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Review article

The sports science of curling: A practical review

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Abstract
Curling is a sport played on ice in which two teams each deliver 8 granite stones towards a target, or 'house'. It is the only sport in which the trajectory of the projectile can be influenced after it has been released by the athlete. This is achieved by sweeping the ice in front of the stone to change the stone-ice friction and thereby enable to stone to travel further, curl more or stay straight. Hard sweeping is physically demanding. Different techniques of sweeping can also have different effects on the stone. This paper will review the current research behind sweeping a curling stone, outline the physiological demands of sweeping, the associated performance effects and suggest potential strategies of sweeping that can be used by both coaches and curling teams.

Key words: Sweeping, winter sports, physiological demands, sweep strategy, training.

Introduction

Curling is a game of skill and tradition and is one of the fastest growing winter sports (Royal Caledonian Curling Club, 2008). It is also a game that at the highest level has unique physical demands. A typical curling game lasting 2.5 hours. At Olympic and World level it can take up to 14 games to get to the podium, playing usually up to 2 games per day, sometimes with only a short break between. This can result in up to 35 hours of competitive play, making curling one of the longest of the Olympic sports. Curling has been a regular Olympic sport since 1998 and sports science is playing an increasing role in assisting in the preparation of elite curlers. The aim of this article is to outline how sports science can play a part in curling. It will look at the science behind the sport and how this can inform coaching and playing strategies.

Curling is a sport in which two teams of four players (usually all male or all female although some competitions are for mixed teams) deliver two ~18.6kg granite stones each on an approximate 42m x 4.5m sheet of ice towards a target or house (Figure 1). The stones are delivered from the hack and the aim is to get one or more of your teams' stones nearest the centre of house. Curling is the only sport where the trajectory of the projectile can be influenced after the stone has been released. Players sweep the ice in front of the stone to momentarily increase the temperature of the ice as the stone passes over it and reduce the friction between the stone and the ice (Buckingham et al., 2006). Depending on the direction the stone is rotating (the 'handle') and the side of the stone the player is standing to sweep, this will allow the stone to stay straighter in its path or to curl more. The dynamics of curling stones have been the subject of a number of studies (Denny, 1998; Jensen and Shegelski, 2004; Marmo and Blackford, 2004; Penner, 2001; Shegelski et al., 1996). It has been shown that the motion of a stone and the amount of curl is due to the thin liquid film between the stone and the ice. Sweeping the ice in front of the stone can change this stone-ice interface by two possible mechanisms in theory: 1) increasing the ice temperature momentarily; 2) smoothing the ice by removing frost or debris. However, in frost-free conditions, any reduction in surface roughness ('polishing') will have a negligible effect compared to the roughness of the stone (Marmo et al, 2006a). Therefore, in these conditions raising the temperature of the ice by sweeping has the greatest effect on the reduction in friction between the stone and the ice.

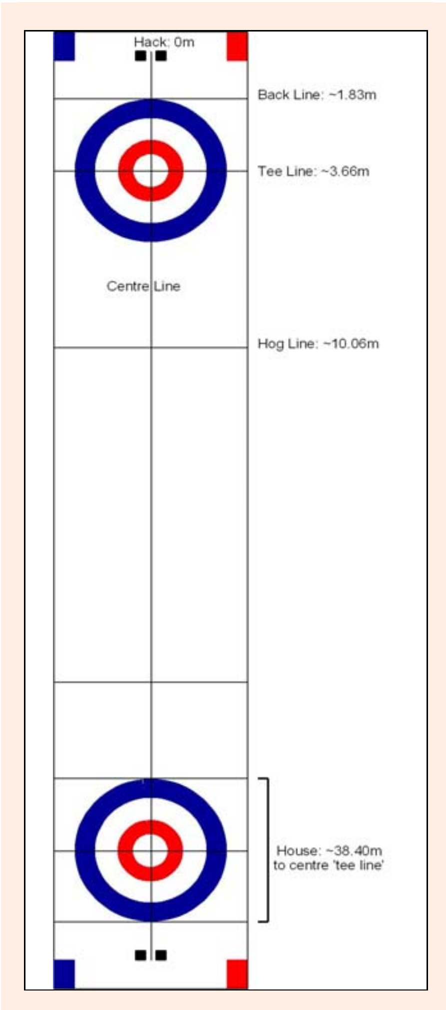

Figure 1. The layout of a curling rink. Distances are given from the Hack.

