Head, Shoulders and Hips Behaviors during Turning

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Abstract. Turning behavior is part of the basic library of motor synergies. It involves a complex interplay between the different body parts. In this study, we investigate the behavior of shoulders, hips and head during walking and turning tasks with various emotional states and different angles. We found that shoulders and hips follow a strong linear relationship during turning with different angles and styles of walk, while the head behavior is affected by these variables.

Keywords: Turning, Head behavior, Shoulders movement, Hips movement.

1 Introduction

The turning task, and more generally the change of direction in locomotion, was studied in many fields of research including clinical domain, neuroscience, computer animation, locomotion behavior annotation, analysis and synthesis. Turning can be considered as a part of the basic library of motor synergies characterized with an adaptive and stable behavior [1], [2]. Turning behavior involves a complex interplay between the different body parts. Previous researches revealed interesting founding that concern the interaction between the trunk, the head, the eyes [3], and also the coordination between lower body parts [2] during turning task. However, the coordination between shoulders and hips during turning movement has not been widely studied. The interaction between head and trunk movement during turn was mostly studied in turns within a restricted range around 90°. Only few studies investigated the head and trunk behavior during turning task from different angles [4]. Since the head and trunk movement were studied on neutral turning behavior, it is still unclear whether they depends on the style of walk during turning task.

In the following section, we will discuss the different properties of turning task found in previous works. Section 3 is devoted to the description of the databases that we used in this study and the segmentation of walking sequences. In Section 4, we will investigate the relationship between shoulders and hips during turning with different angles along with different styles of walk. Finally we will study the head and trunk behavior during turning with different angles and walk styles.

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2 Turning Behavior Properties Studied in Previous Works

Turning behaviors have been studied from a biomechanical point of view. Several approaches studied the trajectory of one or several limbs (mainly pelvis and head) in the space. They focused on the curvature-velocity relationship. Based on the walking trajectories, these studies showed that a power law controls the relation between radius of curvature and velocity of the followed path in cyclic trajectories [5], [6]. This rule is probably the most known assumption used in turning behavior studies from curved trajectories, but it has recently been extended to a single turning task [1]. However, the displacement of the body in the space is not enough to understand the behavior of turning. Thus it is important to study the coordination between the different body parts during turning.

The coordination of lower body limbs has also received a high level of interest in the studies aiming to understand the turning task. This is because the locomotion behavior is mainly and not only based on the production of a motor pattern via lower limbs coordination. It has been shown that the coordination at the level of lower limbs shifts from a symmetric to an asymmetric mode when the person change the direction of walk [2]. The asymmetric mode of coordination at the level of the lower limb was explained with the stabilizing mechanisms for postural control [2].

Other studies focused on the properties related to upper body parts during turning task. It has been shown that upper body parts anticipate the movement toward the direction of turn before lower body parts and that the head systematically shifts toward turns direction before the trunk does [4]. This indicates the role of the head as an inertial guidance platform to which are referred the movements of the other body segments [2]. This anticipation turned out to be occurred at a constant distance rather than at a constant duration before a turn [4]. The anticipation of head direction change to the direction of turn has been used as a mean to detect turning onset and offset [7]. It was also found that there is a strong relationship between head, eyes and body orientation in the locomotion as well as turning behaviors [2], [3],[4].

Apart from the anticipatory orientation of the head, the stabilization of head orientation during turning is considered as a second main factor affecting head movement during turning behavior [4], [2], [3]. The anticipation and stabilization mechanisms are both combined in turning behavior [2]. It has been shown that the head can stabilize itself by looking toward the new direction of walk during turning task. Only few studies investigate the effect of different turning angles on the head behavior during turning [4]. Besides, the effect of the walk style on the head behavior is still unclear. In our work, we study the effect of the angle of turn and the style of walk on the head behavior during turning. Previous works described the head behavior during turning through the maximum orientation of the head around the yaw axis. Two references were used to determine this measure; the heading and the trunk [4]. We used these measure to study the head orientation during turning with respect to the trunk and to the trajectory of walk.

