CHAPTER 3: The neuromuscular system

Practice questions - text book pages 46 - 48

1) Which type of muscle fibre is associated with endurance?
   a. fast twitch muscle fibres, because they store more fuel than the slow twitch muscle fibres.
   b. slow twitch muscle fibres, because they store more fuel than the fast twitch muscle fibres.
   c. fast twitch muscle fibres, because they have a greater aerobic capacity than the slow twitch muscle fibres.
   d. slow twitch muscle fibres, because they have a greater aerobic capacity than the fast twitch muscle fibres.

Answer: d.
Explanation:
- *The main difference between slow and fast twitch fibres is there difference in aerobic capacity, hence choice d. is the correct answer.*

2) In order to control muscle contraction, the cerebellum innervates one or more motor units (each consisting of a single block of muscle fibres and its neurone). Which one of the following statements describes how a single motor unit produces a stronger stimulus?
   a. the motor neurone fires so much that there is no time for relaxation (tetanine contraction).
   b. by repeatedly increasing the frequency of the stimulus (wave summation).
   c. by increasing the number of motor neurones in succession (spatial summation).
   d. both answers b and c apply.

Answer: b
Explanation:
- *The answer is b. since the nervous system achieves greater muscular force by increasing the firing rate of neurones and so the second and subsequent twitches will be stronger that the first and occur before the muscle has completely relaxed. When a fibre is fired repeatedly in this manner, the way in which the force builds up is called wave summation.*
- *Tetan means rigid and so a tetanine contraction happens when muscle relaxation disappears and the contraction fuse into a smooth, sustained contraction plateau.*
- *Spatial summation occurs when different fibre groups are fired in succession and so the total force produced is the sum of the effect of different fibre groups. This produces a constant total force across the muscle bed.*

3) Which description of muscle contraction means that the force produced across a muscle is achieved as a result of multiple fibre twitches:
   a. spatial summation.
   b. wave summation.
   c. tetanine contraction.
   d. a muscle twitch.

Answer: a.
Explanation:
- *The correct answer is spatial summation which is the staggered stimulation of many motor units such that different blocks of muscle fibres contract is succession.*
- *Wave summation is a build up of tension in a single muscle fibre. A muscle twitch is a single firing within a muscle fibre and tetanine contraction occurs when there is a complete lock up of muscle tissue.*

4) The main function of muscle spindles is to:
   a. enable contraction of the muscles.
   b. pass neural information evenly to all parts of the muscle.
   c. detect changes in muscle tension.
   d. act as stretch receptors.

Answer: d.
Explanation:
- *Muscle spindles primarily respond to any muscle stretch. Choice c refers to the role of Golgi tendon organ receptors.*

5) For acutely increasing maximum range of motion, PNF stretching has often been found to be superior to static and ballistic stretching. PNF's superiority is most likely due to PNF producing:
   a. the smallest stretch reflex response.
   b. the largest Golgi tendon organ reflex response.
   c. a larger decrease in muscle-tension unit stiffness.
   d. a greater increase in stretch tolerance.

Answer: d.

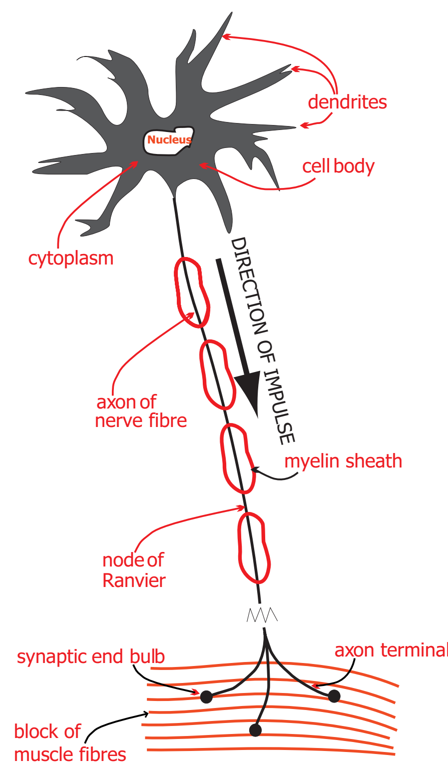
Explanation:
- *For acutely increasing maximum range of motion, PNF stretching's superiority over static and ballistic stretching is most likely due to PNF inducing a greater increase in stretch tolerance as opposed to the other choices.*
- *This is because the aim of PNF is to toughen up or inhibit proprioceptors in the relaxation of muscle tissue.*