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A typical curling game lasts 2.43 hours (73min allowed per team) and consists of 10 ends. An end consists of each team playing their 8 stones. A team of four will consist of a lead player who will always play the first 2 stones from that team, a second, a third and a skip who will always play the last 2 stones from that team. The skip traditionally stands at the house and controls the team strategy for the game. The two players not playing a stone will be available to sweep the stone as directed by the skip. The lead and second players could be asked to sweep 6 stones per end, for 10 ends or 60 stones per game (the third player acts as vice skip, standing in for the skip when he/she is playing their stones). A player could theoretically sweep for up to 1.7km per game. Aggressive sweeping is high intensity. Hard sweeping for 20s can result in the generation of approximately 600-1600kJ of work and produce a typical average heart rate of 170bpm. However this can result in up to 2500kJ of work and a heart rate of almost 200bpm in some individuals [Bradley, unpublished data collected using trials of an instrumented curling brush, (Buckingham et al., 2006)]. This had led to the development of strategies to improve sweeping performance.

Science of sweeping

The stone is delivered from the hack towards the house, some 38m away. The ice surface on a curling rink consists of lots of small raised 'pebbles' caused by water droplets being sprayed onto the ice before play. This pebbled ice surface allows the stone to travel the full distance from hack to house with moderate curl. A non-pebbled ice surface alters the motion of the stone considerably, producing a greater degree of curl with a reduced delivery distance (Jensen and Shegelski, 2004). The stone is released with a clockwise or anti-clockwise rotation (for a right handed curler this is termed in-turn or out-turn respectively) which will cause it to curl to the right or left respectively. The curl is produced due to the lower friction under the forward rotating side of the stone (in the direction of travel) compared to the backward rotating side. This is due to greater rotational velocity relative to the ice under the forward rotating side of the stone causing greater heat generation under that side of the stone. This will momentarily increase the temperature of the ice under that side of the stone, causing a reduction in friction. This produces an asymmetric coefficient of friction and results in the stone curling to the right or left (e.g. a stone rotating anti-clockwise will curl to the left).

During sweeping, the peak downwards force occurs when the brush head is closest to the curler's feet (Figure 2). This is due to the horizontal moment arm from the curler's centre of mass being reduced to a minimum, increasing the vertical force exerted on the brush head (Marmo and Blackford, 2004). This will influence the pattern of heat generation in front of the stone. Depending on the handle of the stone, sweeping on the left or right of the stone can then enhance or partially correct for the friction asymmetry and therefore enhance or reduce the curl of a stone. (This asymmetric generation of heat from sweeping will occur regardless of sweep length. The full width of the running band of the stone must be swept however as it is currently illegal to sweep only part of the running band of a stone, so-called 'corner sweeping'). This is the basis for sweeping strategy and controlling the stone to manoeuvre around a guard stone or draw into the house.

