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Does forced or compensated turnout lead to musculoskeletal injuries in dancers? A systematic review on the complexity of causes

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ABSTRACT

Injury prevalence in dancers is high, and misaligned turnout (TO) is claimed to bear injury risk. This systematic review aimed to investigate if compensating or forcing TO leads to musculoskeletal injuries.

A systematic literature review was conducted according to the PRISMA Guidelines using the databases of PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier, and ScienceDirect. Studies investigating the relationship between compensated or forced TO and injuries in all genders, all ages, and levels of dancers were included. Details on misaligned TO measurements and injuries had to be provided. Screening was performed by two researchers, data extraction and methodological quality assessment executed by one researcher and checked by another.

7 studies with 1293 dancers were included. Methodological quality was low due to study designs and a general lack of standardised definition of pathology and methods of assessment of misaligned TO. The studies investigating the lower extremities showed a hip-focus only. Non-hip contributors as well as their natural anatomical variations were not accounted for, limiting the understanding of injury mechanisms underlying misaligned TO. As such no definite conclusions on the effect of compensating or forcing TO on musculoskeletal injuries could be made.

Total TO is dependent on complex motion cycles rather than generalised (hip) joint dominance only. Objective dual assessment of maximum passive joint range of motion through 3D kinematic analysis in combination with physical examination is needed to account for anatomical variations, locate sites prone to (overuse)injury, and investigate underlying injury mechanisms.

Contents

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1. Introduction

Injury rates in dancers are high, ranging from 0.62 to 5.6 per 1000 dance exposure hours (Allen et al., 2012), mainly sustained to the lower limbs and spine, and overuse in nature (Allen et al., 2012; Byhring and Bo, 2002; Ekegren et al., 2014; Gamboa et al., 2008; Garrick and Requa, 1994; Hincapie et al., 2008; Jacobs et al., 2012; Nilsson et al., 2001; Reid, 1988; Smith et al., 2016). One of the commonly cited risk factors is a misaligned or poorly controlled turnout (TO) (Garrick and Requa, 1994; Gilbert et al., 1998; Jenkinson and Bolin, 2001; Livanelioglu et al., 1998; Rietveld, 2013; Trepman et al., 2005; Watkins et al., 1989). TO can be described as the external rotation of the leg (Bennell et al., 1999; Gilbert et al., 1998) with the aim of increasing overall range of motion (ROM) especially in abduction, as well as stability in static and dynamic balance. It is considered to be the most important technical, stylistic, and aesthetic characteristic of classical ballet and is also used in other dance styles, i.e., modern, contemporary, or jazz dance (Sammarco, 1983). Active aspects of TO ask for high levels of inter- and intra-muscular coordination, fine-tuned proprioception, strength, and strength endurance to allow functional dynamic alignment.

Individual passive anatomical capabilities determine the amount of TO a dancer is maximally able to present while maintaining efficient alignment. Professional ballet dancers display an average functional TO of 133.6° with a passive hip external rotation capability of 50.2° and an active hip external rotation of 35.2° (Washington et al., 2016). However, especially in classical ballet TO has become a search for perfection with dancers trying to achieve an ideal total TO (TTO) of an 180° angle between the bilateral longitudinal axes of the feet (Fig. 1) (Gilbert et al., 1998). In the attempt to achieve the ideal 180° many dancers need to force joints or draw from compensatory mechanisms.

When trying to achieve ideal TO, three different possibilities of compensating or forcing TO are possible: lumbar hyperlordosis, forced tibial external rotation ("screwing the knee"), and hyperpronation/abduction of the feet (Bejjani, 1987; Bowerman et al., 2014; Conti and Wong, 2001; Hamilton, 1988; Jenkinson and Bolin, 2001; Kadel, 2014, 2006; Kadel et al., 1992; Khan et al., 1995; Liederbach et al., 2008; Livanelioglu et al., 1998; Macintyre and Joy, 2000; McNerney et al., 2014; Meuffels and Verhaar, 2008; Micheli et al., 1999; Quirk, 1994; Reish and Caldera, 2012; Russell, 1991; Scioscia et al., 2001; Steinberg et al., 2012; Trepman et al., 2005). It is claimed that these mechanisms lead to injuries within the kinetic chain. However, there is a lack of overview on existing research, in which the effects of compensating or forcing TO are presented. Thus, this systematic review aims to investigate the association between aspects of forced or compensated TO and dancers' musculoskeletal injuries (Khan et al., 1995; Reid, 1988; Rietveld, 2013).

2. Methods

2.1. Search strategy

A systematic literature search was conducted on September, 23rd, 2019, assisted by a librarian, using the databases of PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier, and ScienceDirect, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

