Musculoskeletal Science and Practice 42 (2019) 166–172

Contents lists available at ScienceDirect

Musculoskeletal Science and Practice

journal homepage: www.elsevier.com/locate/msksp

# Single and dual tandem gait assessment post concussion: What performance time is clinically relevant across adult ages and what can influence results?

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ARTICLE INFO

*Keywords:*
Adults
Concussion
Dual task
Mild traumatic brain injury
Healthy individual data
Single tandem gait

ABSTRACT

*Aim:* The three-metre tandem gait test (TG) is used to assess postural control during locomotion following sports concussion. However, values used to determine a pass/fail result are currently based on young athletic populations. Times for test completion may be influenced by several intrinsic or extrinsic factors. The aim of this study was to collate healthy individual single, dual task as well as dual task cost – motor TG times for a non-elite athlete population, across several age groups, and to investigate several potential influencing factors.

*Methods:* Healthy individuals aged 18–55+, who had never experienced a concussion completed single and dual task TG following the SCAT5 protocol. A separate group (n = 20, age, foot length and body mass index matched) performed the tests with alternate instructions.

*Results:* Mean best TG time for all participants were: single task 21.03 ( ± 5.26s), dual task 29.59 ( ± 9.84s) and DTC-motor 8.57 ( ± 7.5s:41.7%). Age and foot length but not specificity of verbal instructions were related to TG times. Significantly slower single and dual task times were identified for the 55 + age group when compared to the three youngest groups ($p < 0.01$). No difference was seen for DTC-motor time or % between age groups ($p > 0.05$).

*Conclusion:* Healthy individual data collected exceeded previously reported average times. Faster times were evident in younger participants and those with longer foot length. Results from this study can be used as a reliable guideline to inform clinical decisions around the pass/fail result of TGT across age ranges in non-elite athlete populations post-concussion.

## 1. Introduction

Locomotor deficits are a recognised sensorimotor impairment following concussion or mild Traumatic Brain Injury (mTBI), and are evident immediately post-injury (Oldham et al., 2018; Howell et al., 2015; Catena et al., 2009a; Parker et al., 2006, 2008). Consequently, tasks including the 3-m tandem gait test (TG) have been incorporated into post concussion assessment tools such as the Sport Concussion Assessment Tool 5th Edition (SCAT-5) (Echemendia et al., 2017; Davis et al., 2017). TG can be assessed as a single task (TGT-S) with individuals required to walk using heel-toe gait along a 3-m line, turn 180° and return, with any failed attempts repeated (Cohen et al., 2012, 2018; Schneiders et al., 2010a). Alternately tandem gait dual task (TGT-D) is performed with cognitive overlay (Cohen et al., 2012, 2018; Howell et al., 2017a, 2017b). Compared to healthy controls longer completion times have consistently been demonstrated in adolescent and young adults acutely post concussion for the TGT-S (Oldham et al., 2018; Howell et al., 2017a), with a more protracted normalization period evident in similar age groups for TGT-D (Howell et al., 2017a). Hence, it has been suggested that TGT-D may be a more suitable gait assessment for monitoring recovery of postural control post concussion (Howell et al., 2017a; Lee et al., 2013).

Advantages of both tests are their simple and easy administration with minimal equipment required, making them suitable for use by health professionals and sports trainers alike, and in most settings (Schneiders et al., 2010b). However, the majority of studies have been conducted in younger individuals (Schneiders et al., 2010a; Howell et al., 2017b; Oldham et al., 2016; Eemanipure et al., 2011). Due to age related changes in postural control (Vereeck et al., 2008; Gill et al., 2001; Hageman et al., 1995; Whipple et al., 1993), proposed healthy individual completion times may not be valid for older individuals. Establishing these values in older populations would seem important

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https://doi.org/10.1016/j.msksp.2019.04.006
Received 30 October 2018; Received in revised form 1 February 2019; Accepted 9 April 2019

given the prevalence and increased morbidity associated with concussion in older populations (44 years + ) (Cassidy et al., 2004).