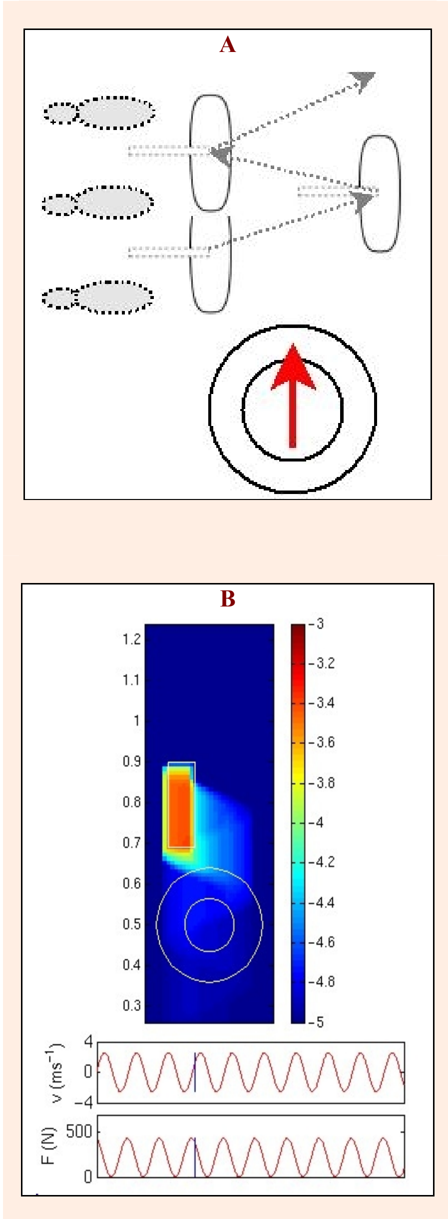

Figure 2. Sweeping the same piece of ice more than once. A illustrates the position of the curler with respect to the stone in conventional sweeping. B is a thermal animation of the heat generated from conventional sweeping [thermal movie reproduced with kind permission from Marmo et al (2006b), available from URL: http://www.jssm.org/vol8/n4/1/curling.htm.

To sweep faster or harder?

Is it better to sweep faster, or to press down into the ice with more force? Both of these strategies will affect stone-ice friction. The stone can be delivered with a velocity of ~2 $m{\cdot}s^{-1}$ and be sliding for up to 30s (Buckingham et al., 2006). The stone will obviously be moving fastest when it is released by the curler and moving slowest as it crosses the hog line and moves into the house. Increasing downward pressure of the brush onto the ice will generate more heat and a consequent reduction in friction between the stone and the ice. Sweeping faster (greater brush head velocity) will also increase the heat generated causing a corresponding reduction in stone-ice friction. Using the model developed by Marmo et al. (2006a; 2006b) it can be shown that doubling the downwards force will increase the heat generated at the brush head by a factor of 2 and doubling the sweep velocity will increase the heat generated by a factor of 1.55. However, sweeping over the same piece of ice more than once has the greatest impact on heat transferred to that part of ice and hence greatest reduction in stone-ice friction (Marmo et al., 2006a). The objective of sweeping is to raise ice temperature and the maximum temperature rises occur where successive brush strokes overlap. Generally speaking, sweeping faster to sweep the same piece of ice several times has a greater effect on reducing stone-ice friction than applying more pressure.

However this changes with the speed of the stone. If the stone is moving at 2m/s, a typical 0.20m brush head used in a conventional sweeping style, standing just in front of the stone perpendicular to the direction of travel, will need to sweep at a rate of 10Hz (sweep 10 times per second) for the brush to cover the same area of ice more than once (Figure. 2). As it is difficult to sweep fast whilst maintaining a high level of downwards force, sweep speed is most important at faster stone velocities (sweeping also has less of an effect on a faster moving stone: Jensen and Shegelski, 2004; Marmo and Blackford, 2004). As the stone slows down the speed of sweeping required for the brush head to sweep over the same area of ice more than once decreases (Table 1). When the stone is moving slowest in the house, sweeping is most effective. Here, greater downwards force will have more influence than sweep speed as it is easy for the brush head to sweep over the same area of ice several times at such slow speeds.

Table 1. Changing sweep speeds with stone velocity to achieve overlapping sweep strokes (for a typical 0.20m length brush head).