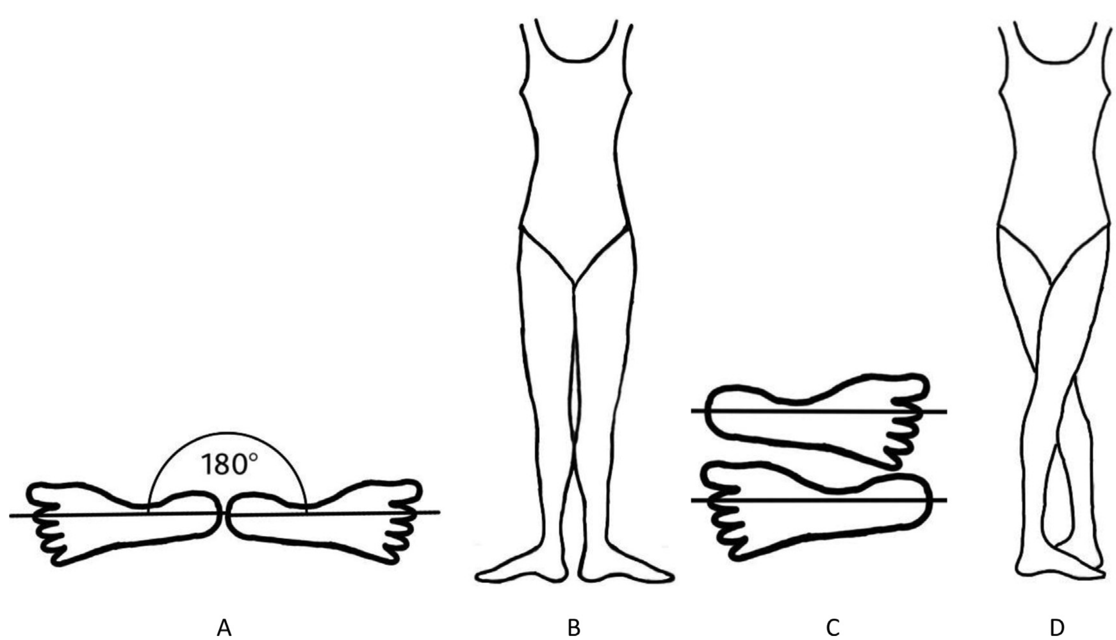

Fig. 1. "ideal" functional turnout in 1st (A + B) and 5th (C + D) classical ballet position.

guidelines. The research used three basic groups of keywords (ballet, and/or dance, turnout and/or pre-identified synonyms, and injury and/or pre-defined synonyms) in different Boolean combinations, including filters and MESH terms (Appendix 1). Additional hand search of reference lists and manual search of the journal "Medical Problems of Performing Artists" was conducted.

2.2. Inclusion & exclusion criteria

Original studies investigating the relationship between compensated or forced TO and musculoskeletal injuries in dancers, males and/or females, as well as all levels of dancers from the dance styles ballet, modern, contemporary, and jazz were included. These styles are chosen as they are mainly or to a certain degree using TO as part of their dance technique. Age was not used as an exclusion criterium. Details on measurements of compensated or forced TO and musculoskeletal injuries had to be provided. Studies, which only described and compared TO and related measurement techniques were excluded, as were case studies and reviews.

2.3. Data extraction

Regular references and meeting abstract references were screened independently by two researchers (J.E.K. and M.G.J.G.), with any disagreements resolved by consensus. Data was extracted using a data-extraction table by J.E.K and checked by M.G.J.G. The following data was extracted: Study design, participants, inclusion/exclusion criteria, exposure, outcome, assessment procedures, and results.

2.4. Methodological quality assessment

The methodological quality of retrieved studies was assessed independently by two researchers (J.E.K. and M.G.J.G.) through questions specifically designed for the purpose of this review. The categories included injury outcome, exposure assessment, selection bias, and handling of confounders. Exposure assessment was subdivided into the categories definition, methods, and measurements, resulting in a mean outcome score. The COSMOS-E (Conducting Systematic Reviews and Meta-Analyses of Observational Studies of Etiology) Guidance was used as a template (Dekkers et al., 2019).

3. Results

3.1. Search

387 articles and 32 abstract references were retrieved. Through the first screening of titles and abstracts (J.E.K., M.G.J.G.) 34 studies and 2 conference abstracts were identified. Additional manual search of "Medical Problems of Performing Artists" as well as retrieved reference lists yielded one additional study and one additional conference abstract. Full text reading and application of exclusion and inclusion criteria resulted in 7 original studies (Fig. 3).

3.2. Study designs and study population

1 study was a longitudinal observational cohort study, while 6 studies had a cross-sectional observational design. The studies included a total of 1293 dancers representing 4 dance styles: classical ballet (n = 4), modern dance (n = 2), contemporary dance (n = 2), and jazz dance (n = 1). The smallest study presented 12 professional contemporary dancers (Cimelli and Curran, 2012), the largest included 1082 amateur dancers from ballet, modern, and jazz (Steinberg et al., 2011). The youngest participants were 8–16 years old in 1 study (Steinberg et al., 2011), while the other studies focused on adolescents and young adults with a mean age ranging from 16,5 (Drężewska and Śliwiński, 2013) to 26,8 (Cimelli and Curran, 2012) years (Table 1*)*.

3.3. Turnout measurements & terminology

The terminology used for TO was heterogeneous as were its definitions and assessments (Table 2). Fig. 2 and Appendix 2 provide an overview of terms, acronyms, and definitions used in research on turnout to support the understanding of our results. The studies investigating the lower extremities used "CTO" ("compensation of TO"), "CTO difference", and "muscular value" to label the misalignment associated with TO and injury. The authors studying hyperpronation of the foot or lumbar hyperlordosis used "forcing", "compensation in the TO position", and "incorrect TO technique" in their exposure terminology. Measurement techniques varied with regard to positions of the dancer, tools used, as well as the calculations applied for exposure assessment.

3.4. Injury definition & assessment

Injury definitions included "timeloss with respect to training, exam, or performance" (Coplan, 2002; Negus et al., 2005), or "timeloss to completion of class" (Jenkins et al., 2013), "current pain in the ankle or foot region, that is, movements or exercises that evoke pain or pain that disturbed her dance practice and daily life activity"(Steinberg et al., 2011), "pain intensity regardless of effect on performance" (Drężewska and Śliwiński, 2013), injuries preventing the executing of functional turnout (Cimelli and Curran, 2012), or "any pain, discomfort, or musculoskeletal problem that would cause modification of technique or time away from dance class, rehearsal, or performance" (van Merkensteijn and Quin, 2015). Injury assessment was executed once via interview in combination with professional diagnosis (Steinberg et al., 2011), in 3 studies by self-report with a questionnaire (Cimelli and Curran, 2012; Coplan, 2002; van Merkensteijn and Quin, 2015), once by interview (Negus et al., 2005), in 1 study by questionnaire and additional evaluation of medical history forms (Drężewska and Śliwiński, 2013), and in another by questionnaire and additional report of the physiotherapist (Jenkins et al., 2013). Injury mechanisms included overuse injuries (Coplan, 2002) as well as overuse and traumatic injuries (Negus et al., 2005; van Merkensteijn and Quin, 2015), but this was not always specified (Cimelli and Curran, 2012; Drężewska and Śliwiński, 2013; Steinberg et al., 2011). Reported injury locations were the lower extremities in 5 studies (Cimelli and Curran, 2012; Coplan, 2002; Drężewska and Śliwiński, 2013; Negus et al., 2005; van Merkensteijn and Quin, 2015), the low back in 4 studies (Coplan, 2002; Drężewska and Śliwiński, 2013; Negus et al., 2005; van Merkensteijn and Quin, 2015), and isolated reports were given on the foot in 2 studies (Cimelli and Curran, 2012; Steinberg et al., 2011). One study only mentioned the number of injuries, but did not include any details on the injury location (Jenkins et al., 2013).