Although several properties of turn were studied previously, studying the relationship between lower and upper body parts to get some insights into how lower and upper body parts are coordinated received little consideration in the studies related to the analysis of walking and turning behavior. In this paper we also studied the relationship between shoulders and hips movement during walk and turning behavior with different angles and different styles of locomotion.

3 Databases Description

In this work, two different databases recorded with two different inertial motion capture systems were used [8], [9]. The first database (eNTERFACE08 3D) is devoted to the study of neutral turning behavior with different angles while the second database (Acted emotional walking database) is used to study the effect of the style of walk on walking and turning behavior with 180 ° turn angle.

In general, in databases of turning behaviors two types of turns are differentiated: Constrained [5] turns and Unconstrained [9] turns (See Fig. 1). In the first type of turn, the person is asked to follow a specific trajectory predefined in advance (See Fig. 1 a)). The advantage of this recording is that there are more accurate information about the angle of turn and the trajectory of the body limbs in space. However, it can result in a non-natural behavior of walking and turning tasks since the person is always looking at the predefined trajectory. In unconstrained turns recording, the person is asked to turn around some obstacles that define the turn angle(See Fig. 1 b)). Both databases that we used in our study are based on the recording of unconstrained turns.

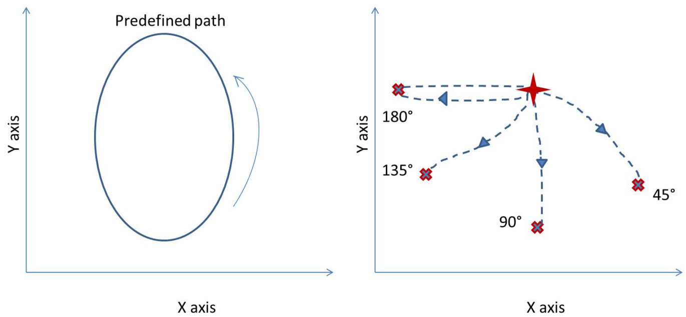

Fig. 1. Two types of turns: a) Constrained turn with predefined path, b) Unconstrained turns

3.1 eNTERFACE08 3D Database

The eNTERFACE08 3D database is described in details in [9]. The movement of the body was recorded through the inertial motion capture system

Animazoo [10]. This database contains, among others, walking sequences containing turning task with different turn angles for 41 subjects. A single turn was performed for each walking sequence. For turning task, the subjects were asked to walk straight starting from a point drawn on the floor until they reached a line (which was also drawn on the floor) from which they must change the direction of walk to reach another point (See Fig. 1 b)). The angles of the direction change were 45 $^\circ$, 90 $^\circ$, 135 $^\circ$ and 180 $^\circ$.

3.2 Acted Emotional Walking Database

The acted emotional walking database was recorded in order to analyze different styles of walking behavior. The intertial motion capture system Xsens [11] was used to record the movement of the whole body (ignoring fingers). The walking behavior of 11 actors (6 female and 5 male) were captured while they expressed 8 emotional states (Joy, Anger, Panic Fear, Anxiety, Sadness, Shame, Pride and Neutral) described with 3 scenarios. The database is described in details in [8].

In this study, only the walking sequences of seven subjects (4 female and 3 male) that are the more expressive among all the subjects were selected. Four styles corresponding to the expression of four emotions: Pride, Anger, Anxiety and Sadness were selected. Previous researches showed that the expression of those styles of walk has a significant influence on the head movement [12]. The actors were not aware of the study of turning behavior. They were rather focused on the style of walk.

3.3 Walking Sequences Segmentation

The segmentation of walking sequences into straight walks sequences and turning movement is a primordial step in our work. It requires to find out the start (onset) and end (offset) of a turn. The study of the relationship between shoulders and hips during turn requires the reduction of the turn interval time in order to focus on turning behavior and to remove straight steps or transitions steps between straight and turning behavior. Thus, we define the onset and offset of turn for this study as the first two foot events that surround the turning movement such as the Swing Heel Off (SW HO) or the heel contact with the floor [13]. The segmentation of walking sequences was first based on the automatic detection of turn instant, and second on the automatic detection of onset and offset of turn. Both the detection of turn instant and turn boundaries (onset and offset) were based on turning angles. Turning angles were measured from hips and shoulders vector orientation around the yaw axis (See Fig. 2).

