**Introduction**

There are many types of handbikes, they come in a variety of sizes and have proved to be very functional tools for transport, fitness, recreation and sport. It is possible to classify these handbikes in a simple way.

There are two types of construction of a handbike: the attachable handbike versus the fixed- or rigid-frame handbike.

The attachable handbike has one wheel and when it is attached to the wheelchair, the handbike and wheelchair become a three-wheeled combination. The front wheels of the wheelchair are lifted by the attachment.

The other type of handbike is a fixed-frame or rigid-frame handbike: a three-wheeled hand operated bike, but as one whole piece. There is no attachment to a wheelchair, but the wheelchair user has to make a transfer to the bike.

There are two ways of propulsion of a handbike: by power, generated via Arm-Power only (AP) or by power, generated by the combination of Arm-Power and upper body power (ATP).

The classification of handbikes leads to four different types of handbikes; they will be discussed in this article (see diagrams).

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**Attachable handbikes**

**Arm-Power type (AP), Attachable handbikes**

The difference between the Arm-Power and Arm-Trunk-Power type of handbike within the category of attachable handbikes is the handlebar/crank position. Handbikes (of the Arm-Power type) use the standard type crank which then means that the chain wheel must be correctly placed at a specific height above the knees. This 17 cm long (standard type) crank must then be able to turn freely in the area above the knees. That means that the top half of the propulsion-circle (high) is situated in front of the chest and often reaches above the shoulder area. The high handlebar position in this case, only allows arm activity in the form of first pushing followed by pulling and the body remains more or less in the upright position. In this way, the shoulders and arms only create the generated power. The use of 15 cm long cranks makes the propulsion-circle smaller and lower and is no real option because shorter cranks require more power because of the shorter moment arm and this is not desirable. In competitive sport the handlebars are rightly lengthened, this will be mentioned later. The effectivity of this hand-bike propulsion; In the push phase there is a tendency for the body to go backwards. As we know, with any action there always follows a reaction. In this way, the push phase can only be effective when the back rest of the wheelchair is sufficiently high enough (meaning high enough for the area between the shoulder blades to be supported) or when the stomach muscles are functional enough, to counter the reaction of the body going backwards. In the pull phase there is the tendency...
that the upper body is pulled forward; the spinal column acts as a hinge, assuming that the pelvis is kept steady in the wheelchair. To summarise, it can be said that the effectiveness of the attachable handbike type Arm-Power is indeed sufficient for normal ADL use and or recreation purposes but improvement in this area is still possible. The attachable handbike type AP has mostly a maintenance free gearbox complete with 7 gears. This is effective for everyday use. A speed of 20 km per hour can be achieved. Examples of these attachable handbikes (Arm-Power type) are Tracker 16 kid, Tracker 16 tour, Runner (Cyclone), Speedy and Stricker.

Arm-Trunk-Power type (ATP), Attachable handbikes
Given that differences exist between the attachable handbike Arm-Power and the Arm-Trunk-Power handbike type, the first noticeable difference is the position in the cranks. The Arm-Trunk-Power type has cranks that are positioned much lower than the Arm-Power type. A lower handlebar position is only possible when “bullhorn” cranks are used (bars in the shape of cow’s horns). This bullhorn crank-shape does make it then possible to place the propulsion-chain wheel in a (much) lower position above the upper legs and knees of the handbiker and the length of the cranks remains at 17 cm, which is the normal standard length. The hands are now positioned besides the upperlegs and not above them when the cranks are in the lowest position. In this way, the propulsion-circle is lower and is close to the upper legs instead of above the shoulders. The result is that the trunk, especially the upper torso, can work together with the arms in a forwards and downward pushing movement. Next to Arm-Power, is trunk-power (this is when the weight of the torso is pushed down by the force of gravity). This counts especially when the stomach muscles are functioning. These stomach muscles support the upper part of the body as it curves forwards, whilst the lower part of the trunk remains against the backrest. Effectivity of this handbike-propulsion; Here the push phase is directed forwards (lower than the Arm-Power type) and slightly downward. This action occurs (besides Arm-Power) because of the natural downward gravitational pull created by the upper part of the body. Therefore a high backrest is not necessary here. The pull phase takes place in a different way than with the Arm-Power type. In the pull phase the direction is not seen as horizontal, but it appears to have a highly slanted backwards direction. In this way, because of the lower propulsion-circle, there is more of a tendency for the handbiker to be pushed further into the wheelchair seat than to be pulled out of it. To summarise, it is possible to say that Arm-Trunk-Power is more effective than the Arm-Power type because the push and pull phases in the propulsion are more effective and the output from invested energy is therefore greater. The attachable handbike type Arm-Trunk-Power has also a simple gearbox (7 inner gears) or a derailleur system (e.g. 3 x 8 = 24 outer gears). The speed that can be reached is about 30 km per hour. Examples of attachable handbikes (Arm-Trunk-Power types) are Tracker 20 sport and the Praschberger challenger (both have bullhorn cranks).
Fixed-frame handbikes
In this article we shall only discuss the three-wheeler fixed-frame handbike with the low sitting position. There are also three-wheeler fixed-frame handbikes available with a high sitting position. The sitting position is here the same as in a wheelchair (e.g. Mach 2 from Sunrise and Top End Excelerator from Invacare). These fixed-frame handbikes will appear less and less because of the increase in the range of attachable handbikes that are much more user friendly. For competition-purposes, the handbikes with the high sitting position are not suitable because they are not optimal for transferring of power, unstable at high speeds and not aerodynamic. Also the two wheel fixed-frame handbike is not to be mentioned in this article. The competition rules for 2002 specify that two wheelers are not allowed and therefore unfortunately they are seldom seen.