3.5. Methodological quality assessment

The methodological quality of the studies was medium to low *(*Table 3*)*. Overall assessment for outcome showed a retrospective approach based on self-report of most of the studies, which could have introduced information bias. In only three studies injuries were objectively scored by medical professionals. Outcome for exposure assessment showed manual measurements (as opposed to 3D kinematic analysis or comparable techniques) and isolated

Table 1
Data extraction.

Author, Year	Publication	Study design	Participants	Inclusion/Exclusion Criteria
Cimelli and Curran, 2012	Influence of turnout on foot posture and its relationship to overuse musculoskeletal injury in professional contemporary dancers: a preliminary investigation. Journal of the American Podiatric Medical Association, 102 (1), 25–33.	cross-sectional observational cohort study	**number:** 12 dancers **sex:** 5 female **dance style:** contemporary **level:** professional **Ø age:** 26.8 years (range: 21–36 years)	**inclusion criteria**: aged 20–40 years; a current traumatic injury that renders him/her unable to assume a functional turnout position; a minimum of 3 years of contemporary and ballet dance training; a minimum of 1 year as professional contemporary dancer. **exclusion criteria**: not provided
Coplan, 2002	Ballet dancer's turnout and its relationship to self-reported injury. The Journal of Orthopaedic and Sports Physical Therapy, 32, 579–584.	cross-sectional observational cohort study	**number:** 30 dancers & instructors **sex:** 27 female **dance style:** ballet **level:** college level & teaching experience **Ø age:** 22 years (range: 16–50 years)	**inclusion criteria**: not provided. Ballet students and their teachers were recruited from 3 colleges offering ballet training (in Baltimore) **exclusion criteria**: not provided.
Drężewska and Śliwiński, 2013	Lumbosacral pain in ballet school students. Pilot study. Ortopedia, Traumatologia, Rehabilitacja, 15, 149–158.	cross-sectional observational cohort study	**number:** 71 dancers **sex:** 45 females **dance style:** ballet **level:** ballet school students **Ø age:** 16.5 years (range: 15–18 years)	**inclusion criteria:** not provided. **exclusion criteria**: dancers with back injury and discontinuation of dance practice due to any injury longer than 3 weeks within the preceding 6 months.
Jenkins et al., 2013	Can turnout measurements be used to predict physiotherapist-reported injury rates in dancers? Medical Problems of Performing Artists, 28(4), 230–235.	longitudinal observational cohort study	**number:** 47 dancers **sex:** all female **dance style:** contemporary **level:** university level **Ø age:** 19.9 years (range: 17–22 years)	**inclusion criteria**: not provided. All participants were enrolled in a BA Dance Theatre at a United Kingdom contemporary dance conservatoire. **exclusion criteria**: not provided.
Negus et al., 2005	Associations between turnout and lower extremity injuries in classical ballet dancers. The Journal of Orthopaedic and Sports Physical Therapy, 35, 307–318.	cross-sectional observational cohort study	**number:** 29 dancers **sex:** 24 female **dance style:** ballet **level:** pre-professional **Ø age**: 18 years (range: 15–22 years)	**inclusion criteria:** not provided. All participants were students in the first- and second year groups of the Advanced Diploma of Dance programme in an Academy for Performing Arts **exclusion criteria**: inclusion was restricted to the programme only to optimize homogeinity of current and previous dance training.
Steinberg et al., 2011	Paratenonitis of the foot and ankle in young female dancers. Foot & Ankle International, 32, 1115–1121.	cross-sectional observational cohort study	**number:** 1082 dancers **sex:** all female **dance style:** ballet, jazz, modern **level:** non-professional **Ø age:** not provided. (range: 8–16 years)	**inclusion criteria**: positive diagnosis by MD on site: Non-professional female dancers (8–16 years old) were screened over the previous 15 years in a Performing Arts medicine Center (Tel Aviv), active in a variety of dance styles. **exclusion criteria**: dancers were excluded from the paratenonitis group if they had concomitant injury or pathology of other ankle/foot structures (e.g., ankle sprain, shin split), a history of ankle/foot surgery, or ankle/foot dislocation or subluxation.
van Merkensteijn and Quin, 2015	Assessment of Compensated Turnout Characteristics and their Relationship to Injuries in University Level Modern Dancers. Journal of Dance Medicine & Science, 19(2).	cross-sectional observational cohort study	**number:** 22 dancers **sex:** 20 female **dance style:** modern **level:** university level **Ø age**: 21.27 years (range: not provided)	**inclusion criteria**: not provided. Modern dancers undertaking a university level modern dance core curriculum were included. **exclusion criteria:** not provided

Table 2
Data extraction.