6) a) What is a motor unit? 2 marks

Answer:

See figure 3.3.
- *A motor unit consists of a block of muscle fibres connected to a single motor neurone.*
- *Which in turn connects to the brain via the nervous system.*

figure 3.3 – structure of a motor neurone (nerve cell)



b) Explain how a motor unit transfers a neural impulse into muscular contraction. 8 marks

Answer:
- *Dendrites receive electrical impulses from other neurones via cell body to axon.*
- *Axon transmits neural impulse away from the cell body towards other neurones or effector cells such as muscle fibres.*
- *Achieved via depolarisation of axon membrane to produce action potential.*
- *An action potential travels down axon via saltatory conduction.*
- *Acetylcholine enables the electrical impulse to jump across the synaptic cleft of neuromuscular junction.*
- *To create a muscle action potential in a block of muscle fibres.*
- *Ca^{++} is released from 'T' vesicles and binds to troponin molecules on actin filament.*
- *Exposing actin-myosin cross bridge binding sites.*
- *Mitochondria produce ATP which provides energy for muscle contraction.*
- *ATP attaches itself to a binding site releasing energy:*
  - $ATP \xrightarrow{ATPase} ADP + P_i + \text{energy}$.
- *Myosin cross bridges swivel towards the centre of the sarcomere (power stroke).*
- *Drawing actin filaments past myosin filaments.*
- *This is the ratchet mechanism (attach, detach, reattach of cross bridges).*
- *To create muscle contraction.*

6) c) The result of an electric impulse reaching the muscle fibres is a maximal contraction of those fibres. Explain this statement and describe how the force exerted by the muscle can vary significantly. 3 marks

Answer:

- *This is the all-or-none law:*
- *The stimulus has to be sufficiently strong enough to make all the muscle fibres within a muscle fibre block (attached to a motor neurone) contract.*

- *The force exerted by the muscle can vary as a result of wave summation.*
- *If the frequency of stimulus increases, there would be no time for the muscle fibre block to relax.*
- *So the force does not drop to zero at the end of a contraction, and the next impulse sends the force up higher (adding on to the force already in the fibres as the next contraction started), then again the force does not drop to zero, and the next contraction sends the force up even higher, until the force reaches maximum.*
- *Hence the force of contraction of this muscle fibre block would increase (see figure 3.5 page 44 in the main text).*

- *Gradation of contraction:*
- *This depends on the number of motor units stimulated at any one time.*
- *The more motor units involved, the more muscle fibres activated and the greater the force exerted by the muscle.*

d) Why is it that muscle fibres attached to different motor units will not necessary contract at the same time? 3 marks

Answer:

- *Motor nerve fibres have different lengths, hence the impulse takes less time down a shorter one, which will cause its muscle fibre to contract earlier (than others connected to longer nerve fibres).*
- *Hence if the shorter of the two motor units is stimulated all the muscle fibres connected to that motor unit will contract - this is the 'all-or-none law'.*
- *But at the same time the longer of the two motor units could be resting and so those muscle fibres connected to that motor neurone would be in a state of relaxation.*
- *It is not necessary for both motor units to be stimulated at the same time = spatial summation.*

7) Table 3.3 shows the percentage composition of slow-twitch fibres found in leg muscles of male athletes specialising at different running distances.

Table 3.3 - **percentage composition of slow twitch fibres in male leg muscle**

event	mean % slow twitch fibres	range of % slow twitch fibres
marathon runners	85	50 - 95
800m runners	55	50 - 80
100/200m sprinters	35	20 - 55

a) Briefly discuss the relationship between the percentage of slow-twitch fibres and race distance, as suggested by the data in table 3.3. 3 marks

Answer:
- *The longer the race distance, the greater the mean percentage of slow twitch fibres.*
- *Although the ranges do slightly overlap.*
- *Suggesting that for example, a sprinter could have more ST fibres than a marathon runner.*
- *Implying that it is not necessarily the proportion of ST fibres per se which decides a person's best running distance.*

b) Which group of athletes is the most specialised in terms of slow twitch muscle fibre composition? Explain your choice by reference to table 3.3. 2 marks

