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Effects of asymmetrical medical conditions on lower limb dominance:

A theoretical review

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I will quote Piet Hein which was Danish like myself and a friend of my Swedish mother in law. It fits well to my life with continuous pain and fatigue.

"If you want to be sure to win, one must fight with himself."

~ Piet Hein ~

2.0 ABSTRACT

Research question of the theoretical review: Medical conditions that cause an asymmetry in the functions of the lower extremities – will they also affect limb dominance?

Methods: A theoretical review with searches in databases for articles about the theory behind limb dominance and for articles with various medical conditions that cause asymmetry in the functions of the lower extremities.

Results: In the medical conditions, there were found asymmetries caused by one affected leg or side. There existed a dominant side of the medical conditions responsible for the affected leg. Often the patients showed plasticity. Plasticity made the patients adapt to the medical condition, by creating a functional pattern in movements based on available possibilities. They often created a functional limb dominance. The new patterns were often less consistent and rigid than normal limb dominance. This might suggest that a basis limb dominance still might exist on the brain level.

Conclusion: Medical conditions that cause an asymmetry in the functions of the lower extremities create a dominant limb in terms of dysfunction. This probably leads to a more unilateral action pattern and a change in functional limb dominance. It is suggested that basis limb dominance might still exist on the brain level. If this is correct, it means that if a person receives a brain injury, this might damage or destroy limb dominance on brain level. To be able to say more about limb dominance on the brain level could be a case for future research.

Key words: Medical conditions, functions of the lower extremities, symmetry, dominance.

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4.0 INTRODUCTION

People in general take a symmetry function of the body for granted. On the outside we have two of everything. If we divide the body in the sagittal plane, the two sides can be mirrored to each other. On the inside of the body we are not symmetrical and we often also have a dominant hand and a dominant foot. Still in common daily life movements we often perform general symmetric actions. This can be seen in walking, standing, sitting down and rising - routinely, 60 sit to stand movements are preformed daily (Highsmith et al., 2011). Not everybody is born with all limbs intact and some of us get sick or injured. Some of these medical conditions cause an asymmetry in the functions of the lower extremities. You can get an affected limb and a non-affected limb. It is easy to take for granted that the non-affected limb within a disease is synonymous with the dominant limb. So, if you have a right limb dominance, then get a right side dominant illness, you will switch to left limb dominance. Several researchers have jumped to that conclusion (Wileym& Damiano, 1998). Is it really so simple? So the research question of this theoretical review became:

Medical conditions that cause an asymmetry in the functions of the lower extremities – will they also affect limb dominance?

Key words: Medical conditions, functions of the lower extremities, symmetry, dominance

The following introduction contains basic theory on different relevant aspects on asymmetry and limb dominance. To be able to look on my research questions, medical conditions will be divided into two groups based on their common features. That would be *the central nervous system* and *musculoskeletal damage and disfunction*. Finely, the findings in the basic theory section will be combined with the findings in the two groups of medical conditions; this forms the foundations for answering my research question.

4.1 Symmetry

In science the recognition and utilization of symmetry is often complex and sophisticated. No attempt in this thesis is made to review the literature on symmetry rules or how science and nature are founded on symmetry.

An action can look symmetrical – when both limbs behave identically. For instance, when walking, the two legs move in an alternating pattern in order to produce forward displacement of the body in a stable manner. But even when it looks symmetrical in for instance human manual behavior, *perfect* symmetry is the exception rather than the rule (Poel et al., 2009). This makes it difficult to create an all embracing and inclusive definition of symmetry. Therefore in this review there is no definite definition of neither symmetry nor asymmetry. If an article has described it as an asymmetry - it is included here as an asymmetry.

4.2 Definition limb dominance

A common definition of limb dominance is:

The limb preferred to execute a manipulative or mobilizing action while the other (nondominant) foot provides stabilizing support, e.g. kicking a ball (Gabbard, Hart, 1996).

The public have a general grasp of what is meant by a dominant (preferred) hand as a behavioral concept. If they don't now, then you can ask them to clap their hands and the upper hand will properly be the dominant hand. In contrast, the notion of *foot dominance* may not be so obvious in light of the feet's relatively unique functional characteristics. If preformed in a bilateral context the upper definition works fine, but in case of a unilateral action, such as one-foot balance and hopping on one limb, they do not provide a clear bilateral role differentiation.

A possibility is to define foot dominance operationally, in light of the behavioral context (stability, mobility, bilateral) and demands (level of complexity) of the particular task (s) performed (Gabbard,, Hart, 1996).

4.3 Normal distribution

Normal distribution of limb dominance is as follows. Approximately 80-90% of humans are right-handed, 60-80% are right footed, and 80% of participants have a dominant hand and foot on the same side (Taylor, Strike, Dabnichki, 2006). In matter of race (black and white) and sex, no difference appears in left-right preferences. However, significantly more females than males, and more blacks than whites, show variable foot preference (Nachshon, Denno, Aurand, 1983). The limb dominance a person has before a potential disease is from now on called *basis limb dominance*.

4.4 Medical conditions, rehabilitation and dominance

In articles lots of different use of the word dominant is found and many conceptions/assumptions of which side might be the dominant one, on which the researchers based their investigations on.

Some diseases affect one side of the body. You can talk about laterality of symptoms –the side most affected (Almeida, 2010). The limb that is predominantly affected is from now on called *medical condition limb dominance.*

When an asymmetry occurs due to a medical condition the clinicians often start a rehabilitation program. In a study of healthy uninjured individuals it was demonstrated that differences in balance strategies existed, and thus the clinician should consider the role of lower-limb dominance and the methods used to assess postural control in a rehabilitation program (Clifford , Powell. 2009). One example on rehabilitations training in asymmetry medical conditions is Constraint-induced movement therapy (CIMT). CIMT forces the use of the affected side by restraining the unaffected side. CIMT has gained considerable popularity as a treatment technique for upper extremity rehabilitation among patients with mild-to-moderate stroke (Reiss, et al. 2012). Among patients who had a stroke within the previous 3 to 9 months, CIMT produced statistically significant and clinically relevant improvements in arm motor function that persisted for at least 1 year (Steven L. Wolf, et al. 2006).

4.5 Hand dominance and limb dominance

The upper and lower limbs play a distinctly different functional role all though foot biases and their interaction with hand biases are of practical importance in the design of human-machine systems (Morris, et al. 2009).

In adult right-handers, the left leg tends to be the longer and heavier one, in keeping with the support role of that leg. In left-handers the functional preferences are less clearly expressed (Peters, 1988). When performing a tapping task the same findings were reported. Left-handers showed smaller left/right differences than right-handers in both hand and foot performance (Peter, Durding, 1979; Augstyn, Peters, 1986). It gets even more interesting when you add a verbal interference on the tapping task. Verbal interference created a significant asymmetric effect with a decremental response in right finger tapping rate and a facilitative effect on left finger-tapping rate. In foot-tapping with verbal interference there was a *bilateral* decremental response in both right and left-handers (Fearing, et. Al 1978). The reason for this can perhaps be found in the explanation that less neural resources are devoted to leg and foot control than to arm and hand control. In addition, in daily life the lower limbs have a uniquely restricted use and the status of foot control differs from that of hand control both early in life and during later years of decline (Peters, 1990).

4.6 Limb dominance and childhood

Do we find asymmetries and limb dominance already in childhood? In human newborn there was no evidence of a lateral preference in terms of the first foot moved. However, several other asymmetries were found. There was a side difference in terms of smoother trajectories of the right leg as a consequence of less movement segmentation compared to the left leg. Also intralimb coordination side differences were found (Hopkins, et al. 2007).

In reaching at the age of 5 months, all but one infant were unimanual reachers. Preferential reaching was space dependent rather than object dependent at this stage. It was found that children who at the age of 5 months had reached for objects in the left hemispace with their left hand proved to be less lateralized in their right hand use approximately 5 years later (Marschik, 2008).

In the age of 3-, 4-, 5- year-olds the majority of children display a preference for one foot over the other (limb dominance), but a large amount of the children exhibited non-established (mixed) behavior (Gabbard, 1991).