Further, there is some uncertainty regarding current values for healthy younger populations with significant variability of completion times for TGT-S ranging between 11 and 16 s depending on testing conditions (Schneiders et al., 2010b; Oldham et al., 2016). As a result, high rates (74%) of false-positive results in healthy controls have been reported using 14 s cut off reported in the SCAT 3 (Santo et al., 2017). Such a finding potentially representing a contributing factor to the decision to remove the criteria from the SCAT 5 user guidelines (Guskiewicz et al., 2013; McCrory et al., 2013; Sport concussion assessme, 2017). Hence, a need clearly exists for greater certainty regarding reliable values encompassing a broader age range in order for tandem gait assessment to retain usefulness in the clinical setting for evaluation post-concussion.

Apart from the necessity of reliable cut off times, the influence of certain intrinsic and extrinsic factors also requires further consideration. To date intrinsic variables including height, Body Mass Index (BMI), gender and level of athletic participation have shown variable amounts of influence on TGT-S (Schneiders et al., 2010a, 2010b; Oldham et al., 2016; Santo et al., 2017) and TGT-D (Howell et al., 2017b). Therefore, further clarification regarding effect of these variables is warranted. Additionally, while height has demonstrated influence on testing times (Santo et al., 2017), a possible associated factor, foot length, has not yet been investigated. Furthermore, while it is known that extrinsic factors including test surface and footwear influence test performance (Schneiders et al., 2010b), specificity of instructions is yet to be investigated for effect. While the test does not specifically prioritise speed or accuracy, if individuals are advised of fail conditions before testing, this could inadvertently contribute to cognitive-motor interference (Strobach and Torsten, 2017) and potentially increase performance times (Al-Yahya et al., 2011).

Finally, it has been suggested that considering the dual task cost (DTC) or the difference between the time taken to complete the dual versus single task may also be a useful measure (DTC-Motor) (Strobach and Torsten, 2017; Sambasivan et al., 2015; Lynall et al., 2017). This measure may prove to be more consistent and independent of extrinsic factors and potentially reduce reliance on baseline testing.

Therefore three specific objectives of this study were to; 1) identify and compare healthy individual data for TGT-S, TGT-D and DTC-Motor across the adult age range of 18–70 years; 2) investigate the influence of certain intrinsic and extrinsic variables on outcomes; 3) compare results of TGT-S, TGT-D and DTC-Motor when specific instructions regarding "fail" conditions are administered prior to testing, or when only instructions related to task performance are given.

It was hypothesized that:

TG values would be greater in older versus younger age groups.

TG values would be influenced by intrinsic factors such as foot length, BMI and physical activity levels and by extrinsic factors such as instructions.

## 2. Materials and methods

### 2.1. Participants and design

Recruitment for this study took place between March and May 2018. Participants included students, staff, and friends or relatives of students from the University of XXXXXXX. Males and females within age ranges (in years): 18–24, 25–34, 35–44, 45–54 and 55 + years were sought. Twenty further subjects recruited for phase two of the study, to investigate the influence of two types of administered instructions, were age, gender, foot length and BMI matched to 20 subjects from phase one of the study for comparison. Exclusion criteria included any known (current or pre-existing) neurological or vestibular impairment; recent (within the preceding 12 months) lower limb trauma or surgery; whiplash injury; chronic headaches or neck pain (longer than 3 month history); or a medically diagnosed concussion or mTBI within the last ten years. The study received ethical approval from the institution's ethics committee (Bellberry HREC2016-04-311). All participants were given participant information sheets and provided written, informed consent prior to participation.

### 2.2. Measures

Thirteen examiners with conferred degrees in human movement or sport science collected all measures. Each examiner received the same training consisting of a one-hour skills session, an information booklet, and standardized instructions and data collection methods.

#### 2.2.1. Demographic information

Prior to participation individuals provided written responses to questions related to age, gender, shoe size, Body Mass Index (BMI) and activity levels using the International Physical Activity Questionnaire – short form (IPAQ) (Craig et al., 2003). Shoe size was converted to foot length using the international shoe size conversion chart (http://www.shoesizes.co), BMI was calculated by dividing weight (in kilograms) by height (in metres squared). Conversion of self-reported activity levels to the metabolic equivalent of task (METS) was performed using the activity level equation suggested by Craig et al. (2003) using a prefabricated excel spreadsheet provided by the Karolinska Institute www.ipaq.ki.se.