Stone velocity ($m \cdot s^{-1}$)	Sweep Speed (Hz)
2.0	10
1.0	5
.5	2.5

Data collected from elite curlers during trials of an instrumented curling brush (developed by Buckingham et al, 2006) can be used to illustrate sweeping technique (Table 2).

Note that from these results the sweeper would struggle to effectively sweep a stone travelling at a velocity of 1.0 $m \cdot s^{-1}$ or higher as the maximum sweep rate is only approximately 4/s.

A typical curling stone is 0.25m in diameter and makes contact with the ice through a circular running band of approximately 0.15m diameter. A sweep length of 0.1071m (Table 2) at first appears not to cover the running band but this does not take into account the curling brush head dimensions (approximately 0.07m wide and 0.20m long). Depending on the orientation of the brush head in front of the stone, the entire running band can be covered. However if during sweeping the longitudinal axis of the brush head is parallel to the direction of stone travel (as illustrated in Figure 2) there is greatest chance that part of the brush head will sweep the same area of ice more than once on faster moving stones (resulting in much more effective sweeping).

As the effect of sweeping on a stone differs according to stone velocity and sweeping style, this has implications for coaching and developing sweep ability. The skip will have most need to sweep a slow moving stone, being in the house area of the sheet for most of the game. The lead and second will mostly sweep faster moving stones as they approach the house. Skips may find the use of downwards force more effective and sweeping speed not as vital to reducing the stone-ice friction as the other team members sweeping when the stone is travelling faster. This has implications for strength and conditioning. Skips and thirds should perhaps be more inclined towards strength development and curlers who will sweep faster stones (leads, seconds) perhaps be more inclined to speed development. Cardiovascular fitness plays a significant role here too. As mentioned earlier, hard sweeping produces an average heart rate of 170bpm. To be able to repeat this throughout a game and a tournament as needed requires considerable cardiovascular fitness. The different strategies and physical characteristics necessary for effective sweeping of faster and slower moving stones may also be useful when selecting the ideal team positions, taking into account individual curlers particular strengths and weaknesses.

Fatigue

The sweep rate and force generated are the principle factors that control the heat generated during sweeping. Sweep rate has been shown to decline during a 20-25s period of hard sweeping. However, the sweep rate recovers quickly and remains relatively consistent in successive bouts separated by a recovery period (Buckingham et al., 2006). In an analysis of sweeping action in 17 elite curlers performing three 20s bouts of hard sweeping separated by 1min recovery (using an instrumented curling brush developed by Buckingham et al., 2006) we looked in more detail at sweep length and vertical force. Sweep length was very similar between male and female curlers and remained remarkably consistent (Figure 3). Vertical force generated by male curlers however was nearly double that generated by female curlers (Table 2). This led to the vertical force in successive 20s bouts of hard sweeping falling significantly in male curlers but being more consistent in female curlers (Figure 4). This is despite the

Table 2. Typical results from 17 elite competitive curlers (5 male, 12 female) performing 20s periods of hard sweeping (mean (SD)).

	Average Sweep Length (m)	Average Sweep Rate (Hz)	Average Total Work (kJ)	Average Heart Rate (bpm)	Vertical Force (N)
Male	.1071 (.013)	4.32 (.66)	1538 (522)	169 (16)	146.3 (29.0)
Female	.1071 (.024)	3.81 (.37)	663 (301)	164 (16)	81.7 (17.7)