Answer:
- *800m.*
- *As they have the smallest range of ST fibre composition.*

c) Arrange the group of runners in rank order according to how closely their slow twitch muscle fibre composition matches the 'ideal' for their distance. 6 marks

Answer:
- *800m runners need a balance (50/50) between ST and FT.*
- *At a mean ST fibres of 55% that are closest to the ideal.*
- *Marathon runners need a high proportion of ST fibres as possible ideally their upper limit is 95%.*
- *At a mean of 85% they are close to this ideal, but not as close as the 800m runners, whilst being closer to their ideal than the sprinters.*
- *Sprinters need as high a proportion of FT fibres as possible, therefore their proportion of ST should be as near the 20% low limit as possible.*
- *At a mean of 35% they are further away than the other two groups of runners.*

d) List three features of slow twitch fibres that contribute to their greater aerobic capacity. 3 marks

Answer:
- *Large number of mitochondria.*
- *High myoglobin content.*
- *High capillary density.*
- *High level of oxidative enzymes*

e) In terms of muscle fibre types, explain why it is sometimes said that 'endurance kills speed'. 3 marks

Answer:
- *Endurance training causes hypertrophy of ST fibres.*
- *And increases the oxidative potential of FT fibres to higher level.*
- *At the cost of their glycolytic anaerobic FT ability.*
- *Possible conversion of FG or type IIb into FOG or type IIa.*
- *Consequently endurance training reduces the muscle's capacity for speed/explosive power.*

f) Briefly discuss the relationship between the percentage of slow-twitch fibres and race distance, as suggested by the data in table 3.3. 3 marks

Answer:
- *The basic trend is that the longer the distance ran, the greater the percentage of slow twitch fibres.*
- *Slow twitch fibres tend to have a greater capacity for aerobic activity - hence use of oxygen efficiently.*
- *Conversely, fast twitch fibres can function without oxygen (mostly), but only operate for short periods of time, hence short distances run quickly by those with higher percentage of fast twitch fibres.*

8) a) Under what conditions would the Golgi tendon organ function to protect voluntary muscle. 2 marks

Answer:
- *Due to excessive tension produced during a concentric or eccentric muscle contraction.*
- *Due to excessive passive stretching, for example, during proprioceptive neuromuscular facilitation (PNF) work.*

b) Explain the role of the muscle spindle apparatus when performing a triple jump. 4 marks

Answer :
- *The muscle spindle apparatus provides information on the state of muscle tension, position and rate of change of muscle length.*
- *During the action of the triple jump the athlete is continually switching from eccentric to concentric muscle contractions of the lower limbs, during runway contacts and flight phases respectively.*
- *Therefore, the muscle spindle apparatus stretch reflex is used to monitor and used adjust the states of muscle tensions in agonists and antagonists muscles in order to complete the jump phases.*

9) Table 3.4 shows the percentage of slow twitch muscle fibres in three muscle groups of elite male (M) and female (F) athletes and non-athletes. The percentage of fast twitch muscle fibre is calculated as the difference between 100% and the percentage of slow twitch fibres. (Data from research literature – source – 'Essentials of Exercise Physiology' 2e, McArdle, Katch and Katch)

Table 3.4 – percentage of slow twitch muscle fibres

athletic group	shoulder (deltoid)	calf (gastrocnemius)	thigh (vastus lateralis)
long distance runners		79% (M) 69% (F)	
canoeists	71% (M)		
triathletes	60% (M)	59% (M)	63% (M)
swimmers	67% (M) 69% (F)		
sprinters		24% (M) 27% (F)	
cyclists			57% (M) 51% (F)
weight lifters	53% (M)	44% (M)	
shot putters		38% (M)	
non-athletes			47% (M) 46% (F)

a) Compare and account for the differences in percentage distribution of slow twitch muscle fibres with respect to long distance runners and sprinters. 3 marks

Answer:
- *Male long distance 79% to male sprinter 24% in calf muscle = difference of 55%.*
- *Female long distance 69% to male sprinter 27% in calf muscle = difference of 42%.*
- *Expected trend, could be the effects of aerobic and anaerobic training.*
- *And/or genetic potential.*

b) Calculate the percentage of fast twitch muscle fibres for the long distance runners and sprinters. 2 marks