**Phase one**

#### 2.2.2. Tandem gait single-task

Participants performed the TGT-S assessment, consistent with SCAT5 protocol (Sport concussion assessme, 2017). *Instruction 1* (Appendix A) was used along with a demonstration of tandem gait. Examiners counted down "3, 2, 1" and participants walked barefoot using a heel-toe gait along a 3-m long 38 mm wide line adhered to a solid even walking surface, turning 180° once both feet had crossed the 3-m indicator line. Individuals then returned to the starting point using the same heel-toe gait. Each repetition was timed using a stopwatch or smartphone to 0.01 ms accuracy. Prior to testing, participants were informed of all "fail" conditions subsequently requiring the trial be repeated. Fail conditions included missing heel-toe contact more than once, stepping off the tape, turning before both feet passed the 3-m mark, steadying themselves on any nearby supports, or total loss of balance. Participants were informed that the test was timed for speed and accuracy, and that they should put in their best effort. Each participant performed three trials and repeated any "failed" performances until times for three accurate trials were recorded (Schneiders et al., 2010a, 2010b). No practice tandem gait attempts were given, although if the first trial time was notably different (more than several seconds difference) to the following trial times, the initial trial was considered a "practice trial" and a fourth trial time was collected. These conditions were consistent for all participants and conditions.

#### 2.2.3. Tandem gait dual-task

The TGT-D repeated the TGT-S protocol while participants counted backwards by three from a number ranging between 70 and 90. Participants practiced the cognitive task prior to commencing the test. If the participant reported they were unable to perform the cognitive task assigned (usually in the case of counting backwards) (Cossette et al., 2016), alternate tasks of reciting the months of the year backwards or counting backwards by two's were provided (Catena et al., 2007). An additional "pass" condition for the TDT-D was the requirement to verbalize the next serial response at least once every four steps. Where the participant did not achieve this, the test was marked as a "fail" and repeated. Participants were again encouraged to put in their best effort and counted down before commencing. Trial times and fails as well as number of cognitive errors were recorded as above.

**Phase two**

#### 2.2.4. Modified instruction tandem gait

A separate group of participants was assessed by 5 of the original 13 examiners and received a reduced set of instructions for both TGT-S and TGT-D (*Instruction 2* - Appendix A). Participants were instructed to complete the test as per instructions for phase one however descriptors of what constituted a failed trial were omitted from instructions.

#### 2.2.5. Data and statistical analysis

Best times for TGT-S, TGT-D were used in analysis and dual task cost (DTC-Motor) was then calculated based on the absolute difference in seconds between the two values as well as the percentage change. A Shapiro-Wilk test inspected distribution of data overall and by group. Subsequently, mean and standard deviation with 95% confidence intervals were calculated for age, foot length, physical activity and BMI for each age group. One-way ANOVA assessed for significant demographic differences for numerical data and a Fisher's exact test assessed for differences in gender proportion between the age groups. Spearman's Rho Correlation identified any relationship between test times as well as intrinsic variables (age, gender, foot length, BMI and physical activity). Factors that demonstrated significant correlations were included in further models as covariates. Four generalised linear models with bonferroni adjustment were used to compare group differences between a) age groups, b) gender c) examiners and d) foot length (grouped as small (23–27 cm) or large (> 27 cm)) on TGT-S, TGT-D time and DTC-Motor. In order to determine the suitability of previously identified cut-off values of 14 s the number of participants who were unable to achieve this for TGT-S and TGT-D was calculated. Finally, independent T-tests were performed to determine any differences in TG times between those who were given *Instruction 1* compared to *Instruction 2*. Data was analysed using SPSS software (IBM Corp. Released, 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.).

## 3. Results

### 3.1. Phase one

One hundred and twenty nine individuals (67M, 62F) participated and were divided into 5 age groups. Table 1 shows demographic details categorised by age group. No significant differences were evident for demographic variables including ratio of males to females, mean foot length or activity levels between age groups. A significant difference in BMI only was evident between the 18–24 and the 45–54 age groups (p0.02).