- **Turn instant detection**;
  Since all the turns were performed with 180 $^\circ$ in the emotional walking database, the turn instant was detected as the frame in which the turning angle reaches 90 $^\circ$. Using the prior knowledge that there is only one turning task in each walking sequence of eNTERFACE08 3D database, the turn instant was defined as

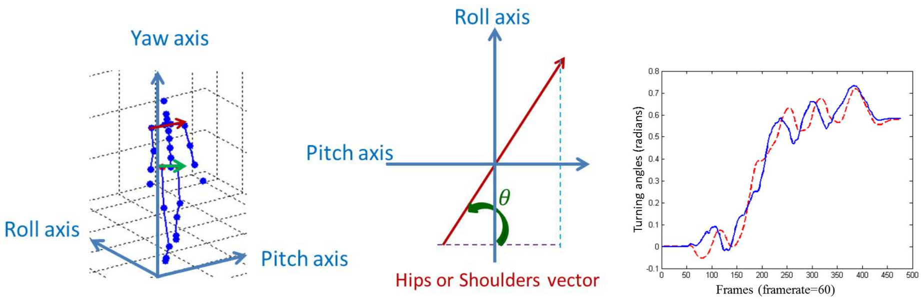

Fig. 2. The measure of Turning angles from hips and shoulders vector orientation around the yaw axis : a) Hips and shoulders vectors based on global positions of joints, b) Turning angle of Hips or Shoulders vector measured at a specific frame, c) Turning angles of hips and shoulders vector for all the sequence

the frame corresponding to the average of turning angle values related to shoulders or hips vector orientation.

- **Turn onset and offset determination**;
  The determination of turn onset and offset is based on the turn instant:
  - First we detect the occurrence of all the foot events in the walking sequence,
  - Second we detect the turning boundaries frames defined as the first local maximum/minimum of turning angles that occur before and after the turn instant,
  - Finally we define the turn onset as the foot event that occurs before the first turning boundary and the turn offset as the foot event that occurs after the second turning boundary. Only few false detection of turn offset and onset instant were detected and corrected by hand (the percentage of false detection was: 24% for 45 $^{\circ}$, 4.87% for 90 $^{\circ}$, 2.43% for 135 $^{\circ}$ and 0% for 180 $^{\circ}$).

4 The Relationship between Shoulders and Hips during Walk and Turn

The relationship between upper and lower parts and their coordination received little consideration in the studies related to walking and turning behavior. In this section, we investigate the relationship between shoulders and hips during walking and turning with different angles and different emotions. We focus on the movement of shoulders and hips in the horizontal plane, that is the orientation of the vectors around the yaw axis. We use the global positions defined in the spatial coordinate system (that reflects the real world) to measure the orientation of the shoulders and hips vectors defined respectively with left and right shoulders positions and left and right hips positions (See Fig. 2 a)). At each frame of the motion sequence, the turning angle of the shoulders vector is deduced from the cosine and the sinus of this vector with respect to Pitch and Roll axes (See Fig. 2 b)). The same procedure is adopted to measure hips turning angles based on the positions of right and left hips.

In the following, we will look at the coordination between shoulders and hips movement during turning task (between the onset and the offset of the turn) studying different angles and different styles of turning behavior. Based on the assumption that the behavior of the pelvis is more linear in walking along curved path than in walking along straight path [14], we tried to see whether the shoulders movement follow the same pattern as the pelvis during a turning behavior and if maintains the same properties for different angles and different styles of walk.