Author, Year	Exposure	Outcome	Measurement Procedures	Results	
				Injuries	Turnout
Cimelli and Curran, 2012	CTO = increase of foot pronation with increasing TO (compensation = "forcing" or "excessive pronation")	**location:** injuries to the spine, hip, thigh, knee, lower leg, ankle, foot **mechanism:** not stated **definition:** All injuries that prevented execution of a functional TO	**turnout:** angle of TO and angle of gait on tracing paper and via Foot Posture Index **injuries:** self-reported occurence before the previous 12 months, and during the previous 12 months via dance history and injury questionnaire no details on questionnaire provided	**number of injuries:** 28 injuries reported in 12 dancers 7 male dancers: 2.86 SD ± 0.55 5 female dancers: 1.6 SD ± 0.55 of which 11 injuries occured in the previous 12 months **injury location:** spine (n = 5) hip (n = 6) thigh (n = 2) knee (n = 6) ankle (n = 5) foot (n = 4)	relationships found between (1) Foot Posture Index and angle of TO (ρ = 0.933–0.968, P < 0.01) and (2) the number of reported injuries and change in foot posture in the angle of TO for the right foot only (ρ = 0.789, P < 0.01)Dancers showed a tendency toward pronation when moving into TO.
Coplan, 2002	CTO = FTO – bilateral pHER (compensated TO = functional TO minus bilateral passive hip external rotation) "TO was considered compensated when FTO was greater than total passive hip external rotation"	**location:** low back and/or lower extremity **mechanism:** non-traumatic/overuse injuries **definition:** Any pain or dysfunction of the low back or lower extremities that impacted the dancer's ability to practice or perform.	**turnout:** CTO values for injured and non-injured dancers derrived from: (1) passive hip external and internal rotation (prone, hips in neutral position) goniometer (2) total passive hip external and internal rotation ROM (sum of left and right hip values) (3) FTO in 1st position (standing on a sheet of paper, tracing footprints with pen) **injuries:** self-reported throughout the dance career via questionnaire no details on questionnaire provided	**number of injuries:** 22 injuries reported in 14 dancers (47%) 23.5% (n = 7) reported>1 injury **injury location:** low back: 13.6% (n = 3) knee 36% (n = 8) shin 22.7% (n = 5) ankle 13.6% (n = 3) hip 4.5% (n = 1) foot 4.5% (n = 1)	CTO differences found between injured dancers: Ø 25.4° ± 21.3 (P = 0.006) and non-injured dancers: Ø 4.7° ± 16.3 (P = 0.006) Ø CTO-angle was 20.8° greater for injured group than non-injured group (95% CI, CTO range: 7.0°–34.5°)
Dreżewska and Śliwiński, 2013	CTO = increasing sacral inclination in relationship to increasing TO in 1st position ("Compensation in the TO position")	**location:** low back pain **mechanism:** pain intensity **definition:** Pain intensity regardless of its effect on physical performance	**turnout:** (1) angle of sacral bone inclination (baseline mechanical inclinometer) in standing parallel and maximum TO 1st position **pain:** (1) details on occurence, duration, intensity retrieved from medical history forms (2) on-site assessment of pain intensity via Visual Analogue Scale (VAS scale). (3) source for co-existing complaints not clearly stated.	**number of injuries:** 44 dancers reported low back pain (62%) **injury location:** co-existing complaints reported: talo-crural pain (n = 10) knee pain (n = 10) hip pain (n = 7) groin pain (n = 6) right thigh pain (n = 3) right hallux valgus (n = 3)	relationship found between angle of sacral inclination in TO position and pain: subjects with $\geq$ 30° of sacral inclination showed higher Ø pain scores than those with $\leq$ 29°. < 29° sacral inclination in TO: VAS 4.86; range 2–8 (P < 0.05) $\geq$ 30° sacral inclination in TO: VAS 6.32; range 3–9 (P < 0.05) Relationship between sacral inclination angle in parallel position and pain was similar between subjects: $\leq$ 25° sacral inclination in parallel: VAS 5.25; range 2–8; (P > 0.05) > 25° sacral inclination in parallel: VAS 5.74; range 2–8; (P > 0.05)

(*continued on next page*)

Table 2 (*continued*)

Author, Year	Exposure	Outcome	Measurement Procedures	Results	
				Injuries	Turnout
Jenkins et al., 2013	CTO = TPT – pER (compensated TO difference = total passive TO minus passive hip external rotation) muscular-value = TAT/pER (Total active TO as a ratio of passive hip external rotation)	**location:** not provided **mechanism:** traumatic and overuse injuries **definition:** physical damage to the body or a body part, which prevented completion of one or more entire curriculum class.	**turnout:** (1) FTO (measured like, equalled to, and further referred to as Total Active TO = TAT): Functional Footprints® (2) Total passive TO (TPT): goniometer (supine, hip neutral) (3) Passive hip ER (pER): goniometer (supine, hip flexed 90°) (4) CTO: TPT – pER (total passive TO minus bilateral passive hip external rotation) (5) Active external rotation lag: TPT – TAT (6) Muscular-value: TAT/pER (Total active TO as a ratio of passive hip external rotation) **injuries:** (1a) records of physiotherapist-reported injuries (used for assessment) (1b) self-reported over a 10 months period via Dance UK Injury Questionnaire	**number of injuries:** total of 47 injuries physiotherapist-reported: 0 injuries (12%) 1 injury (24%) 2 injuries (6%) 3 inuries (4%) 4 injuries (1%) **location of injuries:** no further information provided due to a lack of consistent information	CTO and muscular-value were found positively predictive for physiotherapist-reported injuries. CTO and muscular values are predictive of>2 injuries (2 +): CTO difference odds ratio 1.090, 95% CI (1.002–1.186) for every 1% increase in CTO, there is a 9% increase in the odds that the dancer will be in the 2 + injury group (compared to the 0–1 injury groups) Muscular-value odds ratio: 1.084, 95% CI (1.021–1.151) for every 1& increase in the muscular-value, there is an 8.4% increase in the odds that the dancer will be in the 2 + injury group (compared to the 0–1 injury groups)
Negus et al., 2005	CTO = static FTO – bilateral aHER (compensated TO = static functional TO minus bilateral active hip external rotation)	**location:** low back, lower extremity **mechanism:** non-traumatic/overuse and traumatic **definition:** any pain, discomfort, or other musculoskeletal problem, which required modification of, or time away from, dance training, examinations, or performance in the previous 2 years.	**turnout:** (1) Passive and active hip external rotation; supine, hip extended, knee flexed; goniometer (2) static FTO (sFTO): standing 1st position, both 5th positions tracing paper dynamic FTO (dFTO): tracings after 3 jumps (1st + 5th position) (3) Active external rotation lag: total passive hip external rotation – total active hip external rotation (4) CTO: static FTO – total active hip external rotation (5) Static-dynamic TO difference: sFTO – dFTO **injuries:** self-reported via interview to assess lower extremity non-traumatic and traumatic injury history over the previous 2 years	**number of injuries**: 100% (n = 29) reported injuries over the previous 2 years overuse: 93.1% (n = 27) traumatic: 41.4% (n = 12) 27 participants (93.1%) reported to be currently injuried: 86.2% (n = 25) overuse injuries 24.1% traumatic injuries **location of injuries:** (non-traumatic; traumatic): hip: 23.5% (n = 16); 35.7% (n = 5) ankle: 22.0% (n = 15); 42.9% (n = 6) lower leg: 23.5% (n = 16); 0.0% (n = 0) foot: 10.3% (n = 7); 14.3% (n = 2) low back: 11.8% (n = 8); 0.0% (n = 0) knee: 7.4% (n = 5); 7.1% (n = 1) thigh: 1.5% (n = 1); 0.0% (n = 0)	correlation found between the number and severity of overuse injuries, which were associated with reduced FTO (r = > 0.38; P < 0.04) but not with hip ROM. The number of overuse injuries was positively correlated with 6 TO variables: CTO in all 3 positions and static-dynamic FTO in all 3 positions: r = 0.39–0.55, P < 0.039 Severity of non-traumatic injuries was positively correlated with 3 TO variables: static-danymic TO difference in all 3 positions: r = 0.38–0.47, P < 0.043 CTO was correlated between all 3 positions (1st, 5th right foot, 5th left foot): r > 0.88, P < 0.001

