HEADING IN THE RIGHT DIRECTION

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Insights

The flying header goal of Robin van Persie in the world cup game against Spain is a special and memorable moment in the Dutch soccer history. However, there are concerns about the possible consequences of heading on the brain and therefore there is even thought about a ban. Will we be able to enjoy such nice goals in the future or does this need to end?

Background

In contrast to other ball games, the unprotected head is purposefully used in playing soccer to deliberately impact the ball and direct it during play. As a result, heading might be harmful to the brain. The Union of European Football Associations (UEFA) and the Royal Dutch Soccer Association (KNVB) started a research on this for youth soccer [1]. During non-professional matches, balls travel at velocities of 80 km per hour or more. On average, players head the ball 6-12 times during competitive games and during practice sessions, this frequency can even reach up to 30 or more headings [2]. The median number of headings a year is 432 [3]. When heading a ball, an average g-force of 16-28 g and peak forces of up to 60 g are established [4,5,6]. Repeatedly heading a ball during soccer is therefore a risk for repetitive minor head injury or repetitive subconcussive head impact (RSHI). As a result, neuronal changes smaller, but similar to those in a concussion appear, without the symptoms of a concussion; immediate but temporary impairment of brain functions, such as thinking, vision, equilibrium, and consciousness [6,7]. In a concussion, due to a head impact neurons will stretch and even tear, causing a disruption in neuronal communication. Additionally, dead neurons will degenerate and release toxins and because of this, other neurons will die too. A subconcussive injury will only damage and not tear neurons (Figure 1). The dysfunction of neurons will stay below the concussion threshold and therefore not severe enough to release symptoms [8]. The act of heading during soccer also increases the risk of a concussion. Compared to other sports (baseball, basketball, field hockey, football, gymnastics, ice hockey, lacrosse, softball, volleyball, and wrestling) this risk of a concussion is higher when playing soccer [9,10]. These two types of head injuries related to heading, RSHI and concussion, can have consequences, and with more than 250 million active players in over 200 countries this might become a serious problem [11]. This raises the question whether heading should be banned in soccer. To investigate this an overview of the short- and long-term consequences of (repeatedly) heading the ball in soccer will be given.

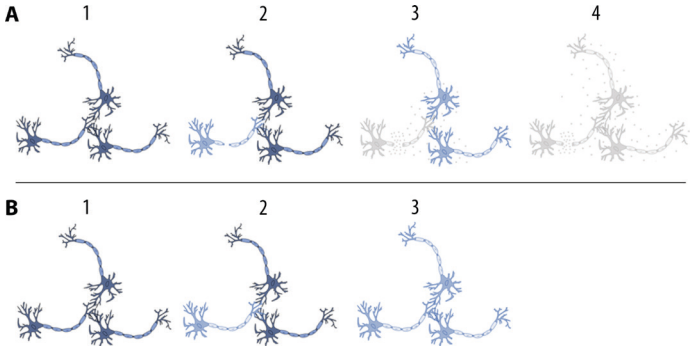

Figure 1: Neuronal mechanisms of a concussion (A) and subconcussive head impacts (B).

A. *The brain consists of a neuronal structure (**A1**) and after a head impact, some neurons will tear (**A2**) causing a disruption in neuronal communication, degeneration of the torn neurons and a release of toxins (**A3**) with the result that other neurons will die too (**A4**). These neuronal changes will give immediate but temporary impairment of brain functions.*

B. *The brain consists of a neuronal structure (**B1**) and after a head impact some neurons will be damaged (**B2**) therefore there will be a disruption in neuronal communication (**B3**). However, the dysfunction of these neurons will stay below the concussion threshold with no symptoms as a result.*

Heading and concussion

A retrospective study using medical history questionnaires of 201 soccer players showed that 62.7% experienced symptoms of a concussion during the previous year [12]. They were asked if they experienced some of the following symptoms in the previous year after being hit on the head playing soccer: knocked unconscious; felt nauseous or vomited; felt confused or disoriented ; experienced dizziness, headaches, memory difficulties, blurred or abnormal vision; or experienced any other symptoms that affected their ability to play soccer or football (e.g., hearing problems, inability to tolerate bright lights) [12]. Concussions related to soccer are more likely to occur in the act of heading than with other aspects of the game [9,13]. There are several contradictory, explanatory mechanisms for the development of these concussions. First, according to a descriptive epidemiology study, the activity most frequently associated with a concussion would be the contact between the head and the ball [14]. In contrast, another study suggests that concussion from heading the ball without other contact to the head appears rare in adult players [9]. Therefore, player-to-player contact in the act of heading would be the most frequent mechanism for a concussion instead of the impact of the ball on the head [9,15]. There are concerns about the short- and long-term effects of these sport-related concussions (SRC) for over 110 years [16,17]. Short-term effects of SRC (0-9 days post-injury) are temporarily significant impairments in neurocognitive performance; memory, reaction time, and visual motor-processing speed [18]. This performance has been measured with a computer-based neuropsychological testing battery. Additionally, players with a history of concussion have more impairments than players with a first concussion [18]. The group of players with a history of concussion is also at risk for lasting deficits, months after the injury [19]. Furthermore, this group is 5.8 times more likely to develop a new concussion than those without a prior concussion [20]. In conclusion, (repetitive) SRC can have short- and long-term consequences on neurocognitive performance. The introduction of an abolishment

on heading will potentially decrease the incidence and therefore the accumulation of SRC, including their potential consequences.