4.7 Asymmetry and Limb dominance in able-bodied gait

Laterality has been cited as an explanation for the existence of functional differences between the lower extremities in able-bodied gait, although a number of studies do not support the hypothesis of a relationship between gait asymmetry and laterality (Sadeghi et al. 2000).

In fact, an angular asymmetry was demonstrated between the two legs during walking in healthy subjects, but no correlation between this asymmetry and lateralities were found (Maupas, et al. 2002). All though limb dominance do exists in walking, it has been shown that limb dominance affects the vertical ground reaction force and center of pressure during walking gait (Wang, Watanabe, 2012).

In preferred speed able-bodied walking asymmetry were found, but the reason are probably not limb dominance. No significant bilateral differences existed between sample means for vertical (support) or propulsive impulses at slow or preferred speed, yet at fast speed dominant-limb propulsive impulse was 7 % greater than non-dominant limb propulsive. Impulses were therefore generally symmetrical except at high speed (Seeley, et al.. 2008; Riskowski, et al. 2012). Leg-length inequality is one among many possible causes for able-bodied gait asymmetries. Other factors that likely contribute to these gait asymmetries could be other morphological asymmetries as well as asymmetrical neuromuscular input to the lower limb muscles (Seeley, 2010).

4.8 Plasticity and limb dominance

The term plasticity can be used if limb dominance can be reduced or even eliminated by practice. Professional soccer players were studied and there was a slight tendency for less right-foot bias (Carey, et al. 2009). In amateurs the right-foot biases were very similar to those seen in the general population. Professionals were remarkably adept on those occasions when they used their non-dominant foot, but if they could choose between dominant and non-dominant foot they still preferred the dominant foot, suggesting that skill cannot explain asymmetry of choice (Carey, et al. 2009). Plasticity would also mean that in theory one leg could take over the function of the other leg. This would be an effective compensation strategy if one of the legs is markedly affected (Kooij, et al. 2007). When a leg has the dominance in function it is from now on called the *functional limb dominance.*

Seventeen right leg-dominant male participants with chronic anterior cruciate ligament deficiency and 18 matched healthy male participants were investigated whether this kind of injury causes plastic changes in brain activation patterns. They found that this kind of injury can cause reorganization of the central nervous system, suggesting that such an injury might be regarded as a neurophysiologic dysfunction, not a simple peripheral musculoskeletal injury (Kapreli, et al. 2009). This study might indicate on which level plasticity operates, because this kind of injury can cause plasticity changes in brain activation patterns.

If a person has his right arm in a cast as the result of a fracture, he rapidly becomes dexterous in the use of the left limb. By contrast, a patient with a right hemiplegia can show even poorer performance with his left limb than an unpracticed normal person would exhibit. The patient with a fracture can learn to use his previous store of motor skills in the left hemisphere to direct the control of the left arm by the right hemisphere, this is an expression of plasticity. The patient with a right hemiplegia has suffered destruction of the left premotor area and can have lost a part of his motor learning (Geschwind, 1975). In fact, already in 1939 investigators saw a correlation between brain and coordination, it was reported that cerebellar lesioned patients encountered difficulties with reversing directions in two limbs at the same time (Debaere, et al. 2000).

4.9 Explanation and evolution of lateralization

Functional Magnetic Resonance Imaging (fMRI) is a technique measuring changes in the amount of oxygenated blood in the brain. The increased activity in the cells of the brain alters oxygen levels and these changes can be detected and localized using fMRI. In this way you can create visual representations of which areas in the brain that are particularly active at any time, and in conjunction with various physical and mental tasks. This technique is used to investigate among others factors movements and their interaction with the brain.

If the brain is scanned while participants experienced an illusion for each limb elicited by vibrating its tendon at 110 Hz (Illusion) and as control applied identical stimuli to the skin over a nearby bone, which does not elicit illusions (Vibration). This demonstrated a complete set of brain representations related to kinesthetic processing of single-joint movement of the four human extremities (Naito, et all. 2007). This means that the extremities are connected to the brain, but how is the brain connected to the extremities' limb dominance?

There exist many articles about lateralization they do not all say the same, but there is a general agreement that the primary motor cortex of each hemisphere controls most aspects of voluntary movement primarily in the contralateral side of the body. The dominant hemisphere is the one controlling a given function. For instance preferred spontaneous use of the right-hand is an expression of left hemispheric dominance of motor function, commonly called right-hand dominance (Maupas, et al. 2002; Gabbard, Hart, 1996).

A theory is that in most human (about two thirds) a left-otolithic advantage underlies the reliance (in essence, creating a predisposition to) the "left side of the body for postural control" and "the right side for voluntary (mobilizing) motor function" (Kalaycioglu, et al. 2008). Additionally, skilled and unskilled foot movements utilize different pathways (pyramidal tracts). The asymmetrical lateral (corticospinal) pathway control skilled movements while the medial pathways control unskilled movements (Kalaycioglu, et al. 2008).

Some researchers go even further in describing the relationship between the brain and dominant joints. In a motor block design study by Kapreli and colleagues, participants performed unilateral right and left repetitive knee, ankle and toe flexion/extension movements. The brain activation during movement of the non-dominant joints was more bilateral than during the same movement performed with the dominant joints. Finger movement had a stronger lateralized pattern of activation in comparison with lower limb joints, and differences were also evident between the joints of the lower limb (Kapreli, et al. 2006).

In functional magnetic resonance imaging (fMRI), hemispheric dominance is generally indicated by a measure called the laterality index. Lateralization index in primary sensorimotor cortex and basal ganglia was significantly affected by the main effect of dominance, whereas the lateralization index in cerebellum was significantly affected by the joint main effect, this demonstrates that the lateralization index increases from proximal to distal joints (Kapreli, et al. 2006).

In the evolutionary basis of lateralization and dominance one could look at animals. Rats for instants display a strong asymmetry, they do not show dominance with respect to limb use, but there was a significant correlation between the degree of lateralization and success of limb use (Whishaw, 1992). Furthermore, in a number of primate and prosimian species there were found preferential use of the *left* limb (Whishaw, 1992).

Looking at the people who are left-handed, one can often see a familial sinistrality (the condition of being left-handed). Mother's left-handedness is associated with an increase in the incidence of sinistrality for sons and daughters, while father's left handedness is related only to sons (Spiegler, Yeni-Komshian, 1983). Is this environmental impact or hereditary? What if both parents are left-handed? There is a theory that claims that usually biasing handedness is toward dextrality is absent in these children (*non*-right handedness) and that their laterality is determined mainly by accidental variation (Annett, 1974). Familial legacy and influence could be one explanation for developing sinistrality, another possible explanation for developing human lateralization could be asymmetric prenatal development of the ear and labyrinth and position of the fetus (cephalic-leftward-right ear facing out) during the final trimester (Gabbard, Hart, 1996). However, the dominant hemisphere-laterality relationship must be considered in light of genetics, environmental and socio-cultural factors.

Lateralization seems to be of slightly smaller importance for lower limbs than upper limbs. In daily life few activities of the lower limbs are lateralized; exceptions are changing gear when driving, some sports, or certain musical instruments (Maupas, et al. 2002; Toga, Thompson, 2003). There for problems may arise when comparing the upper limbs with the lower limbs.

Why do we need limb dominance and why do we have a majority distribution of right-footed dominance? It is suggested that lateralized brains are more efficient (Ghirlanda, et al. 2008). This is based on the theory that it will spare neural tissue by avoiding duplication of functions in the two hemispheres and by preventing the simultaneous initiation of incompatible responses by allowing one hemisphere to have control over actions. However, individual efficiency does not require an alignment of lateralization at the population level.

One could argue that population-level lateralization is more a by-product of genetic expression. Population-level lateralization can arise as an evolutionarily stable strategy when individually asymmetrical organisms must coordinate their behavior with that of other asymmetrical organisms. When a population consists of left- and right- lateralized individuals in unequal numbers they also can be evolutionarily stable, this based on strategic factors arising from the balance between antagonistic (competitive) and synergistic (cooperative) interactions (Ghirlanda, et al. 2008).