Table 2 (*continued*)

Author, Year	Exposure	Outcome	Measurement Procedures	Results	
				Injuries	Turnout
Steinberg et al., 2011	"Incorrect TO technique" (anterior pelvic tilt and sickling of the feet in plié) as a risk factor for paratenonitis	**location:** paratenonitis of the ankle and foot **mechanism:** no details provided **definition:** current pain in the ankle or foot region, that is, movements or exercises that evoke pain or pain that disturbed her dance practice and daily life activity.	**turnout:** no measurements provided; results based on clinical examination and observation of technique **injuries:** medical examination records on current foot or ankle paratenonitis	**number of injuries**: 8.6% (n = 93) paratenonitis of foot or ankle joints **location of injuries**: paratenonitis of the joints of foot or ankle	lumbar hyperlordosis in the attempt to increase TO resulted in higher risk for paratenonitis compared to dancers with correct technique (no numbers provided) further associations: dancers with paratenonitis had greater hip external rotation ROM compared to dancers without paratenonitis (OR, 1.048, 95%; CI 1.014–1.083) 38% of dancers with hyper hip external rotation were injured compared to 20% of non-injured dancers with hyper hip external rotation (P = 0.001) (no further numbers provided)
van Merkensteijn and Quin, 2015	CTO = FTO – aHER (compensated TO = functional TO in 1st position minus total active hip external rotation)	**location:** low back, lower extremities **mechanism:** traumatic and non-traumatic/ injuries **definition:** any pain, discomfort, or musculoskeletal problem, that would cause modification of technique or time away from dance class, rehearsal, or performance in the previous 2 years.	**turnout:** active hip external rotation (AHER): prone; goniometer FTO: foot tracing on white paper in standing 1st position **injuries:** self-reported via questionnaire over the pevious two years; injury questionnaire was referenced to Trepman et al. (2005) Spinal problems in dancers. In: R. Solomon, J. Solomon, & S.C. Minton: Preventing Dance Injuries. Champain, Human Kinetcs, p.85–97.	**number of injuries:** non-traumatic/overuse: 68% (n = 15) traumatic: 36% (n = 8) **location of injuries:** foot/ankle: (n = 16) knee: (n = 7) low back: (n = 6) hip pain: (n = 5) shin splints: (n = 1)	correlation found between CTO with 1 + traumatic injury: r = 0.45, (n = 22), P = 0.04 correlation found between CTO Ø 43° with 2 + injuries: r = 0.45, (n = 22), P = 0.04 no correlation found between CTO and nontaumatic/overuse injuries: r = 0.20, (n = 22), P = 0.36 relationship found between increased CTO and low back pain (r = 0.50, (n = 22), P = 0.02) but not between CTO and other injuries All participants compensated TO (3°-72°) Ø CTO: 36° ± 17° Ø FTO: 113° ± 14° Ø active hip external rotation: 78° ± 16°

TO: turnout.
CTO: compensated TO.
FTO: functional TO.

approach to TO, i.e., the focus on the hip, spine, or foot only instead of assessment of the spine, pelvis, and lower extremities as an entity of TO. Information on missing data was not reported, and apart from Jenkins et al., where confounder adjustment was not applicable as they focused on prediction and not on etiology, none of the other studies addressed handling of confounders, although dancing style (Kenny et al., 2016; Sobrino et al., 2015), expertise (Caine et al., 2016; Lee et al., 2017), or age (Kenny et al., 2016; Leanderson et al., 2011) might have led to confounding. Selection bias and small sample sizes were also likely to have had an impact on the validity of the presented results. One study used their exposure in the definition of the outcome, which is equally likely to have influenced the results (Cimelli and Curran, 2012).

3.6. Detailed results

Different anatomical foci and a variability of methods of TO assessment (measurement and calculation) of the studies prevented pooling of results and generalizability.

3.7. Misaligned turnout – Focus on spine and feet

3 studies investigated the relationship between specific body parts and/or specific injuries, and misaligned TO. Steinberg et al. focused on tendinopathies of the ankle and foot in 1082 young female amateur dancers and found a relationship between hyperlordosis and paratenonitis, but no correlation with "sickling" or "rolling" of the foot. Cimelli et al. investigated change in foot posture in relationship to TO angle and injury in 5 female and 7 male contemporary dancers. The authors found relationships between the foot's tendency towards pronation with increasing angle of TO, as well as the number of reported injuries and amount of pronation of the (right) foot in TO. Drężewska et al. studied lumbosacral pain in 45 female and 26 male pre-professional ballet students and reported a correlation between the degree of TO and low back pain through a compensatory anterior pelvic tilt. A sacral bone inclination angle of $\geq 30^\circ$ was related to an increase of risk and intensity of low back pain in dancers.