4.1 Shoulders and Hips Relationship during Walk and Turn with Different Angles

We used the eNTERFACE08 3D database to study the behavior of shoulders with regards to the behavior of hips in turning task with different angles. We tried to see whether there is a linear relation between those two different body parts for different turn angles. Using the results of motion sequences segmentation, we fit a linear model to the data projected in shoulders and hips turning angle space between the onset and offset of turn. We found that the shoulders and hips movement are related through a positive linear relationship during turning behavior (see Fig. 3). The coefficient of determination (R^2) was measured for each linear model fitted to the relationship between shoulders and hips between turn onset and turn offset. After applying One-way Anova, we found that the angle that characterized the turning movement had a significant effect on the value of R^2 ($p< 0.001$). The higher is the turning angle, the higher is the average value of R^2 for all the samples (See Table 1).

To measure the global properties of the linear relationship between shoulders and pelvis movement, we fitted the linear model to all the samples of the eNTERFACE08 3D database for each of the four sets of turning behavior (related to 45°, 90°, 135° and 180° angles). Figure 3 illustrates the linear regression models for the samples related to each set of turning behavior. The corresponding R^2 for each linear model are shown in Table 1. They indicate a strong linear relationship between shoulders and hips movement during turning task with different angles. The low value of R^2 related to 45° turns is mainly due to the variation of turning behavior with 45° among the subjects ; since the turning task was unconstrained, subjects tend to turn with angles different from 45° (mostly lower than 45°). Overall, the higher was the turn angle the stronger was the relationship between hips and shoulders with slight differences in the coefficient of the model between 90°, 135° and 180° (See Fig. 3 where the 95% interval of confidence diminishes as turn angle increases).

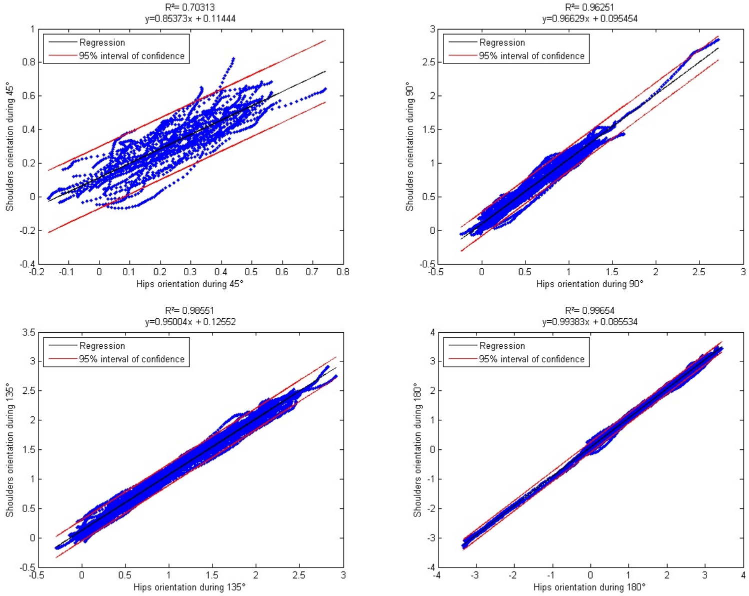

Fig. 3. Positive linear relationship between hips and shoulders movement for a) 45 ° turn angle, b) 90 ° turn angle, c)135 ° turn angle, d)180 ° turn angle

Table 1. The results of fitting a linear model to the shoulders-hips relationship in eNTERFACE08 3D database

Parameters	**45 °**	**90 °**	**135 °**	**180 °**
Average of R^2	0.9057	0.9783	0.9927	0.9973
Linear model coefficients	(0.8537,0.1144)	(0.9963,0.0955)	(0.95,0.1255)	(0.9938,0.0855)
R^2 of the linear model fitted to all the samples	0.7031	0.9625	0.9855	0.9965

4.2 Shoulders and Hips Relationship during Walk and Turn Back with Different Emotions

Although we previously showed the strength of the linear relationship between shoulders and pelvis movement during turning with different angles and especially for 180 ° , it is important to see whether we obtain the same results when studying different styles of walking and turning behavior. The acted emotional walk database was used for this purpose. After applying One-way Anova, we found that there was a significant effect of the emotions and all the subjects on the coefficient of determination R^2 and on the slope of the linear model ($P<0.001$). However, the standard deviation of R^2 for all the samples was 0.0047 (R^2 ranged from 0.9526 to 0.9999) which means that the variance that explained