Answer:
- *Long distance runner: males 21%, females 31%.*
- *Sprinters: males 76%, females 73%.*

c) Data collected for male triathletes shows a fairly even distribution of slow twitch muscle fibres across all three muscle groups. Discuss two possible reasons for this trend. 3 marks

Answer:
- *Male triathletes would be expected to have a fairly high even distribution of ST fibres in all three muscle groups.*
- *This trend could be explained due to aerobically stressing all three muscle groups during the swimming, cycling and running parts of this event, both in training and competition.*
- *On the other hand, it is not fully proved whether fibre type changes in response to training or whether these fibre type distributions are genetically determined.*
- *And so the performances of these elite athletes may be a consequence of abnormal fibre type distribution.*

9) d) For shot putters, only the calf muscle is given a value in the table. What percentage distribution of slow twitch muscle fibres would you expect in the deltoid muscle for shot putters? Give a reason to support your answer. 2 marks

Answer:

Expected percentage:

- *Less than 30% of ST fibres.*

Reason:

- *Because shot putting is an anaerobic power event it relies on flat-out explosive action.*
- *Stressing the predominant use of FT fibres in the deltoid muscle.*

10) Analyse how the characteristics of different skeletal muscle fibres help contribute to success in different sports. 8 marks

Answer:

8 marks to cover all fibre types:

- *There are 2 main types of skeletal muscle fibre - slow twitch (ST) and fast twitch (FT – type I Ia, type I Ib).*
- *Exercise may produce transitions between FT and ST fibres to create FT-type I Ia.*

- *Fibre type distribution varies between individuals.*
- *Endurance-based athletes have a higher percentage of slow twitch muscle fibres in their leg muscles.*
- *Whereas anaerobic-based athletes, such as explosive elite sprinters and throwers, have a greater percentage of fast twitch muscle fibres in their leg muscles.*

- *These proportions are genetically determined.*
- *And to a degree could account for specialisms of individuals.*
- *Such as whether a person becomes good at marathon running or weight lifting.*
- *ST fibres contain large amounts of myoglobin, mitochondria and blood capillaries.*
- *Mitochondrial proteins and oxidative enzymes are important determinants of the duration during submaximal exercise.*
- *High capillary density and myoglobin content ensure a continuous supply of oxygen to mitochondria (the powerhouse of tissue respiration) which have a high capacity to generate ATP by oxidative metabolic processes.*
- *Supported by high glycogen stores.*

- *Slow twitch fibres split ATP at a slow rate and so have a slow contraction velocity.*
- *Are very resistant to fatigue.*

- *ST fibres have greater triglyceride stores when compared with FT fibres.*
- *And may account for over 50% of the total lipid oxidised during endurance-based exercise.*
- *Thus supporting endurance-based activities such as marathon running.*
- *Type IIb fibres.*
- *These fibres, also called fast twitch or fast glycolytic fibres, contain a low content of myoglobin, relatively few mitochondria, relatively few blood capillaries and large amounts glycogen.*
- *Type IIb fibres are white and are geared to generate ATP by anaerobic metabolic processes.*
- *Because type IIb fibres are unable to supply skeletal muscle fibres continuously with sufficient ATP they fatigue easily.*
- *Type IIb fibres split ATP at a fast rate and have a fast contraction speed.*
- *Elite sprinters and throwers are found to have a greater percentage of fast twitch muscle fibres in their leg muscle, when compared with sedentary or endurance-based athletes.*
- *These characteristics help contribute to the success of high, explosive activity such as sprinting and shot putting where speed and power components of physical fitness of required.*
- *Fast twitch type IIa fibres are red, have a very high capacity for generating ATP by oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.*
- *They manufacture and split ATP at a fast rate by utilising both aerobic and anaerobic metabolism and so produce fast, strong muscle contractions, although they are more prone to fatigue than type I fibres.*
- *Resistance training can change type IIb fibres into type IIa due to an increase in the ability to utilise the oxidative cycle.*
- *This physiological training adaptation contributes to the success in sports that require a mixed contribution of energy supply from aerobic and anaerobic pathways.*
- *For example, a tennis match or football game where both speed, power and endurance are important physical fitness components.*

11) A Level. Explain the role of motor units in controlling the strength of muscular contractions in sports movements.