3.8. Compensated turnout – Focus on the lower extremities

In general, CTO was defined as the difference in degrees between the bilateral angle of (active or passive) hip external rotation and the angle of (active or passive) total turnout in the dancer. However, 4 studies used various calculations of "compensated TO" ("CTO") to investigate the lower extremities (Table 2). Coplan found that 90% of the college level ballet dancers and instructors with CTO > 25° were injured, van Merkensteijn et al. confirmed that modern dancers with CTO < 26° had no injury, whereas dancers with 2 or more injuries had CTO of > 43°. Negus et al. showed that poor dynamic control of functional TO and compensated TO in pre-professional ballet dancers were linked to severity of (overuse) injuries and a history of injuries in 100% of the dancers. CTO ranged from 68.9° in 1st to 86.9° in 5th position. Jenkins et al. investigated if TO measurements can be used to predict physiotherapist-reported injuries in 47 female contemporary dance students. For every 1% of CTO-increase they reported a 9% increase in the odds to sustain 2 or 2+ injuries. Their second variable correlating with injury risk showed that with every increase of 1% in this so-called "muscular value" (i.e., the total active TO as a ratio of passive hip external rotation) the odds to be among the 2+ injury group increased for 8.4%. The authors aimed to quantify the injury risk through CTO in a longitudinal prediction study.

4. Discussion

The purpose of this review was to find out if there is conclusive evidence for the often-claimed relationship between misaligned TO and the incidence of injuries of the lower back and lower extremity. In our systematic review, 1 longitudinal and 6 cross-sectional studies reported that compensated or forced TO can be linked to musculoskeletal injuries in dancers. However, a cross-sectional study design cannot allow conclusions on a causative relationship between exposure and outcome. Both occur at different points in time and thus cannot be identified if only one point in time (the cross-sectional study design) is investigated. For that matter, current injuries (Cimelli and Curran, 2012; Negus et al., 2005), injuries reported in the dancers' injury histories prior to testing (Coplan, 2002; Steinberg et al., 2011; van Merkensteijn and Quin, 2015), or which occurred during longitudinal study procedures (Jenkins et al., 2013) may also have led to misaligned TO and confounded the exposure measurements. Thirdly, none of the studies evaluated the overall musculoskeletal system involved in TO (i.e. spine and the lower extremity as an entity), but focused on isolated anatomical aspects only. The methodological quality of the reviewed articles stress the need for better research methods on a potential association between forced TO and occurrence of injuries.

4.1. The complexity of dynamic turnout and related misalignment

In efficient motion, optimal movements need the least amount of force. In any other case overstrain and injuries might occur. The amount of TO a dancer is maximally able to present ("functional TO") when maintaining efficient alignment is determined by passive anatomical structures (i.e. bony-cartilage articulations and ligaments), the dancer's "total passive TO", regardless of strength and motor control (i.e., the dancer's "total active TO"). On average, functional TO-values of 134° have been found in professional dancers (Washington et al., 2016). The difference between these values and the "desired 180°" is regarded as compensating or forcing TO. This can be achieved by 3 mechanisms: lumbar hyperlordosis, forced shank external rotation ("screwing the knee"), and hyperpronation/abduction of the feet ("rolling-in-phenomenon") (Clippinger, 2005), most probably employed in various combinations (Fig. 2).

Individual anatomical predispositions as well as reasons for forcing or compensating can be manifold. They may range from neuropsychological aspects, such as personal motivation and perfectionistic striving, (lack of) knowledge and awareness, stress, or poor coping skills, to faulty technique, lack of inter- and intramuscular co-ordination and strength endurance, poor dynamic motor control, especially in end range co-ordination, or general fatigue (Grossman et al., 2005, 2008; Picon et al., 2018). Hence, concise definition of compensating or forcing is essential for analysis of injury mechanisms and locations, especially because both entities describe differently related aspects (Fig. 2).

The high prevalence of low back pain as well as injuries to the knee, lower leg, foot, and ankle in dancers are commonly attributed to compensating and forcing of TTO (Arendt and Kerschbaumer, 2003; Cimelli and Curran, 2012; Khan et al., 1995; Rietveld, 2013; Steinberg et al., 2011, 2012). However, the reviewed studies present large heterogeneity in their outcome measures, i.e., numbers and locations of injuries, as well as underlying mechanisms, i.e., overuse and traumatic injuries. Since compensation might be present at one or several locations simultaneously (lumbar spine, lower extremity: knee joints, ankle, or foot), the association between the occurrence of compensation and the locations of misalignment leading to injury is poorly understood. When forcing

