in DSST (p=0.72) ,TMT (p=0.21) or RT (p=0.053) scores for the concussed or for the control group. | 6 | 4 |
| McClincy et al., 200630(2001-2004) | Case Series | Prospective | 104;16.1±2.2;91 [88] | 213; 122 | AF, FB, BB, wrestling, IH, FH, others;high school, college | None | Yes | The American Academy of Neurology | NA;NA;NA | 2 d (2.42± 3.1) d), 1 wk (7.6±4.5 d), 2 wks (14.4±7.3 d) | Symptoms [ImPACT- 21 items] CNP [ImPACT] | Compared to baseline, concussed athletes scored significantly worse on all ImPACT composite scores including total symptom score two days after injury (p<0.0001 in all conditions). 7 days after injury significant difference were still found for verbal memory (p<0.0001), visual memory (p<0.01), reaction time (p<0.0002) and total symptom score (p<0.0001). After 14 days significant difference were only found for verbal memory (p<0.0003). | 5 | 4 |
| McCrea et al., 200231(NA) | PCS | Prospective | 91;17.5± 2.10;91 [100] | 257; 138 | AF;high school, college | None | Yes (partly: n=45) | The American Academy of Neurology practice parameterThe American Congress of Rehabilitation Medicine | Certified athletic trainer;sideline;immediately | 15 min, 48 hrs, 90 d | Neuropsychological [SAC] | Compared to baseline, SAC scores were significantly lower in concussed athletes 15 minutes after injury (p=0.035-0.008). Concussed athletes who suffered from LOC (n=7) showed most decline (p<0.0001). All groups returned to baseline level within 48 hrs. | 6 | 4 |
| McCrea et al., 200332(1999-2001) | PCS | Prospective | 94;20.0±1.4;94 [100] | 918; 561 | AF;college division I, II, III | Non concussed athletes same team (n=56) | Yes | The American Academy of Neurology | Team physicians or certified athletic trainers;sideline;immediately | 3 hrs, 1, 2, 3, 5, 7, 90 d | Symptoms [GSC, 17 items]Neuropsychological [SAC, HVLT (Immediate, Delayed, Recognition, TMT Part B, SDMT, SCWT, COWAT]Postural stability [BESS] | Compared to controls, concussed athletes scored higher on GSC (mean 20.93 higher), lower on cognitive impairment (mean, 2.94 lower) and worse on balance (5.81 higher). On average symptoms resolved in 7 days. | 8 | 3 |
| Murray et al,. 201433(NA) | CrS | Retrospective | 9;16±3.0;2 [22] | 17; 6 | NANA | Non concussed athletes (n=9) | No | The 4th International Conference on Concussion in Sport | Physician or athletic trainers;NA;NA | 48–72 hrs | Symptoms [22 items]CNP [ImPACT]Postural stability [Nintendo WiFit FB heading game] | Compared to controls, concussed athletes had significantly higher measures on gaze deviation from centre (p<0.001). However, percentage time on centre (p=0.516) and game scores (p=0.344) were not significantly different between groups. | 3 | 4 |
| Parsons et al., 200934(2001-2005) | RCS | Retrospective | 40;18.3 ± 0.6;24 [60] | 31; 15 | AF, FB, lacrosse, wrestling, BB; track;college division I | None | Yes | NA | Sports medicine staff;NA;NA | 60.7 hrs | Symptoms [modified GSC, 18 items]CNP [ANAM],Postural stability [SOT], | Compared to baseline, 14 concussed athletes improved their SMCA after concussion, 7% of these athletes also improved on some parts of the ANAM test. However, none of them improved on any part of SOT or total symptom score. From the 26 athletes, which did not improve on their SMCA after concussion 4-8% showed improvement on parts of the ANAM, 4 % improved on subparts of SOT. | 2 | 4 |
| Pearce et al., 201535(NA) | PCS | Prospective | 8;25.1±4.5;8 [100] | 6; 3 | ARF;amateur | Non concussed athletes same sports (n=15) | No | NA | Sports trainer, or self –observation;sideline;immediately | 48, 96 hrs,, 10 d | Neuropsychological [O’Connor Finger Dexterity test, Visuomotor reaction time, VMRT (RT+MT)],CNP [CNTAB (PAL, IED)],TMS [MEP] | Compared to controls, concussed athletes increased in RT (p=0.02) and MT (p=0.01) 48 hrs after injury, decreased in attentional performance 48 and 96 hrs after injury (p<0.01 for both). Concussed athletes also had an increase in cortical inhibition 48 (p=0.04) and 96 hrs (p=0.02) after injury, which correlated significantly with RT (r=0.48, p<0.01), MT (r=0.42, p=0.02) and attentional performance (r=0.44, p=0.01). | 4 | 4 |
| Pearce et al,. 201536(NA) | CrS | Prospective | 78;14.3±2.8;45 [35] | 6; 3 | NA;high school | None | No | 4th Consensus statement on concussion in sport, Zurich | NA;NA;NA | 5.8, 5.6 d | Symptoms [ImPACT]CNP [ImPACT]NPC | Athletes with near point convergence (NPC) impairment performed worse on verbal memory (p=0.02), visual motor speed (p= 0.02), and reaction time (P =0.001) and had greater total symptom scores (p=0.02) after the injury. NPC distance contributed significantly to the model for reaction time (p=0.001). | 3 | 4 |
| Pedersen et al., 201437(6 years) | Case Series | Retrospective | 14;23± NA;14 [100] | 5; 3 | IH;college | None | Yes | Contact to the head, concussive symptoms, that did not clear within 15min | Athletic trainer;NA;NA | 24hrs | Symptoms [ImPACT]CNP [ImPACT] | A significant (p<0.05) decrease in performance (compared to baseline) on immediate and delayed word recall and designs followed the first concussion. Following a second sport-related concussion, the 4 affected athletes showed significant decrease in visual motor speed. Performance improved on 2 response speed measures (P<0.01). | 5 | 4 |