5.0 METHOD

I primarily used Google scholar as my first tool because you receive hits from a myriad of different databases. In the beginning the searches were broad and synonyms were used. This was good for getting a grip on the different areas and understanding the themes and distributing the subjects into categories.

Example 1: Limb, interlimb, footedness, under extremities, pedal, bipedal, foot, feet
Example 2: Lateralisation, dominance, side effect
Example 3: Symmetry, asymmetry

Next, I narrowed down my search and finalized the specific search strings. For the medical conditions the latter could be the name of the illness; asymmetry/symmetry; dominance/lateralisation/side effect (and lateralization - American spelling); and synonyms for the lower extremities. Then one must reject the articles that obviously do not belong to the assignment**,** like asymmetry in hearing and language dominance and the articles had to include the human body or maybe animals.In all the medical conditions there were few articles that had looked at dominance in terms of the preferred dynamic limb and the weight bearing limb. In the best case, they talked about lateralization of the illness, i.e. which leg was the weight bearing one or the use of the non-effected leg. I finely ended up with a few relevant articles.

I also made a search directly in Medline and PubMed. I looked at recommended articles with similar topics, at article lists from my supervisor, and in the references of included articles. I did not put weight on the articles' publishing year or how many times it has been cited and I included some relevant articles on handedness. The reason was that there were few articles which were relevant in the category of medical conditions in respect to the lower limbs.

A limitation was that very few researchers had looked directly into the effect of or the change in lateralisation in the lower extremities, in the meaning of "the limb preferred to execute a manipulative or mobilizing action while the other (non-dominant) foot provides stabilizing support", e.g. kicking a ball.

6.0 CENTRAL NERVOUS SYSTEM

The nervous system consists of the brain and spinal cord, which combine to form the central nervous system; and the sensory and motor nerves, which form the peripheral nervous system (Nieuwenhuys, et al. 2008). A common feature of this group of medical conditions under study is that they affect the central nervous system. In clinical neurology, unilateral predominance of signs and symptoms are common (Djaldetti, et al. 2006).

6.1 Cerebral Palsy

Cerebral palsy is an umbrella-like term used for a group of non-progressive disorders of movement and posture caused by abnormal development of, or damage to, motor control centers of the brain. Cerebral palsy (CP) is caused by events before, during, or after birth. The abnormalities of muscle control (for example spastic, abridged) that define CP are often accompanied by other neurological and physical abnormalities (for example lack of speech). The term cerebral refers to the brain's two halves, or hemispheres, and palsy describes any disorder that impairs control of body movement. Cerebral palsy can be diplegic (primarily affecting the legs) or hemiplegic (affects one arm and leg on the same side of the body) (Badawi, et al. 1998).

Results:

In children with hemiplegia there are expected asymmetries, but even the non-paretic side should not necessarily be considered “normal” (Wiley, Damiano, 1998). Regardless affected leg, significant proprioception deficits were observed bilaterally in patients with diplegia and hemiplegia (Ounpuu, 1995). This confirms that the non-paretic side should not be considered “normal”.

Asymmetries in strength are shown (Ounpuu, 1995). Children with hemiplegia showed strength differences noted on the non-paretic side compared to the paretic side. Children with diplegia were shown to be weaker than age-matched peers. Power generation of the involved versus non-involved side of persons with hemiplegia suggested that the non-involved limb shows greater than normal power generation to compensate for the weaker non-involved limb (Ounpuu, 1995).

When trying to define dominance in cerebral palsy it can be more clearly seen in articles on arm dominance. When looked on as to how to determine arm dominance a variety of possibilities were used. One method was to use *parent report* to determine arm dominance. This parameter was used when testing the hypotheses that impairment of the dominant arm were more likely to contribute to disability (Sanger, 2007).

Some used *the modified Edinburgh Handedness Inventory*. The modified Edinburgh Handedness Inventory determines the proportion of upper-extremity usage during the following tasks: writing, drawing, throwing, scissoring, brushing teeth, knife and spoon use, upper hand on broom, striking match, and opening a box. A score of 100 indicates complete right upper-extremity dominance, and a score of 0 indicates complete left upper-extremity dominance. Then they assumed that leg dominance was to be ipsilateral to upper-extremity dominance (Wingert, 2009).

Other researchers *simply assumed that the non-paretic side was the dominant side* (Wiley, Damiano, 1998). Another researcher chose to *classify the lower limbs as less/more impaired rather than dominant/non-dominant*. This is based on the conception that limb dominance in individuals with CP may be imposed by brain damage (Crompton, et al. 2007).

When estimating the contribution of body transverse rotations in children with CP, there was noted limb dominance when using two force platforms. However, it was postulated that this dominance was related to limb asymmetry and to differences in foot flatness (Ferdjallah, et al. 2002).

In a survey of joint-position sense and kinesthesia differences between aged-matched controls and 2 groups with CP, it was found that in adults the proprioception impairment in their lower extremities could directly impact balance and gait. Balance difficulties could also lead to balancing on the more functional limb and kicking with the more affected leg (Wingert, et al. 2009).

Cerebral Palsy Discussion:

Medical condition limb dominance and asymmetry were found.

When looking into articles on CP, and how they determined limb dominance and conducted research in this field it seems fairly inconsequently. A lack of proper directions seems to be missing. It also seems necessary to clarify the difference between medical condition limb dominance, basic limb dominance and functional limb dominance. It looks like basic limb dominance does not have to be the same as functional limb dominance. The researchers do not give a clear picture of which leg is the dominant limb, but only witch is the limb in use.

In motor movement it seems there exists an adaptation to a functional pattern and there might also be changes in the functional limb dominance. Limb dominance at the brain level may be amplified on the presumption that limb dominance in individuals with CP may be imposed by brain damage.

6.2 Stroke

Strokes happen when blood flow to the brain stops. Within minutes, brain cells begin to die. A stroke occurs when a blood clot blocks an artery (Ischemic stroke) or a blood vessel breaks (Hemorrhagic stroke). "Mini-strokes" (Ortransient ischemic attacks) occur when the blood supply to the brain is briefly interrupted. When brain cells die during a stroke, abilities controlled by that area of the brain are lost. These abilities include speech, movement and memory. How a stroke patient is affected depends on where the stroke occurs in the brain and how much the brain is damaged (Rudd, et al., 2012).

Results:

More research is often made on the upper extremities than the lower extremities. A good example is a study where they compare the paretic and non-paretic arms in right-handed patients. Upper extremity deficits after stroke may differ depending on the side of stroke. When comparing tapping ability in both the paretic and non-paretic arms in right-handed patients, with left versus right sub-acute stroke, researchers found that in patients with left hemispheric stroke, both their arms demonstrated deficits in tapping frequency, velocity and timing relationships. While showing similar types of deficits, those with right-sided lesions demonstrated those losses only in the paretic limb. When bilateral upper extremity training was conducted on right-hand dominant patients, those with motor dominant stroke (left hemispheric lesion) showed a response advantage when compared to those with motor non-dominant stroke (right hemispheric lesion). This indicated that treatment for upper extremity hemiparesis may need to be more specifically selected based on side of stroke (Waller, et al. 2002).

Several asymmetries in lateralisation have been found in stroke patients. First of all there was asymmetry in weight-bearing (Simons, et al. 2009; Haart, et al. 2004).

In a study they looked at the reduced postural steadiness and asymmetry of weight bearing for characteristic posture after stroke. They found that patients with severe motor impairments of the paretic leg showed greater static (weight-bearing) and dynamic (lateralized control) asymmetries than patients with limited motor impairments. Patients were also found to strongly rely on visual information. Their weight-bearing asymmetry increased when attention was distracted by having patients perform an arithmetic task, suggesting that symmetric weight bearing is attention demanding. Disturbed sensation did not affect weight-bearing asymmetry, postural steadiness, or lateralised control. The results indicated that patients with severe motor impairments of the paretic leg employed an effective compensatory strategy of asymmetric weight bearing and lateralised control (Roerdink, et al. 2009).