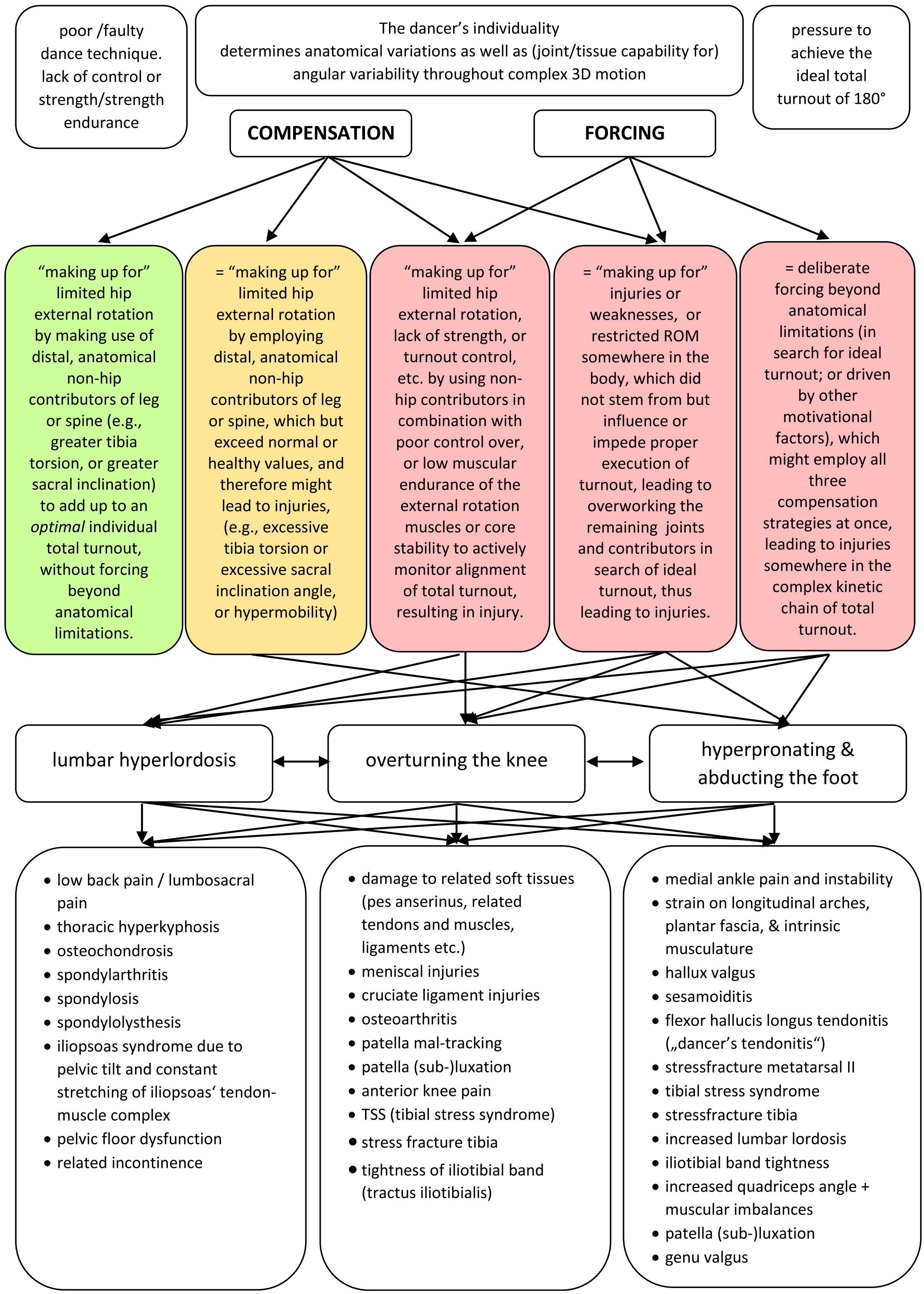

Fig. 2. Definitions and analysis of compensating and forcing turnout as well as related structural and functional impairments and injuries.

TO, dancers may employ 1, 2, or all 3 compensatory mechanisms. One body part might be the location of forcing, another region the one to become injured, while both are compensating for yet a third anatomical part. The complexity is even greater since these in- and extrinsic factors have an intricate interplay as well. These complex interactions remain unaddressed, become generalized, or are labelled in a variety of ways. However, they have to be taken into account in order to locate and prevent injuries.

Table 3
Methodological quality assessment.

	Cimelli	Coplan	Dreżewska	Jenkins	Negus	Steinberg	Merkensteijn
INJURY OUTCOMES	D	D	D	HS	D	S	D
EXPOSURE ASSESSMENT	S	HS	S	D	S	HS	HS
SELECTION BIAS	D	D	D	D	D	D	D
CONFOUNDER ADJUSTMENT	D	D	D	Not applic.	D	D	D

D: deficiencies.
S: sufficient.
HS: high standard approach.

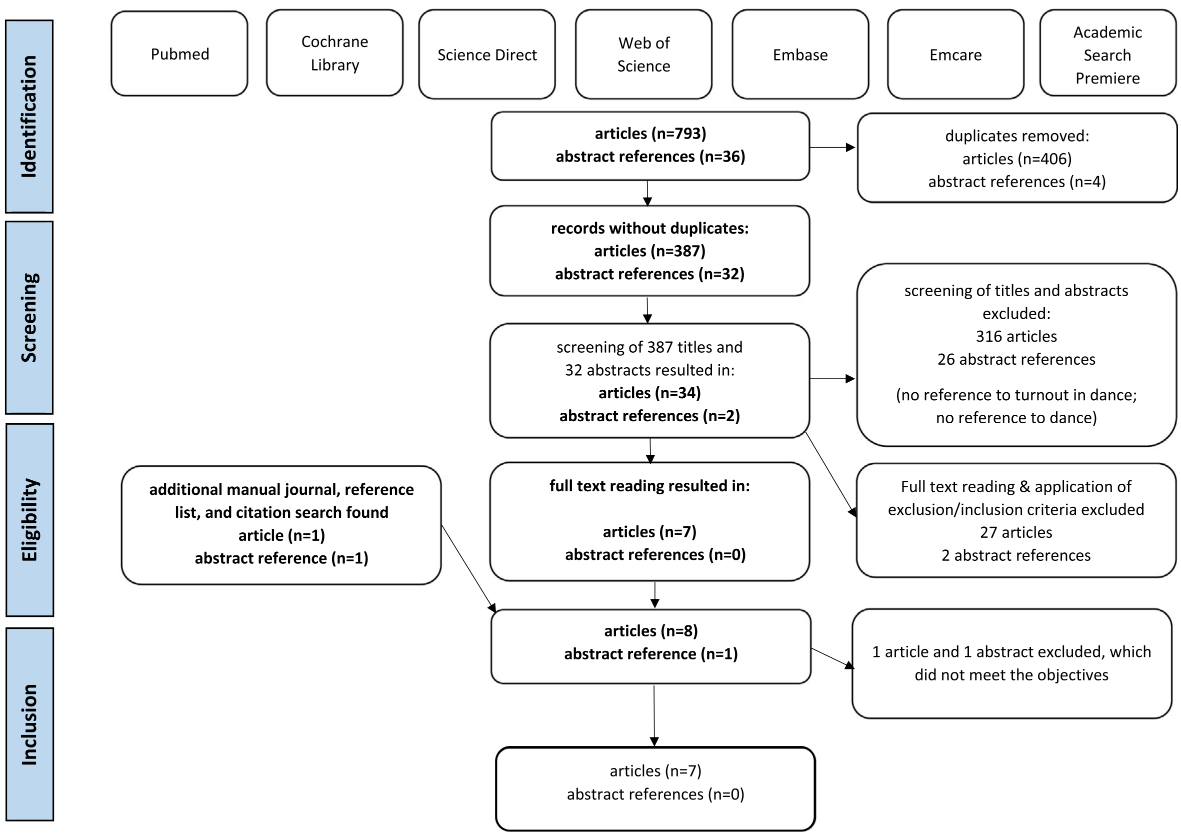

Fig. 3. Search documentation flow chart.