Significant mild to moderate correlations (r 0.18–0.43) were seen between intrinsic factors: age, gender, foot length, BMI and activity levels, and TGT-S and TGT-D with the exception of activity levels for TGT-D. Therefore, all were considered as covariates in further analyses. No correlations were seen for number of cognitive errors or DTC-Motor percentage or DTC-motor time apart from age for time. There was also a highly significant correlation between foot length and gender (r −0.77) (Table 2).

#### 3.1.1. DTC-M dual task cost- motor

Tandem walk times for each age group are shown in Table 3. Fastest

**Table 2**
Correlation values among factors contributing to tandem gait best time and number of cognitive errors.

| | Age | Foot length | Body Mass Index | Activity Level | Gender |
|---|---|---|---|---|---|
| Single Task | 0.43** | −0.29** | 0.21* | −0.19* | 0.25** |
| Dual Task | 0.37** | −0.20* | 0.18* | −0.01 | 0.19* |
| DTC-M | 0.19* | −0.07 | 0.12 | 0.11 | 0.08 |
| DTC-M% | 0.09 | 0.01 | 0.08 | 0.15 | 0.01 |
| Cognitive errors | 0.09 | −0.03 | −0.06 | 0.03 | 0.02 |

* Correlation significant at the 0.05 level.
** Correlation significant at the 0.01 level.

**Table 3**
Mean and standard deviation (SD) of the tandem gait best times in seconds for single and dual task and dual task cost-motor time and percentage and number of cognitive errors among age groups.

| | Mean | SD Deviation | 95% CI | |
|---|---|---|---|---|
| | | | Lower | Upper |
| *Single-Task (TGT-S)* | | | | |
| Age 18-24 | 18.49 | 3.72 | 17.09 | 19.87 |
| Age 25-34 | 19.76 | 3.76 | 18.59 | 20.93 |
| Age 35-44 | 20.58 | 3.24 | 18.79 | 22.38 |
| Age 45-54 | 22.67 | 4.70 | 20.72 | 24.60 |
| Age 55+ | 26.64* | 7.95 | 22.55 | 30.73 |
| **Total** | **21.03** | **5.26** | **20.11** | **21.95** |
| *Dual-Task (TGT-D)* | | | | |
| Age 18-24 | 25.54 | 7.31 | 22.81 | 28.27 |
| Age 25-34 | 27.97 | 8.53 | 25.31 | 30.62 |
| Age 35-44 | 26.40 | 6.42 | 22.85 | 29.96 |
| Age 45-54 | 32.23 | 8.99 | 22.52 | 35.95 |
| Age 55+ | 39.73* | 12.93 | 33.08 | 46.38 |
| **Total** | **29.59** | **9.84** | **27.88** | **31.31** |
| *Dual task cost-Motor time* | | | | |
| Age 18-24 | 7.06 | 7.23 | 4.34 | 9.77 |
| Age 25-34 | 8.20 | 7.46 | 5.88 | 10.53 |
| Age 35-44 | 5.82 | 4.96 | 3.07 | 8.57 |
| Age 45-54 | 9.57 | 6.44 | 6.91 | 12.23 |
| Age 55+ | 13.08 | 9.76 | 8.07 | 18.10 |
| **Total** | **8.57** | **7.52** | **7.26** | **9.88** |
| *Dual task cost–Motor %* | | | | |
| Age 18-24 | 41.80 | 49.2 | 23.43 | 60.18 |
| Age 25-34 | 42.41 | 36.4 | 31.08 | 53.75 |
| Age 35-44 | 28.17 | 22.6 | 15.64 | 40.70 |
| Age 45-54 | 42.33 | 25.0 | 32.00 | 52.65 |
| Age 55+ | 50.91 | 34.8 | 33.02 | 68.80 |
| **Total** | **41.72** | **36.5** | **35.4** | **48.1** |
| *Number of cognitive errors* | | | | |
| Age 18-24 | 0.83 | 0.95 | 0.48 | 1.19 |
| Age 25-34 | 0.71 | 0.89 | 0.44 | 0.99 |
| Age 35-44 | 1.27 | 2.09 | 0.11 | 2.4 |
| Age 45-54 | 1.29 | 0.95 | 0.89 | 1.7 |
| Age 55+ | 0.65 | 0.86 | 0.20 | 1.10 |
| **Total** | **0.91** | **1.13** | **0.71** | **1.10** |

* significant difference from first 3 age groups (p < 0.01).