Arm-Power type (AP), Fixed-frame handbikes
As we know now, the position of the cranks (high or low) forms the distinguishing feature between type AP and type ATP, for the attachable handbikes. Within the category of fixed-frame handbikes the difference between the AP and ATP is the seat posture and the crank-position that follows that seat-position. The seat-posture of the AP type is usually a recumbent seat posture. The upper torso is positioned backwards and the legs are placed forward with the knees slightly bended: a relaxed sitting position close to the ground. This low position increases the stability, which is important with the use of higher speeds. Although high speeds can be reached with these AP fixed-frame handbikes, the trunk can hardly be used for power-transmission. In terms of the effectivity of this handbike-propulsion; in the push phase the power generated by the arms, shoulders and chest is good. The reaction to this pushing force is caught by the long backrest, which supports the upper body completely as well as between the shoulder blades. Fixed-frame handbikes with the backrest more to the vertical position (Quickie/Sopur) mostly have a V-shape handlebar, which ensures that the propulsion-circle is low. In this case, the chance that the upper body will be pulled out of the backrest during the pull phase of the propulsion-circle is minimal. For those fixed-frame handbikes using the lying position, (e.g. Varna tour AP) V-shape cranks are not necessary because the propulsion-circle takes place in front of the chest and not in the lap. Here the pull phase is more effective because the weight of the upper torso mostly erases the reaction that the pull phase of the propulsion normally creates. Thus, it is important to remember that the reaction of the pull phase still exists and it is possible that the torso could fall out from its supportive position. To summarise, it is possible to say that with the fixed-frame handbike (Arm-Power) the power that is generated from the arms is highly effective. The way forward is to look into the possibilities of using more "man-power" whilst hand-biking in order to increase the speed which creates better results. The fixed-frame handbike type Arm-Trunk-Power highlights how this can be done. The fixed-frame Arm-Power handbike type sometimes has a gearbox but mostly it has a derailleur system. The speed that can here be reached, is about 40 km per hour. Another question to be asked is: why is it that the speed of a fixed-frame handbike, type AP (speed of 40 km per hour) is higher than the attachable handbike type ATP (speed of 30 km per hour)? Why is the attachable ATP-type, where a certain amount of trunk-power is used, not faster then the fixed-frame AP type of handbike? Three reasons can be found for this difference in speed. Firstly, the output for fixed-frame AP type handbikes is different to the output for the attachable ATP type handbike. The output of the latter handbike is less than the completely supported Arm-Power handbike with the fixed-frame AP type. Secondly, it is important to look at the weight factor. The attachable unit weighs about 20 kg (10 kg wheelchair + 10 kg attachable handbike). The fixed-frame handbike is lighter by 5 kg and is more robust (stiff) and this creates a situation whereby more energy can be saved. Thirdly, and probably the most important factor of all is the air resistance. A hand-biker seated in an attachable handbike has much more frontal area than the low fixed-frame hand-biker and has more air resistance. This factor is important especially when trying to attain higher speeds. There are many types of the AP type handbike (Varna Tour, Sopur/Quickie Spirit, Top End Excelerator XLT/pro, Freedomrider, Lightning and Hall Defiant).
The distinguishing characteristic between the AP and the ATP types of rigid-frame handbikes are the different seat postures and related crank-positions. With the AP type the handbiker sits or lies in a more or less backward slanting position and with the ATP type handbike the position is more of a forward slanting position of the trunk. Two versions of ATP-type rigid-frame handbikes can be distinguished: the ATP-kneeseat (for athletes with amputation or walking athletes) and the ATP-longseat (for athletes with spinal cord injuries).