4.2. A simplified approach – Hip versus non-hip contribution

Heterogeneity existed on TO assessment and the interpretation of compensating or forcing of TO. For instance, the 4 studies on compensation of the lower extremities used 4 different methods of assessment (2 based on functional TO, 1 on total passive TO, and 1 study based on functional TO, which was equalled to and measured like total active TO). All studies focused on the hip joint only, which is supposed to be responsible for about 60–70° (58–60%) of TTO (Hamilton et al., 1992; Welsh et al., 2008). Although the hip joint is the most efficient monitor of the leg axis, the non-hip contributors (i.e., lower spine, innate femoral torsion, end range rotation of the knee, innate tibial torsion, and pronation of the subtalar complex) add 20-30° or 40% to total TO (Champion and Chatfield, 2008; Clippinger, 2005; Grossman et al., 2005; Hamilton et al., 1992). However, none of these factors were accounted for in the studied articles with a focus on hip external rotation versus non-hip-contributors.

The reduction of “compensation of TO” to the non-hip contributors presents too simplified a model of this complex interplay between spine and all joints and ligaments of the lower extremity. Non-hip contributors play a far greater and more complex role than previously established (Picon et al., 2018; Quanbeck et al., 2017; Washington et al., 2016). Lower spine, knee, ankle, and foot are all part of the overall kinetic chain of TO. Hence, these contributors should be considered in correctly aligned as well as forced or compensated TO. Their anatomical variations may further determine (Grossman et al., 2008), why some dancers are more likely to become injured than others, after the hip *and* non-hip-contributions are exceeded. Studies on isolated anatomical aspects of TTO (Cimelli and Curran, 2012; Dreżewska and Śliwiński, 2013; Steinberg et al., 2011) highlight the importance to account for anatomical variations in the search for objective overall assessment. Thus, a hip-only focus limits the understanding of underlying mechanisms leading to compensation or forcing, resulting in overuse and injury.

4.3. Dynamic- and multiple-position-assessment

TO is a complex dynamic concept, dependent on an intricate interplay of multiple joints, all contributing with different angular velocities, when the dancer moves through TO. Especially in classical ballet, the 5th position (Fig. 1) is the position most often used. But in the reviewed articles the assessment of TO was mainly focused on 1st position and on static measurements. Only Negus et al. stressed the importance of crossed-leg-positions, such as the 5th position, and dynamic assessment through pliés and jumps (Gilbert et al., 1998). The reported compensation in 5th position-TO was characterised by nearly 20° more external rotation of the lower limb compared to 1st position. Other authors showed the coinciding increase in sacral inclination (Jones and Sparkes, 2017). Moreover, in 5th position the dancer can fix the heel of the front foot against the forefoot of the back leg, which allows the subtalar structures to achieve more hyperpronation and more external rotation in the knee compared to the 1st or other open positions (Grossman, 2003). Dynamic knee-motion capture analysis showed that despite a dancer's full knee extension, the thigh and lower leg did not move as one segment in TO, as was previously assumed (Grossman et al., 2008; Quanbeck et al., 2017; Washington et al., 2016). Results indicate that the knee is not protected against shear forces when locked. The dancer's strive for ideal total TO requires intense, yearlong training to achieve the adjustments needed in joints and soft-tissues (Picon et al., 2018; Winslow and Yoder, 1995). Those can lead to injuries (e.g., pes anserinus, meniscus, osteoarthritis (Hempfling and Bohndorf, 2007), subtalar joints, etc.), depending on anatomical variations. Extrinsic factors, such as the need to employ a variety of possibilities of faulty dance technique to be able to accomplish the necessary adaptations (e.g., an incomplete locking of the front knee in the closing of the 5th position (Morris et al., 2014), or the use of plié to force a greater TO angle of the feet (Cimelli and Curran, 2012; Coplan, 2002)) play further important roles. Thus, an analysis of non-hip-contributors throughout dynamic alignment in all positions and not only in the static 1st position is essential when analysing injury risk of (ballet) dancers.

Validated methods of assessing maximum passive ROM of hip and knee joint as well as lumbosacral and subtalar motion exist. For that matter, in prevention of injuries and the planning of training the dancer's phenotype (e.g., monitoring passive range of motion of joints, etc.) and (dynamic) kinematic data (e.g., motion capture) should both be taken in consideration (Armstrong and Relph, 2018; Chorba et al., 2010). The difference between summative TTO and the "ideal TO" of 180° can be used as reference guides for assessment, prevention, treatment, and rehabilitation of (overuse) injuries related to TO, accounting for anatomical variations in the dancer. Active "misaligned-TO-measures" during health screenings or auditions can be used to screen for a higher likelihood of injury using the difference between functional TO (FTO) and total active TO (TAT) as reference for individual dancers, employing goniometer (Grossman et al., 2008), plurimeter (Stoliński et al., 2014), and/or rotator discs. The "FTO minus TAT"-difference may alert the teacher to start preventive measures, such as abstaining from certain positions during ballet, unless all necessary criteria in the individual dancer are met. Finally, neuropsychological aspects, i.e., the constant motivation (perfectionistic tendencies and external pressure) to achieve ideal TTO of 180° as well as acknowledging that and why injuries are occurring through misaligned TO in practice, need to be discussed as part of a prevention of injuries.

Some limitations have to be addressed: First, only 7 studies, relating injuries to compensated or forced turnout could be found, despite a thorough search strategy. Second, due to the large heterogeneity in methodology and presentation of results, no conclusions can be based on the presented articles, highlighting the need for a standardised methodology for assessing TO. As TTO is strongly associated with a complex interaction of dynamic motion of spine, lower extremity joints, ligaments and soft tissue, analysis will be complex. Nevertheless, all these aspects have to be taken into account, rather than generalising isolated anatomical approaches, if an adequate analysis of complaints in these high-performing artistic athletes is executed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2020.110084.

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