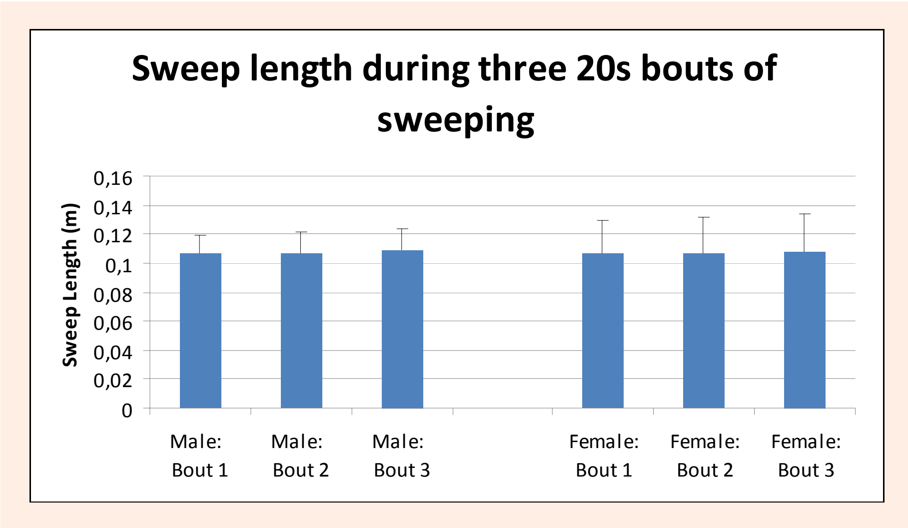

Figure 3. Sweep length during 20s bouts of sweeping in male and female curlers.

work done remaining relatively constant (Table 2). This is due to work done being calculated from the product of horizontal force and sweep length, both remaining consistent in successive bouts of sweeping. Fatigue may be more evident in male curlers during repeated bouts of hard sweeping but the fatigue profile of both male and female curlers within one bout of 20-25s of sweeping will still result in a decline in sweeping rate. This can have considerable impact on the heat generated from sweeping but could be minimised by the development of sweeping strategies.

Sweeping strategies

Sweeping is the most physical aspect of curling. As mentioned above, depending on the rotation of the stone the side the curler stands when sweeping the stone can have very different effects on the stone trajectory. The preferred sweeping side may even change during the course of a throw if a stone needs to stay straight to get past a guard stone then curl get into a scoring position for example. The geometry of a stone is such that the running band of the stone (the area in contact with the ice) is 0.05m from the outside of the stone (Marmo et al., 2006a). Sweeping closest to the stone will have the greatest impact on the stone-ice friction, allowing the shortest time for the ice to re-cool before the stone travels over the swept area. The ice temperature re-cools very quickly following sweeping. Sweeping 0.05m in front of a stone travelling at 0.5 $m \cdot s^{-1}$ means 0.2s will elapse before the running band passes over the swept ice. In this time the ice temperature that had been increased due to sweeping can fall from approximately -3.7ºC to -4.7 ºC (on well prepared ice with a temperature of approximately -5.0 ºC; Marmo et al., 2006a). Sweeping further than 0.05m in front of the stone allows a longer period to elapse before the stone reaches the swept ice, further reducing any reduction in stone-ice friction due to sweeping. This can be useful in situations when a skip does not want a stone to be swept (for example if it is moving too fast). Sweeping 1m or more in front of a stone will clear any debris (to avoid the stone picking anything up that may alter its intended trajectory) but the ice will have re-cooled completely when the stone reaches the swept area.

Sweeping in pairs as a team can be highly effective here. One role of the sweeper may be to clear frost and debris from the path of the stone. With two curlers sweeping in tandem, the sweeper next to the stone will have the greatest impact on stone-ice friction and be sweeping