When disentangling the contribution of the paretic and non-paretic ankle to balance control in stroke patients, the researchers quantified the contribution of the paretic and non-paretic leg in maintaining upright stance, by splitting up the total stabilising mechanism into two parallel stabilising mechanisms: a paretic and non-paretic stabilising mechanism. Each of these stabilising mechanisms consisted of the sensory and motor system of the concerned leg and the part of the CNS that processes sensory signals and generates efferent signals to the motor system (Asseldonk, et al. 2006).

Balance responses in eight chronic hemiparetic stroke patients were elicited by continuous random platform movements. The key finding was that the contribution of the paretic leg to balance was much smaller than its contribution to weight bearing and neither leg showed a clear relation with the contribution to weight-bearing. This implies that the contribution of the paretic leg to balance is not a mere reflection of the weight distribution. The finding that the contributions of the paretic leg to balance control were smaller than its contribution to weight bearing could be because weight bearing is a rather static process, while balance control is highly dynamic (Asseldonk, et al. 2006).

Stroke Discussion:

Medical condition limb dominance and asymmetry were found in all articles.

Based on the finding that in right handed persons, the upper extremity deficits after stroke may differ depending on the side of stroke. Handedness could be affected if the stroke hits certain parts of the brain. This indicates that limb dominance may be connected with the brain function. As described in the theory section 4.5, there is a connection between arms and legs, but the outcome when testing arms contra legs was not equal, suggesting that less neural resources are devoted to leg and foot control than to arm and hand control. However, a relationship between brain and legs seems to have been found. This is based on two chosen parallel stabilising mechanisms: a paretic and non-paretic stabilising mechanism. Each of these stabilising mechanisms consisted of the sensory and motor system *of the concerned leg and the part of the CNS that processes sensory signals and generates efferent signals to the motor system* (Asseldonk, et al. 2006).

When talking about greater static (weight-bearing) and dynamic (lateralized control). This should remind us about the definition of dominant and non-dominant limb: *The limb preferred to execute a manipulative or mobilizing action while the other (non-dominant) foot provides stabilizing* *support, e.g. kicking a ball (Gabbard, Hart, 1996).* Stabilizing support is probably executed by the weight bearing leg. Patients with severe motor impairments of the paretic leg employed an effective compensatory strategy of asymmetric weight bearing and lateralised control (Roerdink, et al. 2009).They might create a functional limb dominance based on the side of the paretic leg.

6.3 Parkinson

Parkinson's disease (PD) is a neurodegenerative disorder, characterised by progressive loss of muscle control, tremor, muscle rigidity, paucity of voluntary movements, and postural instability (Smith, et al 2003). As symptoms worsen, it may become difficult to walk, talk, and complete simple tasks. Parkinson's disease involves the malfunction and death of vital neurons in the brain. Parkinson's disease primarily affects neurons in the area of the brain called the substantia nigra. Some of these dying neurons produce dopamine. Dopamine's function is to send messages to the part of the brain that controls movement and coordination. As PD progresses, the amount of dopamine produced in the brain decreases, leaving a person unable to control movement normally.

Results:

Motor symptoms in Parkinson`s disease are typically asymmetrical (Geurts, 2010). In most cases there is substantial asymmetry of clinical symptoms (unilateral tremor, rigidity, and Bradykinesia) from the onset of the disease this unilateral predominance can persist throughout the span of the diseases progression (Djaldetti, et al. 2006).

More research is often made on the upper extremities than the lower extremities. In a study subjects were asked to maintain their limb in a constant position (30 s) under a postural finger, postural hand and resting tremor condition. All subjects were right hand dominant. The increased regularity from the least affected to the most affected limb was not due to hand dominance. This was based on that four of the Parkinson's disease subjects' left side and four of the subjects' right side was most affected (Vaillancourt, Newell, 2000; Djaldetti, et al. 2006).
Some of the same correlations (affected limb and hand dominance) are seen in a pilot study. There were used a posturography technique that combines dynamic platform perturbations

with a system identification techniques that detect asymmetries in balance control this was carried out on two patients with Parkinson's disease. The founding's were a clear asymmetry in dynamic balance control. Asymmetries were found in weight bearing, but the asymmetries in dynamic balance contribution were larger. Asymmetries in weight bearing and dynamic balance in patients are not so tightly coupled as in healthy controls groups. An interesting finding is that the patients themselves were not aware of any asymmetry and had no subjective problems with stability or standing. The patients with the greatest clinical asymmetry had a less asymmetric balance contribution. Another intriguing observation was that one patient was worse in his left leg (including higher rigidity), but this same left leg contributed more to balance control than his right leg (Kooij, et al. 2007).

Most Clinicians would agree that the side with the most severe tremor was not always the side that revealed the most rigidity and/or showed the most deficits during tapping, pronation/supination, etc. (Almeida, 2009).

Gait in PD is also significant different from the healthy elderly (Miller, et al. 1995). Variability and bilateral symmetry of EMG gait-cycle profiles were studied in parkinsonian and healthy elderly subjects. A portion of the parkinsonian group participated in a 3 week therapy program where they walked to rhythmic auditory stimulation. Bilateral symmetry was investigated using shape and timing measures. The PD group had a significantly lower shape symmetry in the muscles. Within the PD group that was involved in the therapy, significant improvements in symmetry were observed (Miller, et al. 1995).

Parkinson Discussion:

Medical condition limb dominance and asymmetry were found in PD patients. Most interesting here is that it appears that basis dominance was preserved despite a medical conditions limb dominance. Parkinson's disease affects the CNS and it gives many motor functions disruptions, but it seems like the function of limb dominance is not affected. This statement is based on-if the most affected side is coincident with the dominant side, the dominant side did not always reveal the most rigidity and/or show the most deficits. If limb dominance is caused at the nervous level maybe PD does not affect this part of the brain?

6.4 Rett syndrome

Rett syndrome is a disorder of the nervous system that leads to developmental reversals. It mostly occurs in girls. There exist several variants of Rett syndrome. Girls with classic Rett have an apparently normal development for 6 -18 months after birth. Then they develop severe problems with communication and language, learning, coordination, and other brain functions. Rett syndrome is a progressive disease (Santos, et al. 2009).

The vast majority of cases of classic Rett syndrome are caused by mutations of the MECP2 gene. This gene provides instructions for making a protein (MECP2) that is critical for normal brain function, although the exact function of the MECP2 protein is unknown. The congenital variant of Rett syndrome results from mutations in the FOXG1 gene. Mutations in the CDKL5 gene cause the early-onset seizure variant of Rett syndrome (Santos, et al. 2009).

Results:

Investigations of side asymmetries of neuro-impairments revealed a characteristic right-sided dominance in terms of dysfunction and neurology. This was particularly noted in the lower extremities, most markedly in legs and feet (Hagberg, Romell, 2002).

Almost all children with Rett syndrome under age 7 naturally grasp objects left-handed. It was found that at the age of 7 a shift to right-handedness occurred (Olsson, et al. 2005). Children over 7 grasp objects preferably with the right hand and show symptoms of disturbance of the functions of the pyramidal tract that are more pronounced in the left than in the right upper limb (Olsson, et al. 2005).

In connection with the severe developmental retardation of the CNS in Rett syndrome, the right shift factor of handedness is a belated manifestation. Within the framework of a regression of the CNS there occurs a regression which was more pronounced in the right cerebral hemisphere than in the left (Olsson, 2005).

Rett Syndrome Discussion:

It was found that there was a characteristic right-sided Medical condition limb dominance and asymmetry. Arms were investigated according to limb dominance and it is interesting to see such a rigid choice of grasping objects with the left hand before the age of 7 and then a shift to right-handedness after age 7. The researchers' theory was that the right shift of handedness is *a belated manifestation*. Children under the age 3 *exhibited non-established limb dominance* (Hopkins, et al. 2007, Marschik, 2008). In age 3-5, the majority of children display a preference for one foot over the other (limb dominance), but a large amount of the children still exhibited *non-established (mixed) behaviour* (Gabbard, C. 1991). This could indicate that the development went *from mixed to right*, not *from left to right*. This does not seem consistent with a delayed development. Olsson, et al. (2005) found deviations in the pyramidal tract and the right cerebral hemisphere. It seems likely that limb dominance is contiguous with and depends on a normal development in CNS.