| Pellman et al., 200438(1996-2001) | PCS | Prospective | 95;25.4 (NFL, including all), College 20.4);95 [100] | 128; 85 | AF;college, professional | None | Yes | NA | Neuropsychologist;NA;NA | 1.4 d | Symptoms [NA]Neuropsychological [HVLT, BVMT-R, TMT, SDMT, COWF, DST] | The MTBI group did not display significant neuropsychological dysfunction relative to baseline scores (except for TMT, Part A (p=0.03), Digit Span Forward test (p= 0.001), SDMT (p= 0.006). | 6 | 3 |
| Putukian et al., 201539(NA) | Diagnostic Accuracy | Prospective | 32;20.8±1.0;27 [84] | 17; 6 | AF, rugby, IH, water polo, (sprint) FB, BB, lacrosse, FH, wrestling;University, division I | Non concussed contact sport athletes (n=23) | Yes | NA | Team physician;NA;NA | 12.5 hrs | Symptoms [SCAT-2]Questionnaire [GAD-7, PHQ-9]Neuropsychological [SCAT2]Balance [SCAT2] | Compared with baseline the total SCAT2 score and the composite scores of symptoms, symptom severity and balance were significantly different post-concussion; compared with controls all subcomponents of the SCAT2 were significantly different (p< 0.01); When compared with baseline, a 3.5-point drop in SCAT2 score had 96% sensitivity and 81% specificity in detecting concussion. When examined to exclude baseline scores, a cut off value of 74.5 was associated with 83% sensitivity and 91% specificity in predicting concussion vs. control status | 6 | 3 |
| Register-Mihalik et al., 201340(NA) | CrS | Retrospective | 132;18.6±1.1;86 [65] | 40; 18 | Athletes not specified;college | Healthy male college football student athletes (n=38) | Yes | NA | Physicians;NA;NA | Within 5 d56.6 hrs | Symptoms [GSC 17 items]CNP [ANAM],Postural stability [SOT], | Application of the reliable change parameters suggests that a small percentage of concussed participants were impaired on each measure. A low sensitivity of the entire battery (all measures combined) of 50%, but high specificity of 96% was identified. | 3 | 4 |
| Schatz et al., 200641(2000-2002) | Diagnostic Accuracy | Retrospective | 72;16.5±2.3;57 [79] | 337; 195 | AF, FB,IH, FH, BB, others;high school | Non concussed athletes (n=66) | Yes | AAN, 1997, Field et al, 2003 | Certified athletic trainers or team physicians;sideline;immediately | 72 hrs | Symptoms [ImPACT]CNP [ImPACT] | MANOVA revealed a significant multivariate effect of concussion on test performance (p <0.001); Approximately 82% of participants in the concussion group and 89% of participants in the control group were correctly classified. Using these data, the sensitivity of ImPACT was 81.9%, and the specificity 89.4%. | 4 | 4 |
| Schatz et al,. 201442(2010-2013) | RCS | Retrospective | 250;15.8±1.9;183 [73] | 6; 3 | AF, FB, BB, lacrosse, VB, cheerleading, FH, IH, softball, wrestlingNA | None | Yes | NA | Certified athletic trainer or sports medicine professional;sideline;immediately | Within 1 wk | Symptoms [ImPACT]CNP [ImPACT] | Normative comparisons identified fewer symptomatic, concussed athletes than reliable change indices (RCIs) and regression based measures (RBm).Both RCIs and RBz consistently identified “impairment” at 1 and 1.5 SD, regardless of baseline level, whereas normative comparisons identified 46–48% fewer athletes performing “above average” at baseline using a cut-off of 1 SD and 36-38% fewer using a cut-off of 1.5 SD. | 3 | 4 |
| Schmidt et al., 201243(2001-2010) | PCS | Prospective | 258;male: 18.8±1.6female: 18.5±1.1;182 [71 | 56; 38 | NA;college | None | Yes (n=175) | Guskiewicz et al. 2003 | Medical staff;NA;NA | Within 10 d (mean 2.7 d) | Symptoms [GSC, 15 items]CNP [ANAM]Postural stability [SOT] | The baseline comparison method identified 2.6 times more impairments than the normative comparison method for the Simple Reaction Time Test 1 (P = 0.043). The normative comparison method identified 7.6 times more impairments than the baseline comparison method for Mathematical Processing (P G 0.001). No other disagreements were observed for postural control or symptom severity. | 5 | 4 |
| Seidman et al., 201544(2013) | PCS | Prospective | 9;15.6±1.0;9 [100] | 4; 3 | AF | athletes same sports without concussion | Yes | "Neuro-metabolic cascade of events that involves bio-energetic challenges, cytoskeletal and axonal alterations, impairments in neurotransmission, vulnerability to delayed cell death and chronic dysfunction | Certified team staff;sideline;immediately | 30 min | Symptoms [ImPACT]CNP [ImPACT, SCAT3]Postural stability [SCAT3]Visual and ocular motor [KD] | In all concussed players, cumulative read times for the KD test were significantly increased (p= 0.001) | 6 | 4 |
| Tsushima et al,. 201345(2009) | CrS | Retrospective | 26;15.2±1.7;26 [100] | 9; 5 | AF; FB, wrestling, BB, Softball, judo, lacrosse, cheerleading;high school | Non concussed athletes (n=25) | Yes | The American Academy of Neurology (1997) | Certified athletic trainer;NA;NA | 6.8 d | Symptoms [ImPACT]CNP [ImPACT] | The composite scores of the concussed athletes were lower but not statistically different than the non concussed controls.. | 3 | 4 |
| Van Kampen et al., 200646 | PCS | Prospective | 122;16,6;100 [82] | 243; 142 | AF, FB, BB, IH, wrestling, lacrosse; high school, college | None concussed athletes different sports (swimmer, FB, track, wrestling, lacrosse) (n=70) | Yes | The American Academy of Neurology | Certified athletic trainer or physician;sideline;immediately | 48 hrs | Symptoms [ImPACT]CNP [ImPACT] | Compared with baseline a significant increase in symptoms was reported in 64% of the concussed athletes, 83% of the concussed sample demonstrated significantly poorer neurocognitive test results relative to baseline performance. The addition of neurocognitive testing resulted in a net increase in sensitivity of 19%. | 5 | 4 |

