Classical Gait Analysis reveals Regular Movement Cycles in Spontaneous Movements of Human Neonates

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Summary

We studied limb coordination in human neonates by applying the procedure of classical gait analysis – definition of gait cycles and normalization to percentages of these cycles - to kinematic data of spontaneous limb movements of human neonates in the supine position. Movement cycles of the limbs in the supine position were defined by maximal and minimal values of distance trajectories of the hands and feet from the centre of the torso, which is analogous to the definition of gait cycles of limb movements in the erect posture by initial contacts of the limbs with the ground. In addition to gait analysis, in which the gait cycles are commonly defined by the contact values of one limb, we extended the procedure to a parallel eightfold analysis by defining the minimal and maximal values of each of the four limbs as starting point for a new cycle, respectively. This new application of the classical analysis revealed regular movement cycles with integer ratios as well as symmetric cycles as known from adult gait patterns in the spontaneous movement behavior of human neonates in the first days of life.

Introduction

The investigation of spontaneous movements of neonates has experienced a huge transformation from traditional observation and categorization of e.g. primitive reflexes and general movements [1] to sophisticated methods from nonlinear dynamics, that e.g. describe spontaneous single-limb-activity by chaotic dynamics [2,3] and limit cycles [4]. In former studies, we analyzed the neonatal four-limb-system with methods from nonlinear dynamics, i.e. recurrence plot analysis and symbolic dynamics, and found evidence for processes of self-organization towards a system of transient reference configurations [5]. In search for the underlying mechanisms of the emergence of the documented system of four-limb-configurations, we adapted the classical gait analysis to analyse the neonate movements in the supine position and demonstrate how this traditional observation procedure can reveal hidden regularities in highly complex behavioral systems of several interacting and interdependent components.

Material and Methods

Subjects were six neonates, all healthy, normal, full-term infants, with Apgar scores of 8 or more at the age of 1 to 10 days (mean age = 3.2 days). Kinematic data collection used video recording with three synchronized cameras (50Hz) that focussed into a volume calibrated by a calibration frame. Kinematic data (4Hz) of movement relevant joints were computed using the Ariel Performance Analysis System (APAS) for time spans of 5- 20 minutes from each of the six infants on 2-3 different days. Distance trajectories of the endeffectors of the arms (wrists) and legs (ankles) from the centre of the trunk in the xz-dimension, and the minimal and maximal values of the latter, were calculated from the coordinate data. Movement cycles were defined from one maximum (or minimum) of the distance trajectory of one limb to the following maximum (or minimum) of the respective limb. The data for each cycle was normalized to percentage of cycle and the ratios to the maxima and minima values of the remaining limbs were calculated. The parallel procedure of maximal and minimal values for four limbs resulted in 8 cycle series, two for each limb respectively.

Results

With the parallel procedure of cycle analysis from maxima to maxima of each limb and minima to minima of each limb we got 8 cycle series. For each cycle of the eight series, the ratio of the second value of the respective limb (e.g. minima, if maxima defined the cycle) and the ratios of the remaining three limbs were calculated. Table 1 shows an example of 9 cycles defined by the maximal values of the distance trajectory of the left hand (LHmax). Cycle 22, 25 and 31 display integer ratios for all limbs involved. In cycle 22, the minimum of the left hand (LHmin) occured at 70% of the cycle, the maximum of the right foot (RFmax) and the right hand (RHmax) at 10% of the cycle as well as the minimum of the right hand (RHmin) at 100%, indicating synchronous movement of the latter with the left hand (LHmax). Simultaneous movements always occurred at 100% with the event defining the cycle (LHmax in table 1) as well as if concurrent values are displayed: e.g. the left hand minimum (LHmin) and the right foot minimum (RFmin) coincided in cycle 25 at 60% and the left hand minimum coincided with the left foot minimum in cycle 26 at 75%.

In general, regular and irregular cycles alternated within the whole movement episodes, with the percentage of regular cycles ranging from 21 to 34% for each cycle series. This means that altogether, ca. 80% of a movement episode was involved in regular cycles in reference to a minimal or maximal value of at least one of the limbs.

Table 1. *Illustrative section of a movement cycle analysis of 9 cycles of one movement episode (N=1898 cycles; Mean duration: 5s, SD: 5s) with maximal values of the left hand (LHmax) defining the onset and termination of a cycle. The left column 'Cycle' shows the number of the movement cycle. t displays the duration of the cycle from one maximum of the left hand (LHmax) to the following one. Percentages of the cycle at maximal and minimal values of the limbs are displayed: LH, left hand; RF, right foot; RH, right hand; LF, left foot; min, minimum; max, maximum.*

LHmax

Cycle	t [s]	LH min [%]	RF min [%]	RF max [%]	RH min [%]	RH max [%]	LF min [%]	LF max [%]
22	2.5	**70**		**10**	**100**	**10**		
23	9.25	29.72972973	8.108108108	32.43243243		35.13513514	16.21621622	37.83783784
			56.75675676	70.27027027	75.67567568	89.18918919	40.54054054	54.05405405
			78.37837838	91.89189189				
24	3	41.66666667	8.333333333	58.33333333	16.66666667			
25	6.25	**60**	**60**	**72**	**44**	**20**	**72**	
			80	**92**	**100**	**92**		
26	4	**75**	**31.25**	**43.75**		**18.75**	**75**	**31.25**
			81.25		**68.75**			
27	6.5	11.53846154	65.38461538	42.30769231	80.76923077	19.23076923	69.23076923	15.38461538
//								
31	3	**50**		**100**	**50**			
32	5.25	52.38095238	61.9047619		9.523809524	23.80952381		
					33.33333333	95.23809524		
33	2	**50**			**50**	**62.5**	**87.5**	**12.5**

Conclusions

Movement behavior often appears irregular and without any structure. In particular, if more than one channel of activity or information is involved. With our analysis, we want to show, how the parallel application of the classical procedure of gait analysis can unravel the clutter of single limb movements, general movements and reflexes by revealing that cycles with regular ratios as well as cycles with synchrony (100%) and 50% ratios (see cycle 31 and 33) - which are both common in adult gait patterns – were inherent in the movement flow and become obvious, if behavior is measured in respect to adequate reference points [5,7].

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