The upper and lower limbs play a distinctly different functional role allthough foot biases and their interaction with hand biases are of practical importance. It is not known whether the changes that occur in the arms are present in the legs as well. It would be interesting to know this especially because dysfunction and neurology were particularly noted in the lower extremities, most markedly in legs and feet.

6.5 Pain

Physical pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage. Pain can be temporary or chronic. Pain receptors called Nociceptors detect the damaged or potentially damaged area and they send an impulse through the nerve into the spinal cord, and on to the brain (Anand, Craig, 1996).

Results:

Pain in its self is not a disease, though many diseases are combined with pain. Pain may be symmetrical in distribution or predominantly lateralised to one side. Merskey & Watson (1979) looked into the distribution of pain in 10 clinical reports and they found that it tends to be more frequent on the left hand side of the body. This makes pain more often lateralized on the left hand side of the body, except in the case of trigeminal neuralgia (a neuropathic disorder characterized by episodes of intense pain in the face). One reason might be that the right hemisphere is less efficient than the left in processing cutaneous sensory input (Merskey, Watson, 1979). Additionally the right hemisphere might be dominant for emotional experience and this may help to determine the left-sided preponderance of pain (Merskey, Watson, 1979).

Pain Discussion:

According to Merskey and Watson (1979), pain has a fundamental lateralisation to the left. That makes for an interesting thought. What if you have a condition like Rett syndrome which contains a characteristic right-sided dominance in terms of dysfunction and neurology that can interfere with normal limb dominance and create enforced limb dominance. What happens if a person with Rett syndrome damages his left foot? Will that provide greater pain and less control? Another paradox might be if you have a right limb dominance and then damage your left foot combined with pain and destruction of the foot. Then you may get a more unilateral action. You use the right leg to initiate and facilitate weight bearing, but you cannot use the left leg to initiate and facilitate dynamic actions because of the damage and the increased pain, this could end up as a more unilateral action.

6.6 “Retarded males”

Euphemisms have been substituted for the term ‘retarded’ which is no longer in general use today. Malina and Buschang (1984) use this expression in their article - Anthropometric asymmetry in normal and mentally retarded males. The battery of measurements was taken on about 200 mentally retarded males. The sample of mentally retarded males ranged from 9 to 52 years, and all were residents at a state-run school. Medical personnel evaluated the sample of mentally retarded. The mentally retarded were subdivided by I.Q. (range 0-70) and type of mental retardation. The categories of I.Q. differed from mild, moderate, severe to profound. Type of mental retardation consisted of Down`s Syndrome, unknown (non-specific), mental retardation with cerebral palsy, and others, including rubella, anoxia, prematurity, encephalitis, meningitis (Malina, Buschang, 1984).

Results:

Mentally retarded individuals show greater anthropometric asymmetry than normal individuals (Malina, Buschang, 1984). The distribution of the differences are broader in the retarded, one see more variability and less rigid pattern. The variances of left-right differences are greater than variances associated with the normal population. Left-right differences between the normal and the retarded males occur primarily in the upper extremity. Side differences in the lower extremity are not great. Within the mentally retarded sample, there were significant left- right differences among aetiological categories. Those with neurological impairment were more structural asymmetric. However, there was no significant left-right difference among the different I.Q. categories, but there were in the different types of mental retardations. Results of this study indicate a significant role for mental functioning relative to asymmetry (Malina, Buschang, 1984).

Retarded discussion:

Asymmetries were found among the “retarded males”. In the “retarded males” the distributions of the differences are broader, not as rigid as in the normal population. It seems likely that symmetry and limb dominance are contiguous with mental functioning. This based on that mental functioning is relative to asymmetry and the variances of left-right differences are greater among the retarded than in the normal population (Malina, Buschang, 1984). It is not the amount of I.Q. but the type of mental retardations that is relevant. Suggesting that there is talk about a building construction error within the brain in the mental handicapped compared to the normal population.

7.0 MUSCOLOSKELETAL DAMAGE AND DISFUNCTION

A common feature of these diseases is that they cause musculoskeletal damage, dysfunction or a deviation.

7.1 Human sacral morphelogy

The study of the effects of physical activity patterns on the skeleton in past populations is here used for the identification of directional bilateral asymmetries (Plochocki, 2002). The sacrum represents the pivoting zone and primary region of weight transmission between the upper and lower body. During asymmetric activities of the upper body, the lumbosacral joint has been shown to experience greater loading from body weight, greater joint moment dominance, and stronger surrounding muscle contractions on the side opposite from the loaded upper limb (Plochocki, 2002).

Results:

In considering the effects of mechanical loading on the morphology of the sacrum, skeletons of a sample of 238 modern individuals were examined (Plochocki, 2002). They were provided by the Hamann-Todd skeletal collection at the Cleveland Museum of Natural History and the Terry skeletal collection housed at the Smithsonian Institution in Washington D.C. There were found significant directional asymmetry in all three dimensions in sacrum. The pattern of asymmetry is consistent with models describing the influence of right-handedness on the lower body, which predicts that left side dimensions will be larger (Plochocki, 2002).

Human sacral morphology Discussion:

Asymmetries consisting with models describing the influence of right-handedness on the lower body were found. This could confirm the existence of lateralisation of a dominant foot with a manipulative or mobilizing action and a non-dominant foot providing stabilising support shown on the morphology of sacrum. This confirms normal distribution of limb dominance (Taylor, Strike, Dabnichki, 2006).

7.2 Leg length inequality

A bilateral asymmetry in lower limb lengths is called leg length inequality (LLI). It is important to differentiate between an anatomical short leg, a functional short leg and an environmental LLI. An anatomical short leg occurs when there is an actual length difference in the bone components of the lower limb. A functional short leg occur secondary to a rotated pelvis caused by joint contractures and/or axial misalignment, including scoliosis. Environmental LLI occurs when runners with existing LLI use the drainage slope built into roads to attenuate, eliminate or even reverse the inequality of the LLI (McCaw, et al. 1991). Leg length inequality can cause back pain (Juhl, et al. 2004) and LLI is associated with radiographic knee osteoarthritis (OA) (Golightly, 2007).

Results:

Leg length inequality is often proposed as an additional cause for asymmetry in other articles (Seeley, 2010).

In 25 patients with limb length discrepancy, foot loading patterns and neuromuscular function of both limbs during walking were investigated. Plantar pressures and 2-D ground reaction forces were recorded simultaneously with electromyographic activities at two different walking speeds. Bilateral comparisons indicated that moderate limb length discrepancies resulted in asymmetrical gait pattern (Perttunen, et al.2004). The results imply that the loading of the long limb is greater and the foot loading patterns shifted more to the forefoot in the long limb to compensate walking disturbances by limb length discrepancies (Perttunen, et al. 2004).

Ttwenty children (mean age, 9.0 ± 3.9 years) with documented limb-length inequalities, were investigated to determine the magnitude of discrepancies that result in gait abnormalities. It was found that asymmetry increased as the limb length inequality increased. However, *the amount of asymmetry varied for each individual* (Kaufman, et al.1996).

Femoral overgrowth can follow after plate fixation of a fractured femur in children (Sulaiman, et al. 2006). This was showed when 15 patients (aged between eight and 14 years old), underwent open reduction and plate fixation for fractures of the femur, they were assessed at two years postoperation for limb length discrepancy. The results showed that there is a significant correlation between age and bone overgrowth. Limb length inequalities are frequently encountered. Limb dominancy and site of fracture had no significant influence on femoral overgrowth (Sulaiman, et al. 2006).

Leg length inequality Discussion:

In leg length inequality asymmetry were found and movement pattern were created based on the individual leg length. Leg length can influence which leg will be the most weight-bearing leg (leg loading), sometimes conflicting with the natural limb dominance. It appears that this may form a functional limb dominance that is created for mechanical reasons. Interestingly, plasticity is seen through the amount of asymmetry variations between the individuals. This based on that even though, asymmetry increased as the limb length inequality increased, *the amount of asymmetry varied for each individual* (Kaufman, et al.1996). Therefore the result of gait pattern may depend on the length of the leg and the person’s capacity for plasticity.