First we will discuss the ATP-kneeseat. The knees are here lower than the pelvis and the legs (if any), are folded beneath the seat. The pelvis is then bent over and positions the spinal column and the upper torso in a forward direction. This sitting position gives greater input as the whole upper body is used, this is therefore extra propulsion-power (see photograph Varna speed ATP-kneeseat). The weight alone of the upper body and arms causes the bike to move forward just by leaning on the cranks and then they spin around. Upper body muscles are necessary for this type of Arm-Trunk-Power. In other words, this type of handbike can probably only be used by athletes from the HC4 handbike-category; athletes with upper body functioning, for e.g. athletes with an amputation and/or athletes who can move via some type of walking. The ATP-kneeseat posture is probably to extreme for athletes with spinal cord injuries, especially for those with the higher thoracal spinal cord injuries. The imbalance of the trunk do make efficient propulsion difficult. For those athletes the ATP-longseat is a better option. In the ATP-longseat the athlete do sit with the legs slightly bended forward. This leg-position do give a better pelvis-stability needed for effective propulsion. The use of the trunk in the propulsion can only be done effectively when wide bullhorn cranks are used. They place the handgrips besides the extended legs (lower then the knees!) and make it possible for the trunk to come forward when pushing.

The effectivity of the propulsion of these ATP-handbikes: the push phase is directed downward because of the shoulders placed (high) above the cranks. There is also a stretching force caused by the arms and an extra large pushing force is created by the body weight of the torso. In other words, the torso falls with gravity downward and forwards, eventually supported by the active working of the stomach muscles. The push off point forms a forward slanting sitting position. This does not depend on a high backrest. This sitting position creates a really powerful push phase and the pull phase is even more efficient than the push phase. Mostly the pull phase in this instance, is in both a backwards and upwards direction and completely opposite to the other handbike sitting positions (Arm-Power) that exist. This therefore creates a steadier initial push off point. It is most noticeable when climbing hills and it is possible to feel the output that can be reached in the pull phase and it then becomes obvious how important that steady push off point is. In this way, a perfect circle is created: the pull phase brings the upper torso upwards and then it falls forwards in a downward direction and helps to support the pushing phase. In this way, an efficient cycle is created because the propulsion phases follow each other fluently and the result is that a very high propulsion-output is achieved. The fixed-frame handbikes type ATP are always fitted with a derailleur-system. It is now interesting to use longer cranks of 20, 21 or even 22 cm, given the fact that extra power can be generated with this type of ATP handbike. Longer cranks means longer leverage. Longer leverage and more power will result in greater momentum, so higher speeds. Hans Mayrhofer, was the first (and fastest) handbiker to use 20 cm long handlebars. The longer handlebars make it possible because of the moment arm, to drive in a lower gear. Here the danger of muscle cramp is decreased because the input of the bigger muscle groups such as the upper body is greater with this type of handbike and speeds of 45/50 km per hour can be reached. There are only a few examples of these rigid-frame handbikes (type ATP) at present. Hans Mayrhofer from Austria has made the first move with his handmade handbike which will hopefully lead to further developments in the ATP handbike field. The Varna Speed ATP-kneeseat and the Varna Speed ATP-longseat are the first ATP handbikes commercially available.
Handbike Choice