**Abbreviations: Study designs**: CrS= Cross-sectional Study, PCS= Prospective Cohort Study, \*CrS= Cross-Sectional Study using retrospectively collected data, RCS= Retrospective Cohort Study

**Tests**: ANAM= Automated Neuropsychological Assessment Metrics, BAM= Health`s Balance Accelerometer Measure, BESS= Balance Error Scoring System, BVMT-R= Brief Visual Spatial Memory Test, CNP= Computerized Neuropsychological Test, CNTAB= Cambridge Neuropsychological Test Automated Battery, CogSport = CogSport Ltd, Melbourne, Australia, COWAT= Controlled Oral Word Association Test, COWF= Controlled Oral Word Fluency, DIVA= Divided Attention, DS= Digit Spam, DSST= Digit Symbol Substitution Test, DST=Digit Spam Test, DT= Decision Time, DTI= Diffusion Tensor Imaging, FCRT= Four Choice Reaction Time, GAD= Generalize Anxiety Disorder-7 item, GCS= Glasgow Coma Scale, GSC= Graded Symptom Checklist, HCRI= HeadMinder Concussion Resolution Index, HIT-6= Headache Impact Test 6, HRQoL= Health Related Quality of Life, HVLT= Hopkins Verbal Learning Test, IED= Intra-Extra Dimensional Set Shift, ImPACT= Immediate Post Concussion Assessment and Cognitive Testing, KD= King-Devick Test, LLDS= List Learning, LOC= Loss of Consciousness, MEP=Motor Evoked Potential, MFS= Multidimensional Fatigue Scale, MRS= Magnetic Resonance Spectroscopy MT= Movement Time, NPC= Near Point Convergence , PAL= Paired-Associative Learning, PASAT= Paced Auditory Serial Addition Test, PCSS= Post Concussion Symptom Scale, PedsQL= Paediatric Quality of Life inventory, PHQ-9= Patient Health Questionnaire-9, PSCA= Pitch Side Concussion Assessment, PSCT= Penn State Cancellation Test, RT= Reaction Time, SAC= Standardized Assessment of Concussion, SCAT= Sport Concussion Assessment Tool, SCAT2= Sport Concussion Assessment Tool 2nd edition, SCAT3= Sport Concussion Assessment Tool 3rd edition, SCWT= Stroop Colour-Word Test, SDMT= Symbol Digit Modalities Test, SOT= NeuroCom Sensory Organization Test, SRT= Simple Reaction Time, SWI= Susceptibility Weighted Imaging, T-MRI= Tesla magnetic resonance imaging, TMS= Transcranial Magnetic Stimulation, TMT= Trail Making Test, VCPT= Vigil Continuous Performance Test, VMRT= Visuomotor Reaction Time

**Type of sports:** AF= American Football, ARF= Australian Rules Football, BB= Basketball, FB= Football/ (soccer), FH= Field Hockey, IH= Ice Hockey, VB= Volleyball, others = mixed

**Others**: d= day; FU= Follow Up, hrs= hours, min= minutes, mth= month, NA= Not available, SD= Standard Deviation, wk= week

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