Limb dominancy and site of fracture in children had no significant influence on femoral overgrowth in children. This might mean that limb dominance do not provoke an overgrowth (leg length inequality), but if you get an overgrowth (leg length inequality) this can influence your limb dominance.

7.3 Amputation

Amputation results in a limb being removed from the body. Causes can be traumatic etiology (traumatic causation like car accident) or dysvascular etiology (defective blood supply in conjunction with illness like angina). Toe-to-hand transfer is a surgical procedure whereby you amputate the patient's toe and use it to replace a missing thumb (High-smith, et al. 2011; Spanie, et al. 2004). After any kind of amputation, one can experience immediate and Long-Term Phantom Limb Pain (Jensen, et al. 1984).

Results:

If you are left-handed, is there an increased risk for amputation? In fact there seems to be a higher risk. To investigate the relationship between hand dominance and the risk of major hand injury, a case recorded 125 patients who had been treated for digital amputation. This study revealed that left-handed people were more likely to have an amputating injury of their dominant hand than were right-handed people. The most common mechanism of amputating injury was by power saw (Taras. et al. 1995). It has been suggested that left-handed individuals have a relative risk of sustaining an amputating injury that is 4.9 times greater than the right-handed individual. Minor hand trauma occurs at rates proportional within the normal population (Taras. et al. 1995)

Amputees possess by definition a functional asymmetry. Lower leg amputation generally includes asymmetrical weight-bearing with more weight on the non-prosthetic leg (Duclos, et al. 2008; Nadollek, et al. 2002). This can be detrimental to an amputee's long term quality of life. Increased strains on joint surfaces that receive additional weight load can cause back and leg pain, premature wear etc (Duclos, et al. 2008; Nadollek, et al. 2002). Training for a well-functioning standing posture is an important issue in the rehabilitation of persons with uni-lateral lower limb amputation. Fifteen subjects with a unilateral lower leg amputation and 17 control subjects participated in a study. Centre of pressure (CP) position was recorded during standing posture, under eyes closed and open conditions. Recordings were carried out before the subjects performed a 30-s voluntary isometric lateral neck muscle contraction. Founding was that 30-s voluntary isometric contraction can change the standing posture of persons with lower leg amputation (Duclos, et al. 2008; Nadollek, et al. 2002).

In an investigation on turning bias and lateral dominance a total of 100 able-bodied participants, and 30 trans-tibial amputees who, by definition, possess a functional asymmetry, volunteered to participate. In the able-bodied sample the right hand and right foot were significantly dominant. Also the amputees were significantly right-hand dominant, the side of the amputation influenced foot dominance. Turning is a normal human action. When turning bias and lateral dominance were compared able-bodied participants showed a significant turning preference towards the left, which was opposite to the dominant hand and foot. The amputees showed no *preferred* turning direction, even though they were significantly right-hand dominant. Turning direction *depended* on which leg that was amputated. Side of foot dominance were influenced by the amputation. Turning bias indices in the amputee sample were not significantly associated with handedness, footedness, side of amputation, or dominance prior to amputation. The researchers suggested that biomechanical asymmetries can influence turning bias (Taylor, et al. 2006).

Amputee Discussion:

Clear asymmetry was found mainly because amputees possess by definition a functional asymmetry. In the turning bias the amputees were significantly right-hand dominant and the side of their amputation influenced their foot dominance. Is their foot dominance maybe based on plasticity? Even though the amputees were right-hand dominant, they showed no preferred turning direction. Could it be that the choice of turning direction depends on biomechanical reasons and that their basis limb dominance still exists on the nervous level? They were still right-hand dominant, but turning direction was depending on biomechanical reasons. They may use plasticity to get functional limb dominance but what if the prosthetics were as good as a normal leg, would they then turn as the non- amputees towards the left?

High tech developments are rapidly occurring at present in the innovation of prostheses (Grabowski, 2011). For example, bionic prostheses can use a computer chip that is attached to the remaining nerve ending and is therefore capable of registering signals from the brain. These signals are then sent via wireless to the skin, where they are perceived by a receiver. The received signals are then send to a new chip. This chip decodes the signals and sends the information to a computer. The computer activates the motor function units and the prosthesis performs the desired movement (Grabowski, 2011). Bionic ankle-foot prostheses can normalize walking gait for persons with leg amputation (Grabowski, 2011). This method shows the connection between brain and movement. Bionic prostheses are attached to the existing system regardless the injury in the leg. When only the leg and not the brain are injured, could it be that basis limb dominance might still exist on a nervous level?

Bionic ankle-foot prosthesis is a new development, but why not just grow a new foot to replace your amputated foot? Is this a science fiction fantasy or could it become reality? The Wake Forest Institute for Regenerative Medicine (WFIRM) is a leader in translating scientific discovery into clinical therapies. Physicians and scientists at WFIRM were the first in the world to engineer laboratory-grown organs that were successfully implanted into humans. So in the future it might just be possible to clone a new foot and thereby you might retain and use your basis limb dominance.

7.4 Arthritis

Arthritis is not a single disease - it is a term that covers over 100 medical conditions. The majority of arthritis conditions are considered to be autoimmune diseases. Osteoarthritis (OA) is the most common form of arthritis and generally affects elderly patients (Ekdahl, Andersson, 1989; Viton, et al. 2000). Osteoarthritis is not considered to be an autoimmune disease but a chronic degenerative disorder. The symptoms are similar and disease-related characteristics are: pain, - stiffness, - fatigue, - inactivity, - joint destruction, - muscle dysfunction (decrease of muscular strength and alteration of proprioception), and instability of weight-bearing joints (Ekdahl, Andersson, 1989; Viton, et al. 2000).

Results:

Since, in rheumatoid patients, the foot is enervated while bearing weight, change in weight bearing has been found (Bove, et al. 2003). Bove et al. (2003) described an in vivo model in rats in which change in weight distribution was used as a measure of disease progression and efficacy of acetaminophen (painkiller) and two nonsteroidal anti-inflammatory drugs (NSAIDs, anti inflammatory painkiller) in a model of monosodium iodoacetate (MIA, reagent for the modification of cysteine residues in proteins.) used to induce osteoarthritis (OA) in animal. They found that after intra-articular injection of MIA a concentration-dependent *increase* of weight distribution in the hind paw occurred. Both naproxen and rofecoxib demonstrated the capacity to significantly *decrease* hind paw weight distribution in a dose-dependent fashion, (Bove, et al. 2003).

Is there a connection between limb dominance and the incidence of witch joints that get affected? Joint use has been felt to increase the severity of rheumatoid synovitis (rheumatoid is a common kind of arthritis). Rheumatoid arthritis patients were studied for clinical and radiological findings to see the effect of dominancy on the severity of the arthritis (Boonsaner, et al. 1992). In this study Boonsaner, et al (1992) found that the dominant side showed significantly greater total swelling scores. This was explained predominantly by greater severity of arthritis in dominant arms and hands. Furthermore, the dominant side received more surgical operations (Boonsaner, et al. 1992).

Arthroplasty (joint replacement) becomes a question after long term illness and joint destruction. Before reaching that stage, will patients with knee arthritis modify their equilibrium and movement control strategies during gait initiation? The conclusion was that gait initiation is an asymmetrical process in uni-lateral knee arthritis patients, who developed adaptive posturomotor strategies that shortened the single stance phase on the affected leg (Viton, et al. 2000).

Arthroplasty replacement is not uncommon after joint destruction caused by arthritis. Patients with unilateral hip or knee replacements for end-stage osteoarthritis (OA) are at risk of future progression of OA in other joints of the lower extremities. It invariably follows that after one joint is replaced, the contralateral limb is significantly more likely to show progression of OA than is the ipsilateral limb (Shakoor, N. et al. 2002). In patients with bilateral severe knee OA who had undergone unilateral knee arthroplasty, there were poor knee and ankle kinetics on the operated side during gait (referanse). It seems that unilateral total knee replacement produces a very asymmetrical gait in a bilateral severe OA knee patient (Huang, H. et al. 2007).