Heading and concussion in children

Children are probably at higher risk of (repetitive) SRC from heading and corresponding consequences. A factor that would play a role in this is the immature brains' susceptibility to injury [2]. The higher risk is also due to a difference in biomechanical factors because of a less developed technique, the size of the head, and less trunk and neck strength to stabilize the head [2,21]. Therefore, in children there is a less efficient energy transfer from the head to the ball and as a result, children would experience relatively greater forces from heading than adults [2,21]. However, there is limited evidence that proves the theory that heading in youth soccer can cause a concussion more easily or more often than in adult soccer [2,21]. In addition, no relation has been found between soccer heading exposure in youth soccer players and concussive symptoms [22].

Consequences of heading for brain function

Exposure to heading has possible consequences on the brain function, more than unintentional head impacts [23]. These consequences comprise a poorer performance on verbal and visual memory, planning, and visuoperceptual processing tasks [24,25]. The studies about this subject vary in the duration of heading exposure; immediate exposure, short-term exposure (<1 year) and long-term exposure (>1 year) and the results can be divided into three groups. In the first group, a negative effect on brain function is found for immediate exposure. An increasing number of headings is negatively associated with cognitive functioning. [24,25]. Nevertheless, no abnormal levels of biochemical markers for brain injury, NF-L, T-tau, GFAP, S-100B, and albuminin, are found in the serum and/or cerebrospinal fluid after immediate exposure to heading. These levels also did not correlate with the number of headings [26]. Moreover, no significant difference in preseason and postseason cognitive performance testing scores is found [27]. This would indicate that these immediate effects are only temporarily and tend to recover. In the second group, it is suggested that there is no effect on brain function; cumulative heading is not or a marginal predictor of poorer cognitive performance [28]. The last group suggests that the association between heading and brain function is a threshold dose-response relationship. A high exposure frequency (>885) to heading in the past year is nonlinearly associated with worse memory performance [3]. This poorer neurocognitive performance is not significantly associated with a history of one or more concussions [3]. The fact that significant cognitive changes only appear with heading above the threshold of 1,800 headings a year, suggests that repair mechanisms cannot manage the cumulative injury that occurs beyond this number of headings [3]. This also suggests that heading below the threshold is safe, with effective intrinsic injury repair mechanisms [3]. However, it is practically impossible to prohibit heading halfway the season for a player that has reached this threshold.

Consequences of heading for brain structure

Besides the potential consequences of heading on the brain function, exposure to heading is associated with several changes in brain structure. After long-term exposure to heading, slight to moderate central atrophy with widening of the lateral ventricles and greater cortical thinning in the right inferolateral, parietal, temporal, and occipital cortex can occur [24,29,30]. Even short-term exposure is, with thresholds in terms of a number of headings, associated with changes in brain structure such as an abnormal microstructure in the temporo-occipital white matter [3,24]. This abnormal white matter structure can be defined as a lower degree of myelination and axonal density assessed with fMRI as changes in fractional anisotropy. The previously mentioned threshold varies between 885-1,550 headings a year and the abnormal white matter microstructure is not explained by a history of concussion [3,24]. Heading below this threshold can therefore be suggested as safe for changes in the brain structure. However, the possible long-term consequences of these aforementioned changes in brain structure are unclear.

Long-term consequences of heading: dementia

It has been suggested that long-term exposure to repetitive, sub-concussive events may result in persistent cognitive impairments [31]. This is underlined by the finding that 30 out of 37 former professional soccer players had mild-to-severe impairment on neuropsychological examination [32]. High numbers of RSHI's possibly also contribute to an increased risk of neurodegenerative diseases including chronic traumatic encephalopathy (CTE) [31]. The clinical features of CTE are variable and consist of a combination of mood and behavioural changes, memory loss, executive dysfunction, slurred speech, parkinsonism, and gait impairment, which typically manifest years after the injuries. CTE is a potential neurodegenerative cause of dementia and motor impairments in retired professional soccer players, with a history of thousands of RSHI's [33]. However, other studies suggest that CTE relates more to acute severe head injuries instead of repetitive heading. This is because the cumulative effects of heading a ball can cause dementia pugilistica, a chronic brain syndrome which is seen in professional boxers [34]. In addition, there are studies that contradict the accelerated cognitive decline due to heading. The suggestion is that once a player ends their career, their risk of harm declines to that of the general population suggesting that neurological changes are potentially reversible [35].

Conclusion

Millions of people worldwide make thousands of soccer headings in their lifetimes with RSHIs and concussions as a consequence. However, there is no conclusive evidence about the possible harmfulness of RSHIs for brain function, brain structure or dementia after long- and short-term exposure to repeatedly heading in soccer. Factors that can play a role in the contradictory results are the rate of exposure, the time between exposures, the vulnerability of individual players and confounding risk factors like behaviour off the field and concussions not related to ball contact [3,29,32]. The high concussion rate related to the act of heading causes temporarily impairments on neurocognitive performance. Should we not better be safe than sorry by banning heading in soccer? However, this would be very radical and the whole sport would change. An approach could be to protect the immature brain from a delayed start with heading. This is advised in the U.S. Youth Soccer recommendations, with heading being taught in controlled settings after the age of 10. In this approach, heading is banned in games until the age of 14 but ideally, the readiness for heading should be determined for each player individual; based on their strength, skill development, and maturation of the brain [36]. In the meantime, more research has to be done to find more conclusive evidence. Until then, we can continue to enjoy beautiful heading goals.

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