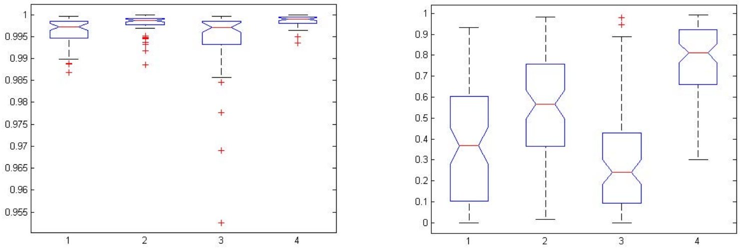

Fig. 4. The distribution and the medians of R^2 in a)emotional turning behavior and b) straight emotional walks, for Anger, Anxiety, Pride and Sadness

the linear model was always small. Figure 4 (a) presents the distribution and the median of R^2 in emotional turning movement for the four sets of turning task.

The hips as well as the shoulders vector movement follow a nonlinear pattern (mostly sinusoidal) during straight walk due to the movement of the legs and the arms. This nonlinear behavior is due to the opposite movement between each two successive steps. In order to study the correlation between upper and lower body parts during straight walk with different emotions (Anger, Anxiety, Pride and Sadness), we applied One-way Anova on the coefficient R^2 for the four emotions studied in our database. We found that emotions have a significant main effect on the correlation between shoulders and pelvis movement during straight walks. Figure 4 (b) shows that the differences between the medians and the distribution of R^2 between emotions are highly significant. The higher median value of R^2 was assigned to the sad emotional walks while the lower median value of R^2 was related to the pride emotional walks. This can be explained as actors tend to walk slowly with less variability of upper body parts and small foot strides. This behavior results in similar patterns between shoulders and hips. Unlike sadness expression, the actors express pride with large foot strides and a large amount of arms swings which leads to an opposite pattern of shoulders with respect to the hips. Anger and Anxiety expression included a significant change at the level of upper body parts as well as lower body parts.

5 Head Behavior during Turning

To be able to compare our results with the results found in previous works, we employ the same parameters used to study the stabilization of head during turn [4]. Thus, the analysis of head behavior was based on three features. The first and second feature represent the relative maximum relative head yaw during turning with respect to two references: heading and trunk yaw. Heading was measured based on the trajectory of body center of mass (CoM) in the space as described in [3]. In the following sections we use the term head-trunk yaw and head-heading yaw to refer respectively to the maximum orientation of the head with respect to the trunk and the heading. The third feature corresponds to the occurrence of the maximum relative head yaw (in seconds) with respect to the onset of turn. As the SW HO is considered as the first event that occurs during a step, it was used as a common reference that represents the onset of turn in this study. We conduct two studies; the first one is focused on the head behavior during turning with different angles while the second one is devoted to the analysis of head behavior during turning with different styles of walk.

5.1 Head Behavior during Turning with Different Angles

In this study, we focus on the orientation of the head around the yaw axis between the onset and the offset of the turn. We measured the maximum head orientation that occur between turn boundaries with respect to the trunk and the heading as explained in section 5. After applying One-way Anova, we found that the turn angle had a significant effect on the relative head orientation ($P< 0.001$) both for heading-head and trunk-head). Similarly to the results presented in [4], we found the same pattern of results for heading and trunk references. The relative head orientation using the trunk or heading as a reference shows a continuous increase for the turn angles up to 135° and a leveling off after that. The estimation of the magnitude of the relative head orientation was different between the two references. The average of the head orientation measured respectively using the heading and the trunk as references are shown in table 2. The trunk-head turned out to be smaller than the heading-head for all the turn angles (See table 2). This is explained by the orientation of the trunk that occurs with the orientation of the head during turning task.

Table 2. Head behavior stabilization measures in eNTERFACE08 3D database

Parameters	**45°**	**90°**	**135°**	**180°**
Heading-head	10.1°	16.1°	23.4°	21.6°
Trunk-head	5.9°	9.9°	15.1°	14.7°
The average of the occurrence of maximum head yaw (in seconds)	0.4375	0.7047	0.9613	1.1812

We also measured the instant when the head orientation reaches the maximum value relative to the SW HO event involving in the first turning steps. The main effect of of turn angle was significant ($P<0.001$) leading to a linear increase from 45° to 180° (See Table 2). This indicates that the instant in which occurs the maximal head orientation toward the turn direction with respect to the onset of turn is also affected by the turn angle.