In patients with rheumatoid arthritis (RA), ischaemic stroke (See section 6.2) frequently leads to an unexplained remission of the arthritis in the paretic limb (Keyszer, et al. 2004). It is suggested that neurovascular mechanisms contribute to the asymmetry of inflammation by impairing the microcirculation in the paretic extremity (Keyszer, et al. 2004). It seems that the medical condition limb dominance is influenced by several factors including non-random progression and other diseases such as stroke (Keyszer, et al. 2004).

Arthritis Discussion:

The illnesses may affect limb dominance. There is often a medical condition limb dominance but this affects the opposite side which is often the next in line to become impaired. Asymmetries and changes in weight bearing are often found. The changes that occur are an effect from the weight bearing enervation of the affected foot. If limb dominance is defined as being associated with weight bearing and the leading leg, then changes in dominance happened. However, there seems to be a change in functional limb dominance because when looking at the results of the rat study by Bove et al. (2003), they changed their weight bearing limbs depending on pain contra non-pain. If the rats could maintain their normal movement pattern, this was their preferred choice. Suggesting, that a basis limb dominance still might exist on a nervous level.

7.5 Fallers

Among the groups of medical conditions that provide an asymmetry in the function of the lower extremities, it is not uncommon to find muscle weakness. The latter is often seen in elderly people as a result of normal ageing (Skelton, et al. 2002). Low strength is a risk factor for falls, and falls can lead to injuries and fear for new fallings, potentially leading to less activity (Skelton, et al. 2002).

Results:

One example is mentioned in regard to the risk of falling. Falling might be a risk for many asymmetrical medical conditions.

A study was done on muscle strength, and explosive power, and the asymmetry of leg strength and power of women aged 65 (Skelton, et al. 2002). Skelton, et al.(2202) found that weakness and asymmetry are prevalent in women aged 65 and over, with and without a history of falls. It was found that both groups were asymmetrical in their lower limb power, but the fallers demonstrated a significantly greater asymmetry (Skelton, et al. 2002). It has been suggested that poor lower limb explosive power combined with asymmetry between limbs may be more predictive of future falls (Skelton, et al. 2002).

Discussion fallers:

Asymmetries were found in fallers. The risk for falling increased with asymmetry and muscle weakness. This is not only relevant for elderly but an extreme risk for the majority of medical conditions mentioned in this thesis (with a possible exception for the skeleton). All the medical conditions created an asymmetry in the lower extremities which could lead to a higher risk of falling.

8.0 Discussion

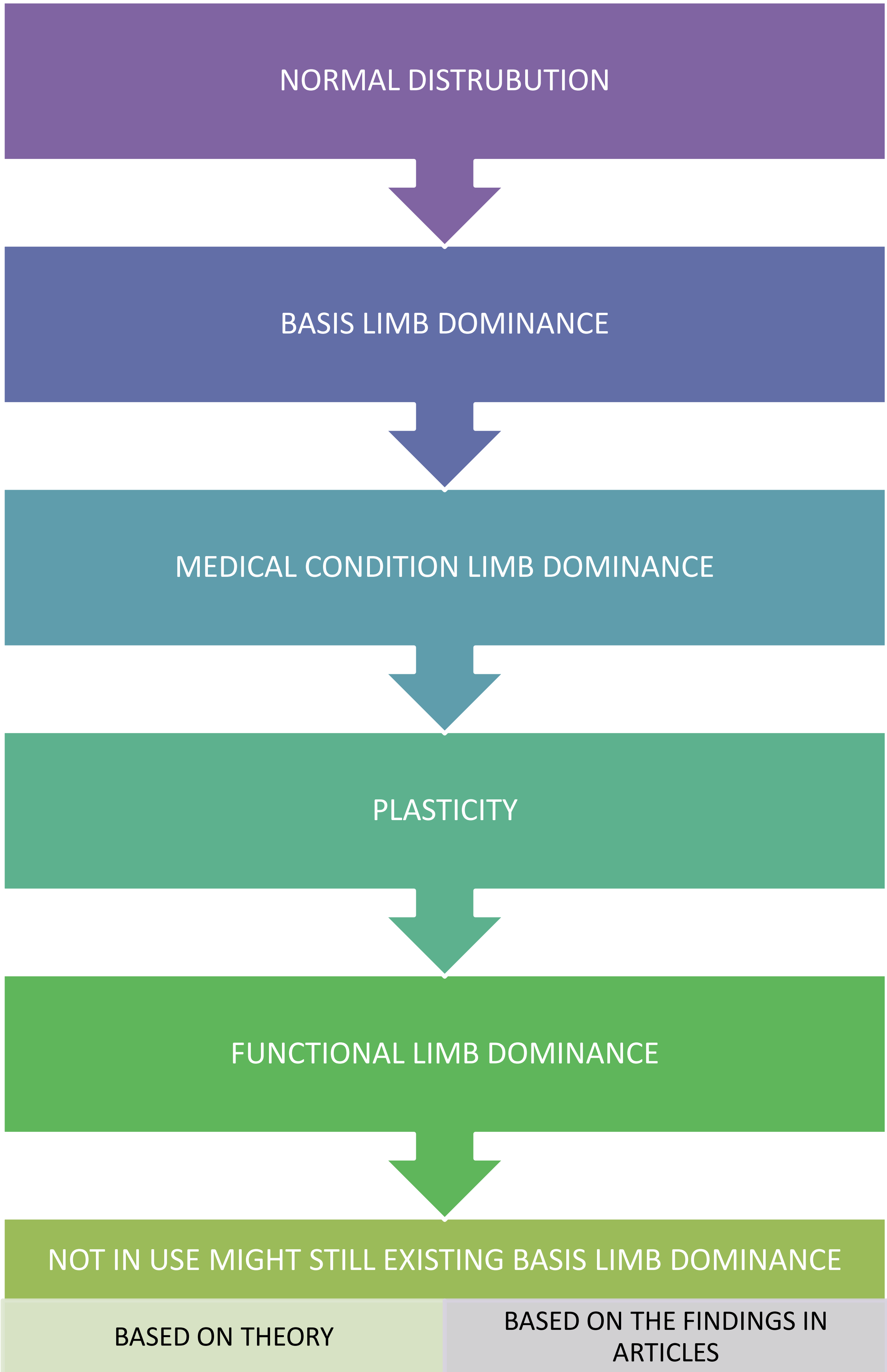
It is easy to take for granted that the non-affected limb within a disease is synonymous with the dominant limb. If for example you have a right limb dominance and contract a right side dominant illness, you will change to left limb dominance. Some researchers have made that conclusion (Wiley, Damiano, 1998). Is it really so simple? The current literature review investigated the following research question:

Medical conditions that cause an asymmetry in the functions of the lower extremities – will they also affect limb dominance?

In the population, there exists a normal distribution of limb dominance, where approximately 60-80% are right footed (Taylor, M. J. D. et al. 2006). In this thesis, the limb dominance a person has before a potential medical condition is called basis limb dominance. Some medical conditions affected mainly one side of the body in which case you can talk about laterality of symptoms, the side most affected (Almeida, Q. J. 2010). In this thesis, the limb that is predominantly affected is called medical condition limb dominance. The term plasticity is used if limb dominance can be reduced by practice or the non- or less-affected leg can take over the function of the affected leg. When a leg has the dominance in function, it is called functional limb dominance in this thesis.

Based on findings in theoretical and empirical articles about medical conditions that provide an asymmetry in the functions of the lower extremities, it can be suggested that after an impact of trauma caused by medical conditions, even when you have changes in functional limb dominance, there might still exist at the brain level the original basis dominance. You have therefore still a not in use existing basis limb dominance. An exception is likely when damage has occurred on the nervous level to the fields that participate in right / left dominance.