Attachable handbikes are a completely different story to rigid-frame handbikes. The great advantage of the attachable handbike is that people can use their own wheelchair and therefore, no need for a transfer is necessary. Basically, in terms of effectiveness, the rigid-frame handbike generates more output than the attachable handbike. Choice of handbike can depend on what kind of housing and general living space that a person has. For example, America and Canada do have a rigid-frame handbike culture because there the population live mostly in one level buildings and the houses, garages and cars also tend to be larger then in Europe. It can also be said that wheelchair access there, is much better than in Europe. In Europe, we tend to have an attachable handbike culture because the population in this geographical area is more likely to live in housing consisting of more than one level and limitations also exist in terms of public space. In this way, choice is greatly encouraged because attachable handbikes are seen as a practical aid to transport. Both of these technical categories have the same Ergonomic classification, Arm-Power and Arm-Trunk-Power. The latter type, Arm-Trunk-Power creates a greater propulsion power next to Arm-Power. Although, the Arm-Trunk-Power type creates a greater output, there is no assurance that this is the best type of handbike. It is not dependant on the type of handbike itself, but it is more about the reason for use (transport, fitness, recreation or sport) and also the functional possibilities of the handbikers themselves. For those people wishing to increase their own personal levels of action then the attachable handbike type AP is definitely better for their use, compared to the actions required by a standard wheelchair (hand driven by a persons own hands). It is a different situation when a person has less propulsion possibilities due to their condition or functional problems that they experience. Here, the effectiveness of the invested energy will be much more important and the ATP type is possibly a better choice. In terms of sport, propulsion is very important. Those people who choose sport for recreational purposes may be best advised to choose an attachable handbike of the type ATP. As we know, this is user friendly and the propulsion is most efficient. Sometimes, the body shape of the handbiker points to an ATP type of handbike, for example, if the user has a really small upper torso or a fat stomach. The use of bullhorn cranks may then be necessary for two reasons. Firstly, the bullhorn cranks avoid too much work above the shoulder area (especially with a small upper torso) and then secondly, bullhorn handlebars can avoid hits to the stomach whilst in turning mode (especially in cases of people that have a combination of a broad upper body and short arms).

In conclusion, it is possible to say that the attachable handbike type ATP is viable for recreational sport as well as in the Ergonomic ADL situation. Those who compete in a sporting environment, are pulled towards the low rigid-frame handbike because it has a higher efficiency than the attachable handbike and is much more stable at higher speeds. Results of all the important handbike-marathons in Europe (in 2001) showed us that the ATP-bikes are the most efficient. The world record handbike (Heidelberg 2001) 1.09.01 and the 1 hour time trial 36.69 km were both done with ATP-handbikes. The Ergonomic change in body-position leading to more propulsion power and therefore more speed, we formerly have seen in wheelchair racing, will be soon seen in handcycling as well.
Ergonomic Classification Of Handbikes

**Attachable handbikes**

- **Arm-Power**
  - Crankposition: high
  - Standard cranks
  - Speed: till 20 km/h
  - Tracker 16 tour
  - Tracker 16 kid

- **Arm-Trunk-Power**
  - Crankposition: low
  - Bullhorn cranks
  - Speed: till 30 km/h
  - Tracker 20 sport
  - Tracker 24 challenger

**Rigid-frame handbikes**

- **Arm-Power**
  - Seat posture: longseat
  - Standard or bullhorn cranks
  - Speed: till 40 km/h
  - Varna tour AP short
  - Varna tour AP long

- **Arm-Trunk-Power**
  - Seat posture: long-seat or knee-seat
  - Lengthened (bullhorn) cranks
  - Speed: till 45 km/h
  - Varna speed ATP longseat
  - Varna speed ATP kneeseat
Ergonomics versus technique
The technical qualities of a handbike are important, but this is greater, if the handbike is made in such a way that it meets the requirements and fulfils the wishes of the individual. At the present time, there is too little attention given to the ergonomics of handbiking. Perfection can only be said to exist, when handbikes are fully adjustable, go hand in hand with the requirements of the user, and produce a productive output. For example, if the position of the cranks does not match the requirement for someone's upper body and length of the arms and/or if the sitting position is not in sync with the handlebars. A good example of this is illustrated via timed races in the biking world where highly technical and advanced bikes are used. But Graham O Bree set the world's best hourly record with a bike that was built from washing machine parts. The ergonomic sitting posture, the so-called egg position (giving excellent aerodynamic shape) was the most important factor of his performance and not the technical qualities of the bike itself. Hans Mayrhofer became world's fastest handbiker in 2000 and 2001, in the same kind of manner. For Hans, it was not the aerodynamics that were optimal (he was as we know, sitting up straight and that is good for wind resistance) but the fact that he was the only person in the year 2000 who drove an Arm-Trunk-Power handbike and therefore managed to generate more propulsion power. It is important to look at how it may be best to get the most out of ergonomic handbikes. Here, the functional possibilities of the individual combined with the propulsion must both play their part. As in the story above, although the bike was less aerodynamic, it gave Mayrhofer an advantage over the other AP handbikers. Within the competitive handbiker circuit, there is great interest in technical novelties and less attention is paid to the best ergonomic athlete-handbike combination. We must not forget, that a discussion about technical issues, such as for instance size of wheels, is deemed inferior, next to ideas about how the body can generate the most power in an aerodynamic way. The future then, lies in ergonomics which is the challenge for all builders of handbikes, advisers on the subject, salespeople, scientists and of course, the athletes themselves.
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