**Table 1**
Demographics (mean and standard deviation) categorised by age group.

| Age Group | N | Age (Years) | Females (Number/%) (F %) | Mean Foot Length (cm) | Body Mass Index (kg/m2) | Activity Level (METs) |
|---|---|---|---|---|---|---|
| 18–24 | 30 | 22.13 (1.66) | 30 (50%) | 26.51 (1.63) | 23.38 (4.36) | 4110.63 (4441.06) |
| 25–34 | 42 | 28.38 (3.27) | 42 (40%) | 26.79 (1.59) | 24.49 (3.30) | 4004.07 (3795.47) |
| 35–44 | 15 | 38.07 (2.60) | 15 (47%) | 26.34 (1.73) | 25.61 (3.08) | 5222.93 (4430.32) |
| 45–54 | 25 | 50.16 (2.82) | 25 (56%) | 26.54 (1.34) | 26.50 (3.59) | 3279.74 (4358.94) |
| 55+ | 17 | 59.76 (3.27) | 17 (53%) | 26.28 (1.29) | 25.92 (3.52) | 4736.67 (4204.06) |

*Abbreviations:* METs = Metabolic equivalent of task, cm = centimetres, kg/m$^2$ = units of 703.07 kg per cubic meter.

**Table 4**
Mean times and standard deviation (SD) of tandem gait **best times** among foot length groups.

| | Mean | SD | p-value |
|---|---|---|---|
| *Single-Task (TGT-S)* | | | |
| Small (23–27 cm) | 22.17 | 4.69 | **0.04** |
| Large (> 27 cm) | 20.10 | 5.54 | |
| *Dual-Task (TGT-S)* | | | |
| Small (23–27 cm) | 31.16 | 9.41 | 0.21 |
| Large (> 27 cm) | 28.32 | 10.07 | |
| *Dual task cost – Motor time* | | | |
| Small (23–27 cm) | 8.99 | 7.54 | 0.76 |
| Large (> 27 cm) | 8.22 | 7.54 | |
| *Dual task cost – Motor %* | | | |
| Small (23–27 cm) | 40.99 | 33.9 | 0.83 |
| Large (> 27 cm) | 42.31 | 38.6 | |

* significant difference ($p < 0.05$).

completion times were recorded for the youngest age group (Gill et al., 2001; Hageman et al., 1995; Whipple et al., 1993; Cassidy et al., 2004; Santo et al., 2017; Guskiewicz et al., 2013; McCrory et al., 2013; Sport concussion assessme, 2017) for both single and dual task times with times increasing consecutively with age. Significantly slower single and dual task times were identified for the 55 + age group when compared to the three youngest groups ($p < 0.01$). No difference was seen for DTC-Motor time, DTC-M percentage or number of cognitive errors between age groups. Combined average time for all participants was TGT-S 21.03 (± 5.26s), TGT-D 29.59 (± 9.84s) and DTC-Motor 8.57 (± 7.5 s), representing a 41.72 (± 36.5) % increase in performance time between single and dual-task conditions. When the current suggested cut off of 14 s was applied to results, only 6 participants (4.65%) for TGT-S and 1 (< 1%) for the TGT-D of our healthy controls were able to perform the task within this time frame.

No significant differences were evident when results were compared for all tests between gender or examiners when covariates were considered. Those in the larger foot length group (> 27 cm) had significantly faster single task times ($p = 0.04$) compared to the smaller foot length group (23–27 cm) (Table 4).

### 3.2. Phase two

Notably, no significant difference for recorded TG times were identified when Instruction 1 was used compared to Instruction 2 for either TGT-S ($p = 0.89$), TGT-D ($p = 0.40$) or calculated DTC-Motor (for time or percentage change; $p = 0.30$, $p = 0.39$ respectively) (Table 5).

