Sophia Chen (2019), *Synchronized Swimming Under The Microscope,* The International Society for Optics and Photonics

The article can be accessed at this link.

You can also download the Cornell notes template for this paper (which includes the same questions) as a Word Document or PDF. Teachers, feel free to download this and forward it on to your students.

This week we're looking at a popular article again, but one that touches upon a further type of scientific writing that's especially important when you embark upon a new direction of research or learning – that is the review article. Review articles are used throughout academia as a way to bring together the major pieces of work within a field and give some form of commentary on them. Review articles might be used to give context to a field, show the progress made within a field, or to try to understand the truth within fields where seemingly opposing ideas have been suggested. In the case of this article, it is to provide an update on the recent progress made within one small part of the realm of biophysics. This article brings together ten pieces of modern research, and some additional quotes and thoughts of scientists, to show the current state of our abilities to manipulate 'microswimmers'.

Your task this week is to:

- Read the article
- Come up with some **skim-read questions** and answer them
- Answer our comprehension questions
- Answer our three summary questions

We'd then like you to go further and:

- Choose ***one*** of the articles that are linked within the piece to read (there are ten links, but only eight of them are open-access so choose one of those).
- Summarise that one article in a short paragraph.

There are no sections, so we'll simply list the summary questions rather than presenting them in a Cornell-notes style. Do try to make use of Cornell notes in your own note-taking though – there does seem to be some benefit in *note-taking by hand* as described in this piece by the Learning Scientists.

COMPREHENSION QUESTIONS

1. What is a microswimmer?

    An object that is in the micrometer size range (1-10micrometers) that can propel itself or be steered externally. It's an object that exists at the nanometer-micrometer level but is controlled, in some sense, by humans.

2. What are the advantages to using light to direct microswimmers over something like electric or magnetic fields?

Light is more tunable – you can alter its wavelength or its polarisation – and so you can transmit more 'instructions' via light. Equally, you can use the multiple channels of light to give different instructions to different microswimmers, whereas an applied electric/magmetic field would tend to affect all of the microswimmers similarly.

3. How does Jinyao Tang use light to steer microswimmers?

    They first coat different microswimmers in different coloured dyes. Each different coloured microswimmer then has a different response to particular portions of the EM spectrum e.g. the red-coated swimmer responds more strongly to red light. Whilst all of the swimmers still have some response to all wavelengths of light, the strongest response is reserved for the swimmer of the corresponding colour.

4. How does Jinyao Tang use light to power microswimmers?

    Light is used as the trigger to initiate chemical reactions between the components of the microswimmer and the surrounding liquid. Tang's simple microswimmer somewhat resembles an arrow – a silicon shaft with titanium bristles at one end. The light stimulates the silicon and the surrounding liquid to produce negatively charged (hydroxide) ions, whilst the titanium bristles react with the liquid (on absorbing light) to produce positively charged (hydrogen) ions. The attraction between these oppositely charged ions brings them towards each other, and the effect of this within the surrounding fluid is to pull the swimmer forwards (due to the shape of the 'arrow').

5. Why is swimming at the microscale different to the macroscale?

    At the macroscale, when humans swim through water, we interact with billions of particles at once, simply pushing against them to swim forwards – it's a very classical picture. At the microscale, a swimmer isn't interacting with a liquid as one continuous body, instead it's small enough to have more complicated interactions with the molecules. Even if we consider the microswimmers as classical objects, as their size is much more comparable to the size of a water molecule, it is difficult to 'flow' through them. It would be like humans trying to swim through a ball pool. And then, on top of this, there are the complex interactions that may occur between the swimmer and the molecules that we can ignore at the macro scale.

6. What are the advantages of using 'chassis from nature' and starting with biological cells?

    These cells have already developed the ability to swim effectively at the micro-scale.

7. "Some algae, for example, can move more than ten times their body length per second, which is more than a speeding car can do on the highway." Find values and perform calculations to prove/disprove this statement.

A typical car has a length of 4m. To travel 10times its length in a second means travelling at 40m/s. To compare this to the speed of a car on a 'highway' (motorway), we need to convert it into km/hour (or miles per hour).
40m/s = 0.04km/s = 0.04x60x60 km/hour = 144km/hour (=90miles per hour). This is definitely speeding.

8. What is phototaxis? Give examples.

   When an organism moves in response to light. Positive phototaxis occurs when an organism moves towards light, negative phototaxis occurs when an organism moves away from light. Moths show positive phototaxis, flying towards sources of light. Jellyfish can show positive or negative phototaxis – a lack of light may incite them to move away (due a predator causing a shadow) and they may move towards a light source to find part of their food source (photosynthesising single celled organisms).

9. How do *Chlamydomonas* manage to respond to light?

   They have an eyespot which acts like a camera. On light hitting the eyespot, chemical reactions lead to the release of ions. Any movement of charge (ions have positive charge) is a current, and this electrical signal (just like those flowing through our own neurons) can trigger the flagella of the *Chlamydomonas* to move either towards or away from light.

10. What unanswered questions are there surrounding microswimmers and their eventual use within the human body?

    We don't yet understand what makes certain materials stick to bacteria – this affects what we could transport with bacteria and where we can send them. We also don't understand why certain organisms move towards or away from light. Light acts to both orient cells and provide a source of energy – we don't know how organisms switch between these uses. We also need to understand how the microswimmers will behave amongst the many different molecules within our blood, for example, which contains a huge number of different cells and molecules – all of which are in motion.

11. Describe the process behind the movement of Celia Lozano's spheres.

    Lozano's spheres are transparent silica half-coated in carbon. Light will naturally interact different with the transparent and opaque portions of the sphere. The darker side will absorb more light, creating a temperature gradient across the sphere. The increased temperature on one side leads to a greater amount of separation between individual molecules in the surrounding fluid. The resulting concentration gradient in the surrounding liquid leads to movement of the liquid particles past the sphere which act to propel the sphere.

12. “To make a microscopic particle respond to light, it just needs to be asymmetrical in some way.” Analyse the truth behind this statement using example microswimmers from the article.

    Lozano’s spheres are asymmetric as one side is coated and the other isn’t. The different coloured dyes used on Tang’s swimmers give them a semblance of asymmetry as they then respond differently to different colours of light. Tang’s other artificial swimmer has an asymmetric shape with bristles at one end of the shaft – the chemical reactions that occur are also asymmetric in the charges they produce which leads to motion. Simmchen and colleagues attached small silicon dioxide spheres to one side of e-coli bacteria to create an asymmetry.

SUMMARY QUESTIONS (submit these, along with your own SKIM-READ questions and answers to thomas.millichamp@warwick.ac.uk)

What different methods have scientists used so far to manipulate the motion of microbots and bacteria? What do you think are the positives and negatives of these methods?

How could synthetic microbots and hijacked biological cells be used? Are there differences between them?

What issues can you foresee within the field of microswimmers?

Your additional summary question is to summarise one of the linked articles from the piece in a short paragraph. Please ensure you say which article you are summarising – preferably in a Harvard Referencing style (to give you practice at working out what this looks like).

FURTHER READING

There is a famous lecture by Richard Feynman entitled Plenty of Room at the Bottom which discusses the early ideas around miniaturisation. You can see a version of the lecture here can access a transcript of a slightly different version of the lecture here.