5.2 Head Behavior during Turning with Different Emotions

The trunk-head and heading-head features were measured between the onset and the offset of 180° turns detected in the emotional walks. The expression of emotions through walking action had a significant effect on the head-trunk orientation as well as on the heading-head orientation (P<0.001). Similarly to the study presented in [4], we found that the head orientation relative to the trunk was smaller than with the heading as a reference. This result shows that the trunk was also rotated to the turn direction regardless of the style of walking and turning actions. Since the heading reference strongly depends on the trajectory of the CoM, we focus only on the maximum head yaw relative to the trunk to compare the head behavior between the different styles of walk and turn.

No significant difference was found between the trunk-head in turning related to the expression of Anger and Pride (P=0.33). The maximum head yaw relative to the trunk ranged from 0.22 ° to 35.22 ° . The effect of the expression of emotion on the trunk-head yaw increase while taking into account Anxiety expression (P<0.001) but the expression of Sadness showed the most significant difference among the other emotion expressions. The median (4.94 °) as well as the range (from 0.1 ° to 14.8 °) of trunk-head yaw in turning while expressing sadness turned out to be smaller than with the other emotion expressions. These results showed that the maximum head orientation relative to the trunk during turning task is not only depending on the angle of turn but also on the style of walk.

Studying the effect of emotions on the occurrence of maximum head yaw (in seconds) with One-way Anova showed a significant differences (P<0.001) among the four groups representing the four emotional behavior. Interestingly, the median related to the occurrence of maximum head yaw showed higher values for Pride ans Sadness (1.5s and 2.1s) and lower values for Anger and Anxiety (1.2s and 1.1s). That means that the maximum head yaw occur earlier with Anger and Anxiety expression than with Pride and Sadness expression. This result is congruent with the activation dimension of the studied emotional states; head orientation is slower for less active emotional states and faster for active emotional states.

6 Conclusion and Future Work

In this paper, we investigate the relationship between upper and lower body parts through the relationship between shoulders and hips movement. We found that those two modalities follow a strong linear relationship during turning task for different turn angles (45 ° , 90 ° , 135 ° and 180 °) and different styles of walk and turn (while expressing Anger, Pride, Anxiety and Sadness). We found that the linear relationship is stronger for higher turn angles. In the future work, we aim to study whether this relationship is maintained for turn angles lower than 45 ° . The relationship between shoulders and hips movement must also be studied in cyclic curved trajectories to see whether it follows the same linear behavior found in turning around a corner. Like hips movement, shoulders movement is characterized with a non linear (sinusoidal) behavior during straight walk. However, shoulders and hips are in opposite of phase, mainly due to arm swings. But we showed that this opposite behavior strongly depends on the style of walk for Anger, Anxiety, Pride and Sadness expression through walking. That is the relationship of phase opposition between shoulders and hips is no more maintained during the sad expression as the body movement is less energetic and arms balance less.

In our work, we also investigate head behavior during turning with different angles and different styles of walk. We found that the maximum head yaw relative to the trunk and heading shows a continuous increase for the turn angles up to 135 $^{\circ}$ and a leveling off after that. This result was found previously in [4] with similar values of maximum head yaw for the different angles. The occurrence of the maximum head yaw was also affected by the turn angle leading to a linear increase from 35 $^{\circ}$ to 180 $^{\circ}$. However, this behavior was not stable while changing the style of walk. The head orientation with respect to the trunk showed a significant decrease in turning task while expressing Sadness than while expressing more active emotional states like Anxiety and Anger. We showed that the occurrence of the maximum head yaw during turning task is also affected by the expression of emotion. The maximum head yaw occurs earlier for active emotional states (Anger and Anxiety) and later for less active emotional states (Pride and Sadness).

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