15 marks

Answer:

- *A muscle twitch is a single stimulus to a single motor unit.*
- *All-or-none' law applies, since all fibres within that motor unit will contract maximally.*

- *Wave summation occurs as a result of quick firing of impulses so that that muscle fibres belonging to that motor unit do not have time to relax.*
- *Therefore force exerted by a single motor unit increases.*
- *For example, maximal forces required in a 100m sprint or gymnastics vault.*

- *Tetanic contraction occurs when impulses fire off so fast that there is no time for relaxation at all.*
- *Muscles may exhibit some level of tetanic activity, leading to muscle tone, in order to maintain posture, For example, holding a plank position that helps develop strength in the core, shoulders, arms, and gluteal muscles.*

- *Gradation of contraction refers to the ability of muscles to produce forces varying from very light to maximum force or tension. This is achieved in two ways :*
- *By varying the frequency of the stimulus.*
- *For example, low frequencies produce relatively weak contractions, whereas high frequencies produce more powerful contractions (as illustrated in wave summation).*
- *By varying the number of motor units recruited for the activity.*
- *Different motor units will be involved, not necessarily the same ones in succession.*
- *Stimulation of many motor units which increases strength of contraction.*
- *Effect is to produce graded strengths required in sports movements.*
- *For example, the difference in graded strengths required for a drop shot and overhead smash in tennis.*

- *Spatial summation refers the fact that when motor units are successively stimulated a slightly out of step, staggered action is created.*
- *But results in a whole muscle contraction.*
- *Reduced fatigue so muscle can work longer.*
- *Long periods of sustained contraction produces isotonic contractions.*
- *Relevant for endurance events such as marathon running.*

- *Fibre type of motor units:*
- *In addition there is a degree of specialisation among the units.*
- *Namely the two main fire types. The fast twitch motor units have large motor neurones, high motor neurone recruitment threshold and fast nerve conduction velocity.*
- *Therefore, the overall tension is great when compared with the slow twitch motor units that have small motor neurones, low recruitment and slow impulse velocity.*

12) Skeletal muscle contains both slow and fast twitch muscle fibres but the proportion of each depends upon the function of a muscle as a whole. Table 3.1, page 41 lists some of the differences between slow and fast twitch muscle fibres.

a) Suggest why the muscles concerned in maintaining the trunk posture of the body of the sprinter might be expected to have a larger percentage of slow twitch muscle fibres.
Using table 3.1 explain why fast twitch muscle fibres may build up an oxygen debt during a 400m sprint. 5 marks

Answer:

Postural muscles in the trunk would have more slow twitch fibres because:

2 marks for 2 of:

- *They maintain posture for long periods of time.*
- *It is important for postural muscles not to get fatigues easlity.*
- *No need for fast, powerful contraction.*

Why fast twitch fibres build up an oxygen debt during a 400m sprint:

3 marks for 3 of:

- *Low capillary density.*
- *Few mitochondria.*
- *Therefore less O_2 supplied because they contain fewer oxidative enzymes.*

b) Account for the difference in the speed of contraction between slow and fast twitch muscle fibre types.
Fast twitch muscle fibres are divided into two types, IIa and IIb. Identify the major functional characteristic between these sub groups.
In what sporting activities would the adaptation of fast twitch type IIb to type IIa fibres be relevant to a sportsperson? 6 marks

Answer:

The two types of fibre contract at different speeds because of:

- *High glycogen content of fast twitch muscle fibres (low in slow twitch muscle fibres).*
- *High levels of phosphocreatine (PC) stores in fast twitch muscle fibres (low levels in slow twitch muscle fibres).*
- *Fast twitch muscle fibres have well-developed sarcoplasmic reticulum, which means more Ca^{++} available and improved transportation system for nutrients (e.g. glucose) compared to slow twitch fibres.*
- *Fast twitch muscle fibres are attached to large motor neurones with fast conductive velocity (small contractile time), compared to smaller motor neurones for slow twitch muscle fibres.*

The two types, IIa and IIb, major functional characteristics between these subgroups:

- *Type IIb fibres have a high capacity for glycolytic release of energy (known as FG).*
- *Type IIa fibres utilise both aerobic and anaerobic energy sources (known as FOG).*

Conversion of type IIb to type IIa:

- *Endurance-based events, such as middle distance running.*