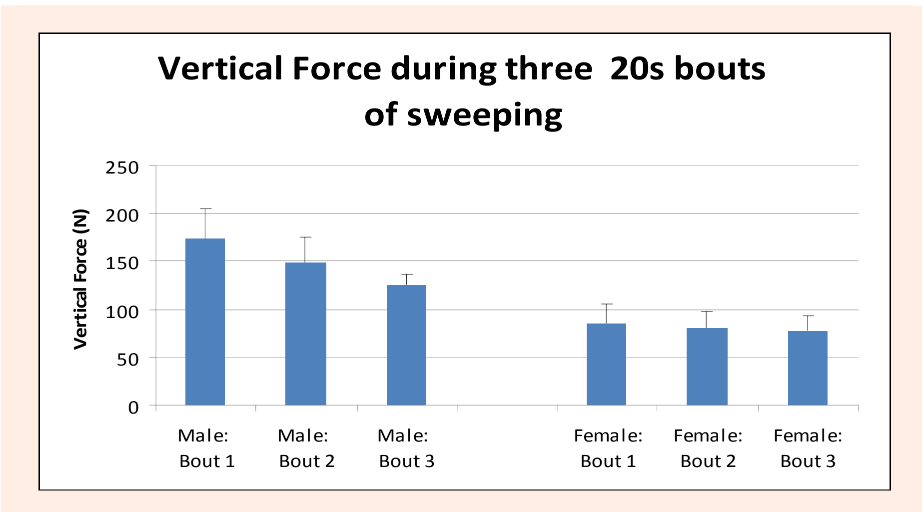

Figure 4. Vertical force during 20s bouts of sweeping in male and female curlers.

vigorously. The second curler can be sweeping in front of the first curler, clearing frost and other debris from the path of the stone, requiring sweeping of much less intensity. As discussed earlier, the fatigue profile within a period of 20-25s of sweeping and in repeated bouts of hard sweeping can show a considerable decline. To overcome this, highly practised pairs of sweepers can change who is sweeping with high intensity next to the stone and who is clearing debris mid-way through a delivery, to sustain vertical force and sweeping rate and maintain a greater effect on reducing stone-ice friction. If the two curlers are on opposite sides of the stone (as is the convention), changing who is sweeping next to the stone mid-way through the stone trajectory will impart some ability to 'steer' the stone on the ice. Changing sweeping sides will allow the stone to stay straighter or curl more depending on the stone rotation.

The high intensity nature of effective sweeping and the long duration nature of curling games and tournaments place considerable emphasis on musculoskeletal conditioning, particularly of the upper body and trunk muscles. Knee, back and shoulder injuries are the most common injuries reported from curlers (Reeser and Berg, 2004). Sweeping the stone carries the greatest risk of provoking an injury, followed by the action of stone delivery (Reeser and Berg, 2004). Focussing on these areas in strength and conditioning will produce more injury-resistant athletes. The ability to sweep on either side of a stone is also a considerable advantage to tactics and strategy of a game and better conditioned curlers will be more able to achieve this skill more effectively.

Recently conditioning programmes for curling have been developed, containing resistance training, cardiovascular training, balance training, core training and flexibility training (Behm, 2007). Adding to this training programme the specific demands of sweeping outlined above and the injury profiles of curlers (Reeser and Berg, 2004) adds support to the development of a specific conditioning programme to support the unique demands of curling.

Conclusion

Curling in major events can require up to 35 hours of competition to get to the podium. Sweeping a stone can be highly physically demanding and whilst not every stone will be swept with maximum intensity, the ability to recovery quickly and sustain sweeping intensity throughout a game and tournament is paramount to success. Effective sweeping can require a combination of greater downward force and faster sweeping speed depending on stone speed and playing position, coupled with the ability to sweep on either side of a stone and a high level of team sweeping coordination and efficiency. This can be incorporated into the selection of players for team position and sweeping/playing tactics. It can also form the basis of a coaching development programme to develop curlers who are comfortable and equally effective sweeping on the left or the right of a stone. The high intensity nature of sweeping produces the most injuries to curlers so highly conditioned athletes will be of considerable benefit to team success through a major tournament.

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Key points

- Sweeping a curling stone can be highly physically demanding.
- Effective sweeping requires a combination of downward force and brush head speed, determined by the stone velocity.
- Sweeping on the left or right of a stone can help the stone to remain straight or curl more depending on the rotation of the stone.
- This can lead to the development of sweeping and playing tactics and contribute to team selection.

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