**Table 5**
Tandem gait best times (mean and standard deviation) among instruction groups.

| | *Mean* | *Standard Deviation* | *p-value* |
|---|---|---|---|
| *Single-Task (TGT-S)* | | | |
| Instruction 1 | 20.24 | 3.75 | 0.89 |
| Instruction 2 | 20.52 | 7.80 | |
| *Dual-Task (TGT-D)* | | | |
| Instruction 1 | 30.27 | 12.14 | 0.40 |
| Instruction 2 | 27.36 | 9.23 | |
| *Dual Task Cost- Motor time* | | | |
| Instruction 1 | 10.02 | 11.82 | 0.30 |
| Instruction 2 | 6.85 | 6.78 | |
| *Dual Task Cost- Motor %* | | | |
| Instruction 1 | 53.28 | 76.21 | 0.39 |
| Instruction 2 | 37.30 | 34.3 | |

* significant difference ($p < 0.05$).

## 4. Discussion

This is the first study to report healthy individual values for the widely used three-metre tandem gait (TG) assessments, TGT-S and TGT-D and DTC-Motor across a broad age range of 18–55 + years. Main findings of this study include an overall average best time for TGT-S of 21.03s (± 5.26), 29.59s (± 9.84) for TGT-D and DTC-Motor of 8.57 (7.52) or 41.72 (± 36.5) % when data for all age ranges was combined. However, fastest times of 18.49 (± 3.72) and 25.54 (± 7.31) for the TGT-S and TGT-D respectively were recorded for the youngest age group (Gill et al., 2001; Hageman et al., 1995; Whipple et al., 1993; Cassidy et al., 2004; Santo et al., 2017; Guskiewicz et al., 2013; McCrory et al., 2013). Significantly slower times were obtained by adults in the 55 + age range compared to the 3 youngest age groups (18–24, 25–34, 35–44 years) for both tasks when covariates age, height, BMI, level of activity and foot length were accounted for ($P < 0.01$). These results correspond to previous studies where a mean best time of 17.1s among student athletes (mean age 15.8 ± 1.2 years) (Santo et al., 2017), and an average time of 16.18s over 3 trials in older adolescent (> 16 years) and adults performed TGT-S courtside in bare feet, were reported (14). These results differ significantly from those identified in elite adult athlete populations, with mean best scores of between 9.54s and 11.8s for TGT-S (Howell et al., 2017a, 2017b; Oldham et al., 2016; Fuller et al., 2018; Moreau et al., 2017) and 12.9 s (± 3.4) for TGT-D (Howell et al., 2017a, 2017b).

Furthermore, in the current study, only 6 participants (4.65%) for TGT-S and 1 (< 1%) for the TGT-D of our healthy individuals performed the task in less than 14s, a suggested cutoff score for passing the test (Guskiewicz et al., 2013; McCrory et al., 2013). Again, our results reflect those reported by Santo et al. (2017) who identified a low pass rate of 24.5% among healthy controls for the TGT-S. By comparison Howell et al. reported significantly higher pass rates of 98% and 50% for the TGT-S and TGT-D respectively for healthy collegiate athletes (Howell et al., 2017b). Hence, it may be that performance is related to level of athletic participation, a finding also identified in other gait studies (Parker et al., 2008). One explanation for the effect of athletic participation may relate to prior exposure to the test, since elite athletes are tested as part of pre-season concussion management. This practice effect has been suggested to influence outcomes of dual task performance in the most recent SCAT guidelines (Echemendia et al., 2017; McCrory et al., 2017) and was thought to explain poorer cognitive performance on the SCAT 3 by younger elite athletes regardless of level of education, compared to their older rehearsed teammates (Fuller et al., 2018).

Regardless, a consistent lack of agreement regarding applicable cutoffs for both TGT-S and TGT-D indicates that current suggested times may not be suitable when assessing the general population. Further research comparing elite and non-elite as well as community participants, tested under the same conditions is required to determine the potential need for athletic level and sport specific healthy individual values.

### 4.1. Intrinsic and extrinsic factors

Several intrinsic and extrinsic factors previously shown to influence results (Howell et al., 2017b; Schneiders et al., 2010b; Santo et al., 2017), in addition to two uninvestigated factors, foot length and specificity of verbal instruction, were analysed in this study. Significant relationships between TGT-S time and age, gender, BMI, activity levels, and foot length were identified ($P < 0.05$). However, when cognitive overlay was added (TGT-D), age, foot length, BMI, and gender but not activity level were mildly correlated with performance times ($P < 0.05$) (Table 2). With respect to influence of gender, no effect was seen when the covariate foot length was taken into account. Interestingly when times were grouped according to foot length, a significant difference in test completion times was apparent for the TGT-S

($p = 0.04$) and mean times differed between the foot size groups by 2 and 3 s for the TGT-S and TGT-D respectively, albeit with large variability. Again, these results reflect those previously published (Santo et al., 2017) where taller subjects achieved faster times with speculation this was due to a larger foot length. As such allowance for a slower performance in individuals with small feet may be required. However since this is the first study to report this, further research is needed to confirm our findings.