From being a member of a normal healthy population to getting sick, starting and going through rehabilitation, the progression of disease and limb dominance might be presented like this:


NORMAL DISTRUBUTION
BASIS LIMB DOMINANCE
MEDICAL CONDITION LIMB DOMINANCE
PLASTICITY
FUNCTIONAL LIMB DOMINANCE
NOT IN USE MIGHT STILL EXISTING BASIS LIMB DOMINANCE
BASED ON THEORY
BASED ON THE FINDINGS IN ARTICLES

8.1 Based on theory

First of all, a dominant hemisphere-laterality relationship is assumed by Maupas, et al. (2002) & Gabbard, Hart, (1996). For instance, preferred spontaneous use of the right-hand is an expression of left hemispheric dominance of motor function, commonly called right-hand dominance (Maupas, E. et al. 2002; Gabbard, C., Hart, S. 1996). Additionally, lateralisation studies indicate that skilled and unskilled foot movements utilise different pathways (pyramidal tract). If this is correct, it would mean that limb dominance might be based on a brain level. This would imply that when your dominant foot gets removed your basis dominance still exists on the brain level, just not in physical use. This gives rise to the question as to whether or not you can change dominance on the brain level. If so you would have to shift the unskilled pathways into a skilled pathway (pyramidal tract). The existence of limb dominance appears to be fixed. We develop side dominance already within the first 3-5 years of age (Maupas, E. et al. 2002; Gabbard, C. 1991) and in the population there exists a non-random normal distribution of limb dominance (Taylor, M. J. D. 2006). Furthermore, a relationship between hands and feet in locomotion exist (Peter, M. & Durding, B. M. 1979; Augstyn, C. & Peters, M. 1986). It seems to be a relative conservative system to change.

To make changes your need plasticity, but does there exist a limitation as to the possibilities? It seems that, when professional soccer players were studied, they were remarkably adept on those occasions when they used their non-dominant foot, but when they could choose between dominant and non-dominant foot, they still preferred the dominant foot, suggesting that skill cannot be explained by asymmetry of choice (Carey, D. P. et al. 2009). It thus appears that no exchange between limb dominance on the brain level occurs, only an expansion of capacity of the non-dominant foot. Plasticity can in theory cause one leg to take over the function of the other leg. This would be an effective compensation strategy if one of the legs is markedly affected (Kooij, H. et al. 2007). This suggests that if a medical condition produces an affected limb, the non-affected limb can become the functional dominant limb, but on a brain level there might still exist a basis limb dominance.

Functional Magnetic Resonance Imaging (FMRI), is a technique measurement used to determine the connection between the brain and a person's intensions and choice of movements. It would be interesting to use this technique in a scientific investigation of limb dominance. This could determine which areas of the brain specifically interact, when conducting spontaneous movements involving limb dominance. That would maybe prove the existents of a basis limb dominance on a nervous level.

8.2 Based on findings in articles

In this thesis, an explicit distinction was made between the difference of medical condition limb dominance, basis limb dominance and functional limb dominance. It appears that basis limb dominance does not have to be the same as functional limb dominance. Medical condition limb dominance and asymmetry were found in all categories of medical conditions. The results of studies on retarded individuals indicated a significant role for mental functioning relative to asymmetry. The distribution of the differences are broader in the retarded, one see more variability and less rigid pattern. The variances of left-right differences are greater than variances associated with the normal population. This can support the theory about the existing dominant hemisphere-laterality relationship. The function in retarded individuals of lateralisation seems not as structured and rigid as in the normal population.

Bionic prostheses might show the connection between brain and movement. Bionic prostheses get attached to the existing system regardless of the injury in the leg. When only the leg and not the brain are injured, could it be that basis limb dominance might still exist on a nervous level? The result of this would be even more important if we in the future can replace damaged limbs with new biological limbs.

What if the brain itself is affected? Would the exact location of the damage in the brain play a role in limb dominance? It appears to be that after a stroke, the upper extremity deficits may differ depending on the side of stroke (Waller, et al. 2002). In right-hand dominant patients, those with a motor dominant stroke (i.e., a left hemispheric lesion) show a response advantage when compared to those with a motor non-dominant stroke (i.e., a right hemispheric lesion). It seems to complicate the situation if several brain areas and loops of information are involved.

When stroke patients performed an arithmetic task and got distracted, an increase in weight bearing asymmetry occurred (Roerdink, et al. 2009). The same pattern is seen in Rett syndrome, a progressive disorder of the nervous system. Unlike normal development, these persons have left-hand dominance until age 7 and then a shift to right-hand dominance occurs (Olsson, et al. 2005). However, these results concern the hands and might differ from results in the lower extremities. To my knowledge, this has not been investigated.

Generally, it seems that plasticity is able to create an adaptation to the medical condition, by creating a functional pattern in motor movements based on available possibilities. That makes it common to see changes in functional limb dominance in asymmetrical medical conditions. An adapting technique is to use the paretic leg as the weight-bearing leg and the other leg to initiate and facilitate dynamic actions (Kooij, et al. 2007). In this way, patients create a functional limb dominance based on the affected leg. This was seen in Cerebral Palsy, stroke, leg length inequality, amputees, and arthritis. The persons who maintained their basis limb dominance were patients with Parkinson disease, persons with Rett syndrome changed limb dominance at age 7 and “retarded males” showed less obviously laterality. This could suggest that an illness can affect basis limb dominance. This if the illness strikes some particular areas in the brain.

Plasticity limitations might be seen in the case of leg length inequality. Researchers found that asymmetry increased as limb length inequality increased (Kaufman, et al.1996). However, the amount of asymmetry varied for each individual (Kaufmann, et al. 1996). This suggests that environmental possibilities and training have an influence on the results. It seems more like “how skilled can you get?" rather than “a change to a new basis?

This leads to the importance of the choice of training method, and the choice of the side one prioritises to give attention to with respect to affected/non-effected versus dominant/not-dominant. Especially because asymmetry, muscle weakness and pain often are present in many of the medical conditions. Pain, for example, is more often lateralised on the left hand side of the body (Merskey, Watson, 1979). This may be an additional burden if it interferes with the affected limb or in case of left limb dominance.

If you want to or just have the opportunity to focus on the affected side Constraint-induced movement therapy (CIMT) could be an option. Good operative movements are always important whether the medical condition has stricken the dominant or non-dominant hand. Daily activities often involve the use of two arms or/and two legs. Even if your non-dominant limb is affected, you need a basis function of movements capacity to perform daily activities. The use of CIMT makes sense when talking about training on daily activities, on the contrary if the goal is to learn tasks that you were not able to do before the illness, CIMT conducted on the non-dominant hand, can seem pointless.

In contrast, if you are an amputee who lost your dominant leg and you are a perfect match for receiving a Bionic prosthesis, you might benefit from focusing your money, training and time on your Bionic prosthesis, and thereby keep your limb dominance.

9.0 CONCLUSION

The aim of this theoretical review has been to examine and discuss medical conditions that cause an asymmetry in the functions of the lower extremities with respect to the whether these conditions will also affect limb dominance.

Medical conditions that cause an asymmetry in the functions of the lower extremities create a dominant limb in terms of dysfunction. This probably leads to a more unilateral action pattern and a change in functional limb dominance. It is suggested that basis limb dominance might still exist on the brain level. If this is correct, it means that if a person receives a brain injury, this might damage or destroy limb dominance on brain level. To be able to say more about limb dominance on the brain level could be a case for future research. It would have been extremely interesting in context of this thesis to use Functional Magnetic Resonance Imaging (FMRI) technique. This could determine which areas of the brain specifically interact, when conducting spontaneous movements involving limb dominance. That would maybe prove the existents of a basis limb dominance on a nervous level.

9.1 Practical and clinical relevance

It would be advisable to consider this review when looking at dominance and medical conditions with laterality of symptoms. To prevent incorrect results when asking questions involving limb dominance, if using weak or perceived definitions of limb dominance.

Next to be considered is retraining after a traumatic impact episode; should we clinically encourage the training of the non-affected limb to become the functional dominant limb or should we try to adapt for instance a prostheses for the best optimal function on the basic dominant limb?

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