Finally, age was positively correlated to performance for TGT-S ($r = 0.43$, $p < 0.01$) and TGT-D ($r = 0.37$, $p < 0.01$) with older individuals taking longer to complete both tasks. While there was no significant difference in DTC-Motor time between age groups, age was the only intrinsic variable that mildly related to DTC-Motor ($r = 0.19$, $p < 0.05$) and older individuals demonstrated greater DTC-Motor time with the upper CI levels ranging from 8.6 to 18.1 s between the age groups. The metric of DTC-Motor %, would seem superior as there were no variables that influenced this result. Interestingly, whilst DTC-Motor was not specifically reported, Howell et al., reported best times of 10.4 and 12.6 for TGT-S and TGT-D respectively which would be a DTC-Motor of approximately 2 s (21%) in high-level athletes. Again this it markedly different to those observed in the population in the current study. These findings, in addition to the longer best times identified by the 55 + age group support the use of age as well as activity specific clinical thresholds for TGT-S and TGT-D, and are consistent with current literature which reports age related changes in other balance outcome measures (Vereeck et al., 2008; Hageman et al., 1995). Furthermore our findings indicate that DTC-Motor % could be a useful TGT metric in the clinical setting due to the limited influence of confounding variables, although somewhat hampered by large confidence interval sizes. Therefore, further studies with larger populations, also including young athletes are required to determine whether a narrower confidence interval for DTC-Motor %can be calculated. In this way, a healthy individual metric for TGT, independent of the influence of intrinsic and extrinsic variables could be developed.

Interestingly, instruction type did not appear to influence the results for either best time TGT-S, TGT-D or DTC-Motor ($p > 0.05$). These findings likely demonstrate the limited influence that instruction type exerts on strategic task prioritization or attention allocation (Strobach and Torsten, 2017) and does not explain differences between results identified in our study and the faster times reported in others (Howell et al., 2017a, 2017b; Oldham et al., 2016; Fuller et al., 2018; Schneiders et al., 2010c).

### 4.2. Limitations

A possible limitation of this study was the number of testers who collected trial times. However, this was a deliberate factor built into the study to mimic the clinical environment. Further, all testers received the same training and data collection pack with no significant differences evident between data sets collected.

Although our study was able to recruit participants above 35 years of age ($n = 57$), lower numbers of participants in this age group were included. This was likely due to exclusion criteria including pre-existing lower limb injuries or surgery. Further research should aim to include larger numbers of participants aged 35 years and over to improve power of healthy individual values reported herein. In addition, shoe size (converted to foot length in cm) was self-reported by participants rather than measured by testers. Measuring an absolute value for foot size prior to testing would improve reliability of foot length data.

Finally, the primary objective of cognitive overlay in the TGT-D is to introduce a dual-cost associated cognitive motor interference observable by changes to gait parameters (Al-Yahya et al., 2011). However, it is difficult to quantify cognitive demands required when subtracting by threes. While data related to years of education or performance on cognitive testing has previously been reported in other dual task gait studies (Catena et al., 2009a, 2009b; Parker et al., 2007; Fait et al., 2013) this has not been investigated in TGT-D. Additionally testing in this study was performed using serial subtraction by 3 rather than 6 or 7 as reported in other TG studies (Catena et al., 2009a; Howell et al., 2017a, 2017b). It is possible this may have influenced TGT-D and DTC-Motor times/% but given the limited ability of some to complete serial subtraction even by 3, the practical value of increasing task difficulty is questionable.

### 4.3. Clinical implications

Recommendation is currently made for use of the TGT-S as part of the initial diagnostic assessment battery for sideline and follow-up assessment of concussion. While our study demonstrates consistency of results when data is collected by multiple assessors, significant variability of cut off times is now reported dependent on age and likely, level of athletic participation. Additionally foot length may also influence performance times by up to 2–3 s whereas DTC-Motor % reported in this study is not influenced by any factors explored in this study. When cognitive overlay accompanies TGT-S (TGT-D), performance times consistently increase (again with large variability of magnitudes between studies). Future studies focusing on TGT-D and DTC-Motor % in particular may be able to identify a better tool for assessing recovery post-concussion.

Given the large variability of test times reported, individualized preseason or baseline results are ideal to compare post concussion, but this is unrealistic among non-athletic or even recreational athletic populations. Thus, the healthy individual values for TGT-S, TGT-D and DTC-Motor provided by this study may at least provide a starting point to aid clinical decision-making and test interpretation for these populations. Further, DTC-Motor % may be most suitable as this measure appears not to be influenced by any factors including age, although future studies should investigate any influence of cognitive function, and or level of athletic participation.

## 5. Conclusion

Healthy individual data for TGT-S, TGT-D and DTC-Motor across varying ages in individuals with non-elite activity levels is a new area of research. Several factors influenced TGT-S including age and foot length, indicating the need for healthy individual values to be grouped by age, with possible time allowance of up to 3 s made for individuals with feet shorter than 27 cm. Additionally, given the large discrepancy between TGT-S and TGT-D times reported in this study and those previously identified, suggested cut off values of 14 s are unlikely to be clinically useful. Further research is needed to clarify test times specific to age and athletic participation for TGT-S and TGT-D. Finally, a possible metric of TGT performance, DTC-Motor % demonstrated no significant relationship with intrinsic and extrinsic variables. Further research with larger cohorts is required in order to identify meaningful DTC-Motor % ranges for use as a potential alternative to TGT-S and TGT-D healthy individual values.

## Conflicts of interest

None declared.

## Ethics

The study received ethical approval from The University of Queensland ethics committee (Bellberry HREC2016-04-311).

## Sources of funding

This study was supported by a Research Training Program Scholarship.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2019.04.006.

## Appendix A

*Study Protocol Phase 1*

*Instruction to participantSingle task Instruction 1*. Stand with both feet behind the starting line (black line marked on tape). You will then walk along the tape in a heel-toe gait (demonstrate) until BOTH feet cross the black line (show which line you are talking about). Once both feet are across the line turn and come straight back. There are some conditions which may make it necessary to repeat the test. If you don't walk with a heel-toe gait, if you step off the tape, if you turn before both feet are across the black line, if you steady yourself on anything. If you fail the test we will need to repeat it. While you need to do this as accurately as possible this is still a speed test so put in your best effort. I will count down 3,2,1, go.

At start of each subsequent trial repeat the instruction “put in your best effort” then count down 3,2,1, go.Dual task. First check the individual can perform the dual task. Get them to count back in 3s from 70 for the practice. Tick the “cognitive task checked” box on your recording sheet.

Instructions: You are now going to do the same walking task while you … (dual task: e.g. count backwards in X s from X). The same conditions apply. Also this time if you step too many times without stating the next (number/month) you will need to stop and repeat the repetition. However, you do not need state a new (number/month) with each step. Errors remain not walking heel to toe, turning before you have both feet across the black line, stepping off the tape, and steadying yourself on anything. Again although we need you to walk accurately, try to walk as quickly as you can. Do your best effort. If you fail the test we will repeat it.

*Study Protocol Phase 2*

Additional testing on 20 individuals to 20 age, gender and BMI matched individuals from phase 1.

*Instruction to participantSingle task Instruction 2*. Stand with your feet together behind the starting line. I will count down "3,2,1, go". On "go" walk along this line heel to toe without stepping off the line as accurately and quickly as possible while keeping in contact with the line. Once you cross the end of the 3 m line, quickly turn 180° and return to the starting point using the same gait. Do your best effort.Dual task. First check the individual can perform the dual task. Get them to count back in 3s from 7 for the practice. Tick the “cognitive task checked” box on your recording sheet.Instructions. You are now going to do the same walking task while you … (dual task: e.g. count backwards in X s from X). The same conditions apply. Also this time if you step too many times without stating the next (number/month) you will need to stop and repeat the repetition. However, you do not need to state a new (number/month) with each step. Do your best effort.

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